IMPROVEMENT OF RING FRAME SPINDLE UTILIZATION IN SHORT STAPLE SPINNING: A CASE STUDY OF A COTTON SPINNING MILL

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DECLARATION

This thesis is my original work and has not been presented for a degree award in any other university/institution.

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DEDICATION

I dedicate this thesis to my spouse Ann and my daughters Patience and Precious for their support, encouragement and understanding throughout my studies.

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Above all, I thank God for His love, protection and provision of wisdom and good health all the time.

ABSTRACT

Spinning mills in Kenya are operated by eight integrated textile industries to produce cotton yarns for internal use by their knitting and weaving departments and for sale to the local market. Fabric requirement estimated at 225 million square meters cannot be supplied by local domestic production and the gap is met through importation of fabrics and finished garments. 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 cotton short staple spinning system to produce yarn from cotton fibers and is used by 7 of the 8 spinning mills. In Kenya, spinning mills have been operating at spindle utilisation between 67 to 80% which is below the recommended standard norm of 98%. The mills have been experiencing yarn production loss occurring from frequent stoppages of the ring frame and increase in the number of spindles running without producing yarn reducing 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, a case study of Sunflag Textile and Knitwear Ltd. The specific objectives were to analyze ring spinning process production parameters, evaluate the factors affecting ring frame spindle utilisation and formulate a productivity improvement method for the mill.

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 Performance Improvement Method (PIM) was used to analyse and evaluate mill production and management practices. A production improvement method was recommended using 7 evaluation criteria of the PIM. 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 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 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 in Kenya can apply the recommendations to improve ring frame productivity in order to reduce the cost of production and improve their competitiveness.

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ABBREVIATION AND ACRONYMS

ACTIF	**-**	African Cotton and Textile Industries Federation
AGOA	**-**	African Growth and Opportunity Act
ANOVA	**-**	Analysis of Variance
BPR	-	Business Process Reengineering
CI	-	Continuous Improvement
DFT	-	Digital Signal Processing
EAC	**-**	East African Community
EPZ	**-**	Export Processing Zone
EPZA	**-**	Export Processing Zone Authority
FMEA	-	Failure Mode and Effects Analysis
GDP	**-**	Gross Domestic Product
ITC	-	International Trade Centre
ITMF	-	International Textile Manufacturers Association
JIPM	-	Japan Institute of Plant Maintenance
JIT	-	Just in Time
KAM	**-**	Kenya Association of Manufacturers
KIPRA	-	Kenya Institute of Public Policy Research and Analysis
KNBS	-	Kenya Bureau of Statistics
LCD	**-**	Liquid Crystal Display
Ls	-	Least Square Means
Ne	**-**	English Count
OEE	**-**	Overall Equipment Effectiveness
OES	**-**	Open End Spinning
PDCA	-	Plan Do Check and Act
PIM	-	Performance Improvement Method
PPT	-	Planned Production Time
QC	-	Quality Control
RCA	-	Root Cause Analysis

RFS	**-**	Ring Frame spinning
RPA	-	Robotic Process Automation
RPM	**-**	Revolutions per Minute
RPN	-	Risk Priority Number
SAS	-	statistical Analysis Software
SEZ	-	Special Economic Zone
SHC	-	Second Hand clothes
SITRA	-	South India Textile Research Association
SMED	**-**	Single Minute Exchange of a Die
SoPs	-	Standards Operating Procedure
SSA	-	Sub-Saharan Africa
SU	**-**	Spindle Utilization
TPM	**-**	Total Productive Maintenance
TQM	-	Total Quality Management
UK	-	United Kingdom
US$	-	United States of America Dollar
USA	**-**	United States of America
5S	-	Five S

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Improvement of production performance is an important aspect in the manufacturing sector, industries that maintain high utilisation of manufacturing equipment are able to improve on production and reduce production costs. Production performance management in modern manufacturing plays a central and strategic role in improving productivity and competitiveness of manufacturing industries.

In Kenya, the textile sub-sector is an important segment of the manufacturing sector which accounts for 24% of the manufacturing contribution to the Gross Domestic Product (GDP) and 50% of the country's export earnings (EPZA, 2005). In 2015, Kenya exported to the United States of America clothing worth $380 million under the AGOA preferential U.S. trade deal with African countries (Gebre, 2016). The textile sub-sector has the greatest potential for increasing the much needed employment opportunities for the fast growing young population, eradicate poverty, decentralize development to rural areas and increase incomes generation in arid and semi-arid areas of the country. The sub-sector has the greatest potential to strengthen the role of industrialization in accelerating economic development in the country and has therefore been classified as a core industry by the Government in deepening the country's movement into middle-income status (KIPRA, 2013). The Government of Kenya identified textile production as one of the primary industry to benefit from the setting of Special Economic Zones (SEZ) that will be established to help boost industrial manufacturing by minimizing regulatory hurdles and lowering of tax levels. The boost in manufacturing is expected to create 1.5 million jobs within a year and 10 million jobs in the next 30 years (Deloitte, 2016).

In textile manufacturing, spinning mills play a significant role of transforming cotton fibers into a continuous strand of yarn to be used for weaving and knitting of fabrics. Ring spinning is the most widely used spinning system with over 140,000 spindles installed in Kenya. This is due to its superior yarn quality compared to other modern spinning systems that offer higher yarn production rates. The ring spinning process consists of blowroom, carding, drawing, combing speed frame and ring frame machines. In textile spinning, utilization of the Ring frame plays an important role and it is used to determine the productivity and competitiveness of the entire mill. Availability of sufficient quality supply of fiber roving material for the ring frame, the condition of the ring frames and management of the production process influences the efficiency of utilisation of the ring frames for yarn production. The process of yarn production at the ring frame is prone to stoppages due to cyclic stoppages for doffing of filled up yarn bobbins, frequent change overs, setting adjustments and under utilisation of individual spindles of the ring frame due to idle spindles and end breakages of the yarn during the production process. This reduces the spindle utilization of the ring frame affecting the production levels and raising the cost of production. Therefore, spindle utilization of the ring frame has direct influence on the productivity and competitiveness of spinning mills, which determine the long-term sustainability of the textile industry.

1.1.1 Performance of the Textile Industry in Kenya

The six (6) major segments in the textile value chain are; (i) the cotton farming, (ii) ginning to extract fiber cotton lint, (iii) yarn production by spinning mills, (iv) fabric formation by weaving or knitting factories (v) garmenting and apparel making and finally (vi) retailing and marketing of the textile products. The success of the textile industry depends on how well all the six segments in the value chain are integrated together.

The textile industry dominated the manufacturing sector in size and employment creation in Kenya before its decline in 1980s. The industry had 52 operational textile mills for yarn and fabric production with an installed capacity of 115 million square meters of fabric (Rates, 2014). Economic policy changes effected in early 1990s for liberalization the country's economy exposed the local textile industries to stiff competition that led to decline of the domestic spinning and weaving capacities to only 8 integrated textile mills that are in operation today. Prior to the economic liberalization, the local textile industry was highly protected through quantitative and tariff restrictions, the manufacturers concentrated on the domestic market and took little consideration on productivity, quality and pricing. The economic liberalization opened the market for imported, affordable low priced textile materials, which have dominated the domestic market thus reducing the market share for the locally made textiles. Most of new fabrics and garments are sourced from China and Asia.

Cheap imported second hand clothes (SHC) locally known as “Mtumba” further weakened the market share of locally manufactured garments. SHC are usually considered cheaper and of superior quality than the new clothing available on the market, hence the demand for SHC has increased (Katende, 2017). USA, UK, Canada and China are the largest exporters of SHC into Kenya. A Study by Garth (2008) showed a negative relationship between recipient countries of SHCs and growth of textile manufacturing and textiles imports; an increase of 1% in importation of SHC resulted in a 0.61% reduction in apparel production performance. According to KNBS, importation of SHC has been on the increase in the last 10 years, Kenya imported 100,000 Metric tons of SHC estimated to be worth $100 million in 2015 as shown in Figure 1.1.

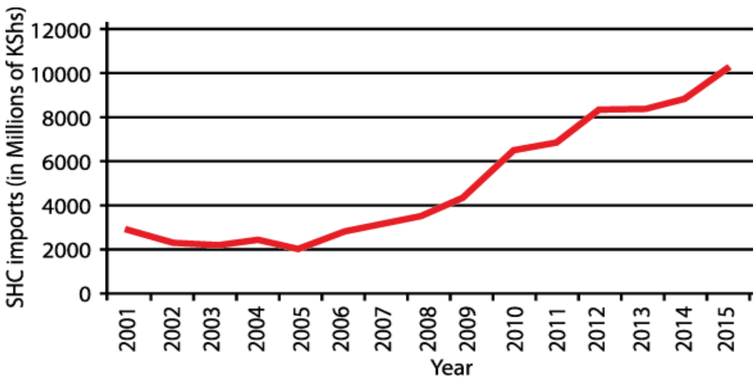


Figure 1.1: Imports of SHC to Kenya growth in Millions, Ksh (2001-2015)

Source: The Kenya National Bureau of Statistic (KNBS)

It is therefore apparent that for the local mills producing textiles in the country to survive, they must improve their productivity, lower the cost of production and improve the quality of textiles they produce in order to be competitive in both local and international markets. The current textile fabric demand in Kenya is estimated at 225 million square meters per annum, and with the sharp decline in the number of operational textile industries in the country, drastic reduction in cotton production, local fabric demand greatly outstrips domestic production. This creates opportunity for more gains, in terms of employment and income generation, which may be derived from reviving the textile industry in the country. A study by the Ministry of Industry, Trade and Cooperatives estimated that the sector has the capacity to employ over 1 million people directly or indirectly, however, it currently operates at less than

10% of the potential capacity (KAM, 2014). Moreover, the garment sector has been recording improved performance under the African Growth and Opportunity Act (AGOA) provision which allows apparels made in Kenya to be exported to the US. The supply of fabric is through inclusion of the 3rd country fabric provision that allowed utilization of imported fabric which has seen Kenya grow to the largest apparel exporter to US market under AGOA in Sub Saharan Africa (SSA) with a market share of 31.6% (KAM, 2014).

However, the success of the apparel industry segment to a large extent has had no direct effect on the backward integration and expansion of existing textile mills in Kenya. It is estimated that Kenya could save Ksh. 12.5 billion in foreign exchange used by EPZs for importation of fabrics (ACTIF, 2013) if the fabric was sourced locally. There is no correlation in growth of local textile industries to that of EPZs, the main reason being the supply of fabric to the garment factories that export to USA under AGOA is sourced from 3rd party countries. Without sourcing of fabric from local industries for export apparel production, the entire textile value chain would remain broken-down and disjointed; Figure 1.2 depicts the current integrated textile manufacturing sub-sector value chain in Kenya.

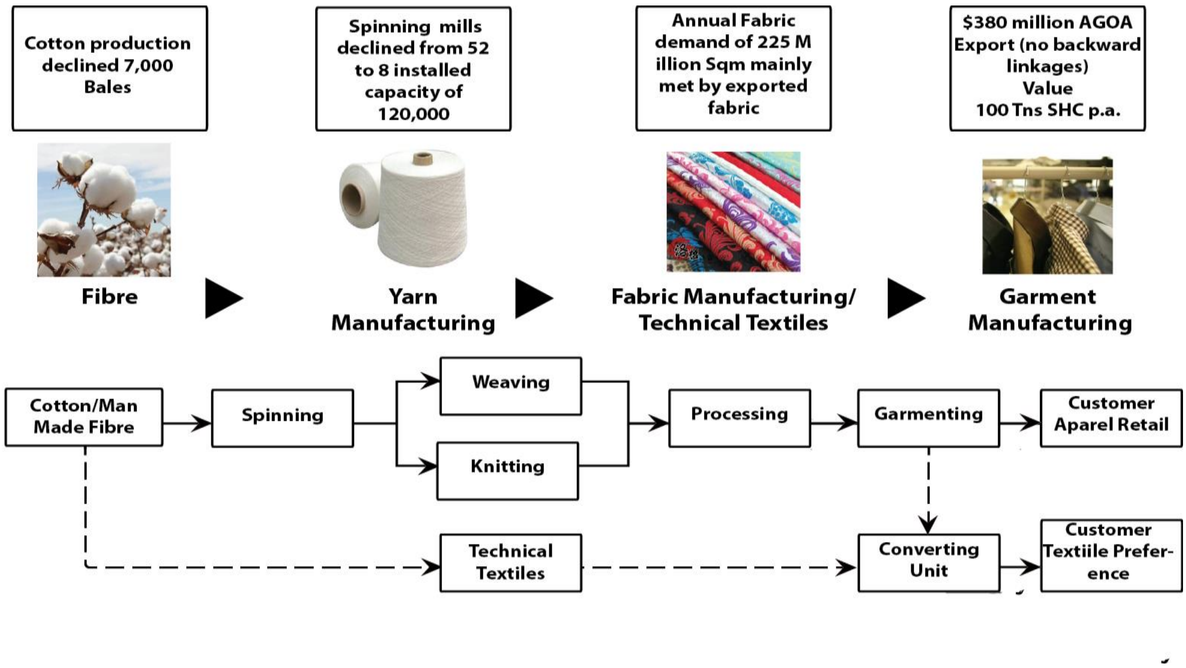


Figure 1.2: Integrated Textile Industry Value Chain in Kenya

Source: Researcher, 2019

1.1.2 Cotton Production

Cotton is the most important raw material for spinning mills; it is a natural fiber that is grown in areas with adequate moisture and heat for formation of mature cotton bolls to produce quality fibers. It can also be grown under irrigation in dry, arid and semi-arid parts of Kenya. Temperatures of over 21°C are required for cellulose formation which make up cotton fibres. The length of fibers determines the quality of cotton and is referred to as the staple length, the longer the length of the fibres the higher the quality in grading the cotton. In best practice cotton quality and prices is graded based on the staple length as; short (0.95cm to 2.4cm), medium (2.54cm to 2.86cm), or long (3cm to 6.35cm) and in some cases extra-long. Cotton plants produce bolls, which contain cotton fibres attached to the seed. A cotton boll has six or seven seeds with up to 20,000 fibers attached to each seed. Harvested cotton is taken to ginneries which separate the lint of fibers from the cotton seed. The seeds are used for making oil and protein rich animal feeds. Cotton lint is compressed into bales packs of 220kgs for transportation to spinning mills.

The highest quality cotton is extra-long and long staple cotton, which is used for spinning strong and fine cotton yarns. Fine cotton yarns have fewer fibers in a given section of yarn as longer fibers provide more contact points for twisting together of fibres during the spinning process. These fine yarns can be woven in to fabrics of high quality which are strong, soft, smooth and of excellent lustrous. In Africa, long staple cotton is grown in Egypt and Sudan which fall in the same ecological zone with Kenya. Cotton for spinning mills in Kenya is sourced from East Africa member countries (EAC), due to decline in local production and low quality of the cotton. Man-made fibres such as polyester, acrylic and viscose which are usually mixed with cotton to produce cotton blend are imported from Asian countries. The mills rely on cotton fibres imported from Uganda and Tanzania, which is often mixed with the low quality short staple cotton mill for spinning.

The statistics on decline of cotton production are shown on Figure 1.3 which indicate that Kenya produced up to 7000T (30,000 bales) of cotton in 2016 against an estimated demand of 140,000 bales.

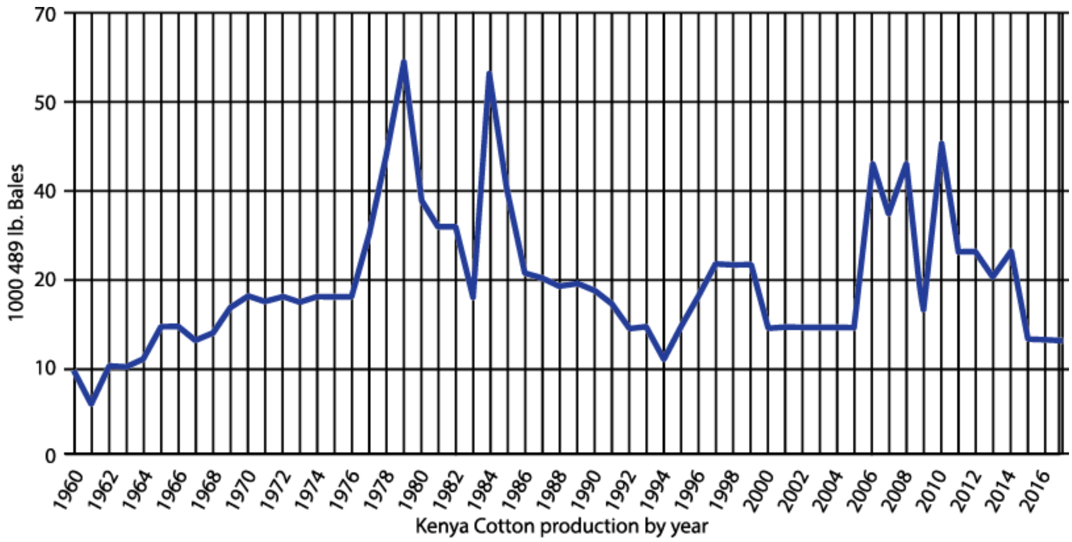


Figure 1.3: Trend in Kenya Cotton Production by year (1980 – 2016)

Source: United States Department of Agriculture

1.1.3 Spinning Industry in Kenya

Spinning mills are the first stage of textile manufacturing that converts the staple fibers into a long continuous and cohesive thread like structure referred as yarn which is suitable to be woven or knitted to produce fabrics or for direct application in sewing or rope making. According to Paropate & Sambhe (2013), the process of spinning involves cleaning and attenuation of cotton fibres by different machines to form a yarn. Kenya has 8 spinning mills that are operated by integrated textile industries to produce yarn for their internal fabric production through knitting or weaving. The industries final products are usually for segments of the local markets in which mills do not face stiff competition as demand is not usually met through imported clothes such as school uniforms, kanga, African-women dress material, blankets, knitting yarn, kitenges, baby shawls and clothes. The integrated textile industries with operational spinning mills, orientation to fabric formation and the final products are shown in Table 1.1.

Table 1.1: Integrated Textile Industries in Kenya with operational spinning Mills

No.	Name	Fabric Production Orientation	Products
1.	Spinners & Spinners	Blanket Production Spinning, knitting, dyeing & finishing	Blankets, yarn and fabric for maasai clothes.
2.	Midco EA	Semi integrated (oriented towards knitting) Spinning-Knitting- Dying-finishing	Polyester circular knitted furnishings fabrics, sport wear, cotton knitted fabrics, warp knitted mosquito nets, fishing nets, t-shirts.
3.	Fine spinners	Semi integrated (oriented towards knitting)	Knitting yarn, sweaters, baby shawls Kikoys & Wraps, Blankets, Maasai shukas.
4.	Rivatex	Semi integrated (oriented towards weaving): Spinning-weaving - Dying-finishing	Polyester/cotton blend, 100% cotton products, khanga, kitenge bed sheets, dress material, military camouflage, school shirting material.
5.	Thika cloth mills	Semi integrated (oriented towards weaving)	100% cotton Polyester/cotton and polyester viscose blends, School uniform fabrics, promotional textiles, household furnishings, corporate uniforms, khangas, kitenges curtains and canvas materials.
6.	TSS	Semi integrated (oriented towards weaving)	Cotton products, thread candle leads, bed sheets, canvas and curtains.
7.	United Textile Industry	Semi integrated (oriented towards weaving)	Woven textile products.
8.	Sunflag Textile & Knitwear Mills ltd	Semi integrated (knitting and weaving) Spinning- knitting and weaving-Dying-finishing	Spun yarn, circular knitted fabric, warp knitted fabric, woven suiting fabric, industrial fabrics and garments.

Source: Field Data, 2019

Ring frame machine has remained the most widely applied system for yarn production amongst the spinning mills and accounts for approximately 85% of the yarn produced all over the world (Lord, 2003). Initially invented in America by Throp in 1828s, its dominance has survived emergence of higher production open end spinning technologies due to the superior yarn quality. Ring frame spinning is also the most versatile spinning technology capable of producing yarns with wide ranges of counts and twist from a great variety of fiber materials.

The yarn formation process in the ring frame involves roving being fed into a drafting zone, insertion of twist during the ballooning effect, winding of the spun yarn strand on the bobbin by set up of a traveler that drags on a ring mounted on the spindle. The traveler clip holds the yarn as it rotates freely on the ring and plays a key role in twist insertion and winding of the yarn on the bobbin mounted on the spindle. The rotating yarn being wound on the bobbin drags the traveler around the ring, creating a ballooning effect, which concurrently inserts twist and winds the yarn on the bobbin (Klein, 2012).

Yarn produced by Kenya spinning mills is cotton and cotton blend yarns. Kenya has an installed capacity of 140,000 short staple ring spindles of which only 120,000 are utilized and 900 Open End (OE) Rotors of which only 840 are utilized with an estimated spinning capacity of 58,872 MT (IMTF, 2012). In the East African Community (EAC) Region, Kenya is ranked second after Tanzania in yarn production as indicated in Figure 1.4.

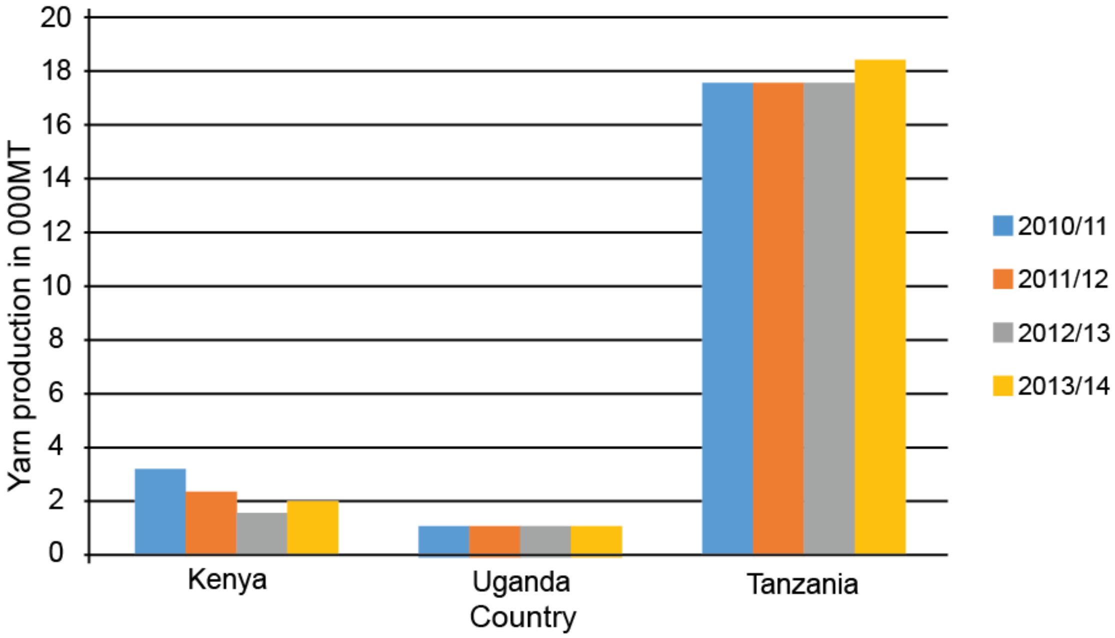


Figure 1.4: EAC Yarn Output (Kenya, Uganda & Tanzania) (in 000 MT)

Source: International Textile Manufactures Federation (ITMF) 2015

1.1.4 Sunflag Textile & Knitwear Mills (Supra Spinning Mill)

Sunflag Group of companies is a multinational group of companies operating textile mills in six countries namely; Canada, India, Thailand, Nigeria, Tanzania and Kenya. The group established the first textile plant in Kenya in 1930s to supply East Africa with quality garments and textiles. The operations included knitting, dyeing, finishing and garment making. The company has since embarked on vertical integration adding spinning and weaving to its operations, which extended the value chain to include yarn spinning and fabric formation. Currently Sun flag Textile and Knitwear limited (Kenya) has four major departments namely spinning, weaving, fabric finishing and garment making. Each department is located on a different site within Nairobi, Industrial Area.

The spinning mill is a standalone plant located along Lunga Lunga Road Industrial Area. The plant operates 24 hours from Monday to Saturday on two shifts, eleven (11) hours' day shift and a thirteen (13) hours' night shift. Cotton fibers, the main raw material for the plant is sourced from the neighboring Uganda and Tanzania in bales of 200 kg duty free under the EAC regional economic integration due to decline in production and low quality of locally produced cotton. The mills specialize in spinning 100% cotton yarn as well as blending with polyester for fabric formation by its weaving and knitting departments located in Nairobi industrial area along Pate Road and Kitui Road respectively or for sale to the local market.

1.2 Problem Environment

Sunflag Textile and Knitwear Ltd spinning mill produce yarn of varying counts using two yarn spinning systems; the Ring Frame Spinning (R.F.S) and the Rotor Open End spinning system (O.E.S) and has an installed capacity of 15,072 ring frame spindles and 432 rotor spindles. The yarn produced is would into cones for sale as cones of yarn to external customers or transported to weaving or knitting department for fabric formation. The company has wide local and regional markets for its products, which include woven, knitted fabric and wide spectrum of garments from basic t-shirts to fashion garments, and it is looking forward to maximize its production to meet the demand of its market segment.

The Ring Frames automatically stop for doffing when the bobbins get filled up with yarn. The operator must remove the full bobbins and fit the empty ones on the spindle, piece broken ends and restart the frame to begin the production cycle again. The frame is also occasionally stopped for cleaning and maintenance.

Idle spindles occur during the running cycle of the machine when any of the individual 960 spindles within a ring frame continues to run without being utilized for yarn production. End breakages may cause yarn producing spindles to be idle further increasing the number of spindles running without producing yarn. The roving feed material is sucked through the pneumafil system as waste fibers. The mill assigns operators to patrol the spinning shed to identify pieces of the broken ends.

Ring frame spindle utilization at the Sunflag spinning mill was estimated at 80% by ITC, 13% higher than the country average of 67% (ITC, 2015). However, this was still below the South India recommended Norm of ring frame spindle utilization of 98%. Ring frame utilization is the single most important benchmark for measuring performance and productivity of the entire spinning plant as it consumes 60% of the production cost of yarn production (Rieter, 2014). Ring frame has also high influence on the quality of yarn produced.

The low spindle utilization below the standard norm can be attributed to several factors such as stoppage of the entire ring frame for doffing full bobbins, idle spindles within the ring frame during running of the ring frame, end breakages and occasional stoppage of the ring frame for cleaning and maintenance of the ring frame. The company operates modern ring frames manufactured by Laxmi Limited and Laxmi Rieter which automatically records all the stoppages of the ring frame and the duration. The information on each stoppage of the ring frame can be retrieved from the LCD display of the machines. In addition, the company technicians and engineers monitor the number of idle spindles in ring frame to minimize loss of production through idle spindles and ensure the ring frame is running optimally.

Higher spindle utilization has therefore direct influence on yarn production and provides great advantage to the mill by reducing the cost per unit leading to marginal profits for the firm while improving the quality of yarn produced. According to research conducted by South India Textile Research Association (SITRA) in India, an increase of 1% in spindle utilization would lead to saving upto Ksh. 750,000 per annum for the 15,000 spindles. It is projected that such savings in the Kenyan industry would be higher given that the cost drivers of production are higher compared to India (Shanmuganandam, 2010).

1.3 Problem Statement

The production management practices at Sunflag Textile Mills & Knitwear mill had not improved the performance and utilization of the ring frame for yarn production contributing to low spindle utilisation of the mill. Loss in production time occurred due to frequent stoppages of ring frames and increased number of spindles running without producing yarn within individual frames. The Ring Frames automatically stopped for doffing every time the bobbins were filled with yarn, other causes of frame stoppages were cleaning, count change, power blackouts and breakdown. Further loss in production time occurred when spindles ran without producing yarn within the ring frame due to idle spindles and end breakages. The low spindle utilization had led to reduced yarn production, increased cost of production affecting the competitiveness and profitability of the mill. The mill did not have a production management system to monitor and evaluate production practices of the ring frame for improvement of spindle utilisation. The mill spindle utilisation of 80% is below the standard recommended norm of 98% affecting the productivity of the mill.

1.4 Objectives of the Study

1.4.1 Main Objective

The main objective of this thesis was to develop a plan to improve Ring Frame Spindle utilization of short staple cotton spinning.

1.4.2 Specific Objectives

The study seeks to achieve the following specific objectives:

1. To analyze the ring spinning process, parameters and production per spindle in short staple cotton spinning.
2. To determine the factors affecting spindle utilization in short staple cotton ring frame spinning.
3. To formulate a productive improvement system to reduce losses incurred in ring spinning spindle utilization and productivity of the ring frame.

1.5 Significance of the Study

The findings of the study were expected to be useful to the textile industry in Kenya and specifically the spinning subsector by studying spindle utilization effects on low productivity in ring spinning.

In particular, the research was also expected to be useful to spinning mills managers by providing information on the factors affecting spindle utilization in ring spinning and the impact they have on yarn production.

It was expected that the research findings would make recommendations on the optimization of spindle utilization with a view of improving ring spinning productivity and efficiency.

Furthermore, the research would also lay ground for future research on the salient factors affecting spindle utilization in ring spinning to improve yarn and fabric quality by reducing defects and minimizing yarn piecing resulting from end breakages.

1.6 Scope of the Study

The study sought to determine the factors effecting ring frame spindle utilization in textile spinning mills in Kenya. However, due to limited time and resources the study was carried out at Sun flag Kenya and focused on fifteen (15) Ring Frames spinning fine, middle and course count yarns. The study focuses on utilisation of ring frames machines which were the Key Performance Indicators that determined productivity and competiveness of spinning mills. Analysis of production loss, factors and mill management practices affecting production was carried out for the mill.

1.7 Research Limitations

Data for the study was collected from Sunflag Kenya spinning mill. This research is limited since the case study did not provide data and statistics on the other eight operational spinning mills in Kenya.

CHAPTER TWO: LITERATURE REVIEW

2.1 Development of Textile Spinning

Until the early middle ages the process of spinning was slow and tedious. Spinning half a kilogram of cotton fibres into what is now a course yarn for fabric formation by weaving and knitting would take a couple of weeks to complete. Spinners twisted fibres directly using their finger and thumb until spindle and whorl was invented as a universal tool for spinning. This was followed by development of a wheel driven spindle and the simple spindle, which had a disadvantage of being discontinuous. In 1519, Leonardo da Vinci invented the spindle and flyer mechanism device, which enabled continuous spinning and marked a breakthrough in combining twisting of fibres and winding of the spun yarn to proceed simultaneously.

The Saxony wheel principle was invented in 1555 as the most efficient way of spinning coarse woolen yarns, which were in high demand at the time in Northern Europe. Richard Arkwright succeeded in establishing the first successful commercial mills in the 1760's that featured automatic continuous spinning machines referred to as water frames. The third step, which completed the first mechanization phase of spinning, was the invention of the mule by Samuel Crompton in 1779. The mule was a hybrid of roller drafting of the water frame for the purpose of achieving fineness and the inherently stable system of drafting against running twist of the Jenny. The mule was the first commercially successful machine to spin fine yarns. Richard Roberts eventually automated it in 1827.

In 1828 John Thorp patented the ring frame which was further improved a year later by introduction of the ring-and-traveler by Addison and Steven. The concept which was established as the spinning device of choice in the 20th century has remained the dominant spinning system to date accounting for 85% of yarn produced worldwide (Lord, 2003). Ring spinning technology has experienced considerable modification but the fundamental concept remains the same.

2.2 Yarn Spinning Systems

In modern spinning mills two spinning systems, the ring spinning and open end spinning systems, are used to produce spun yarns with a wide range of values of characteristics and use at commercial scale. The systems convert ginned cotton fibres into a yarn and involve various systems, which have a sequence of processes that clean, open, straighten, parallelize, remove short fibres, align fibres and ultimately spin the yarn. The choice of the spinning system and the set-up of preparation machinery depend on the end use and the desired quality of yarn. Ring spinning is the conventional spinning system; open-end spinning involves modern faster spinning technologies such as the Rotor, Voltex, Friction and Air-jet spinning. The process flow of the two spinning systems used in Kenya is as indicated in Figure 2.1.

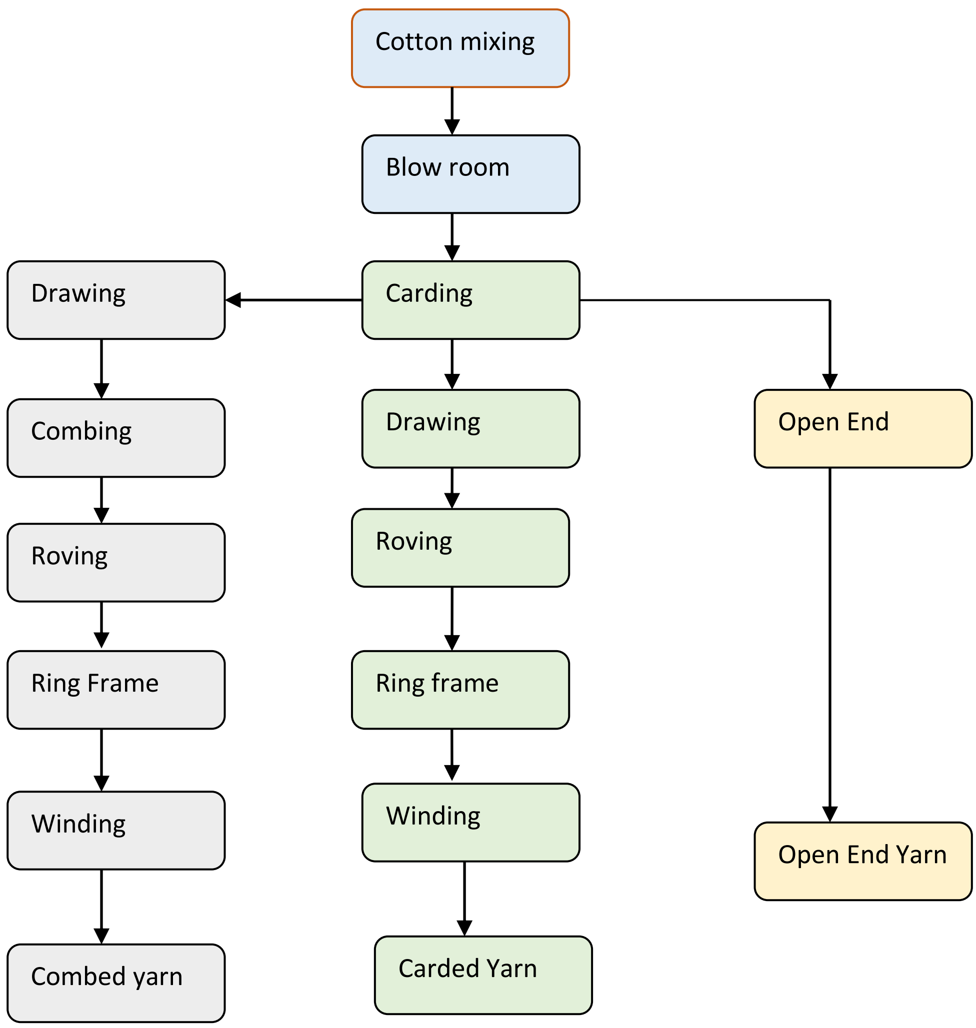


Figure 2.1: Cotton Spinning Process flow in Ring Frame and O.E spinning.

2.2.1 Ring Spinning Systems

Ring spinning has over 213 million ring spindles installed world-wide; its prominence reflects versatility in terms of product variety, wider range of yarn counts that can be produced and adaptability to spin different fibre types and their blends. Ring spun yarns are of superior strength and characteristic in terms of fabric handle and comfort (Ratnam 2005). Most of the spinning mills in Kenya and the East African region produce yarn using the ring spinning system.

2.2.2 Open End Spinning Systems

Open end spinning system is composed of technologies, which form yarn without using the spindle. The Rotor, air-jet spinning, friction and vortex spinning compose open end spinning technologies that have been utilized at commercial scale. In rotor spinning, the fibres sliver is separated into single fibres and brought by an air stream to a collecting rotor where they are drawn off and twisted. Yarn production using rotor has been increasing due to its high production speed, which is 4-6 times higher than that of the ring frame. The system has over 9 million rotor positions installed world-wide accounting for 30% total short staple yarn production (Rieter, 2006).

Air-jet spinning technology, which was initially developed by the Murata Company of Japan, became successful at commercial scale in the early 1980's. The technology was originally designed for fiber blends rich in long staple polyester but has been adopted to spin 100% cotton fibres. Their current installed capacity is estimated at 500,000 air-jet spinning positions world-wide.

The rotor and air-jet spinning have an advantage of higher yarn production of 4-6 times compared to the ring spinning and are mainly used for production of medium to coarse count yarns. In both methods, the feed material is the fiber sliver from the draw frame machine unlike the ring frame that uses a roving bobbin that requires more stages to prepare. In addition, both are able to wind a yarn package that can be used directly for fabric manufacturing by weaving and knitting, therefore the two have an advantage of eliminating the roving formation and winding processes, which are required in ring spinning.

However, these spinning systems have inherent restrictions to production of narrow range, medium and course yarn count and twist levels. Ring spinning offers the highest flexibility in variety of material that can be spun and quality of spinning.

2.3 Ring Spinning Process Flow and Equipment

The process of spinning short staple fibers such as cotton using the ring frame involves a layout of multiple equipment that systematically transform bales of cotton fibers into a suitable feed material for the ring frame called a roving. The process involved includes cotton mixing, blow room line, the card, drawing, comber, simplex, ring spinning and autoconer-winding. The process flow and layout of equipment in cotton ring spinning is shown in Figure 2.2.

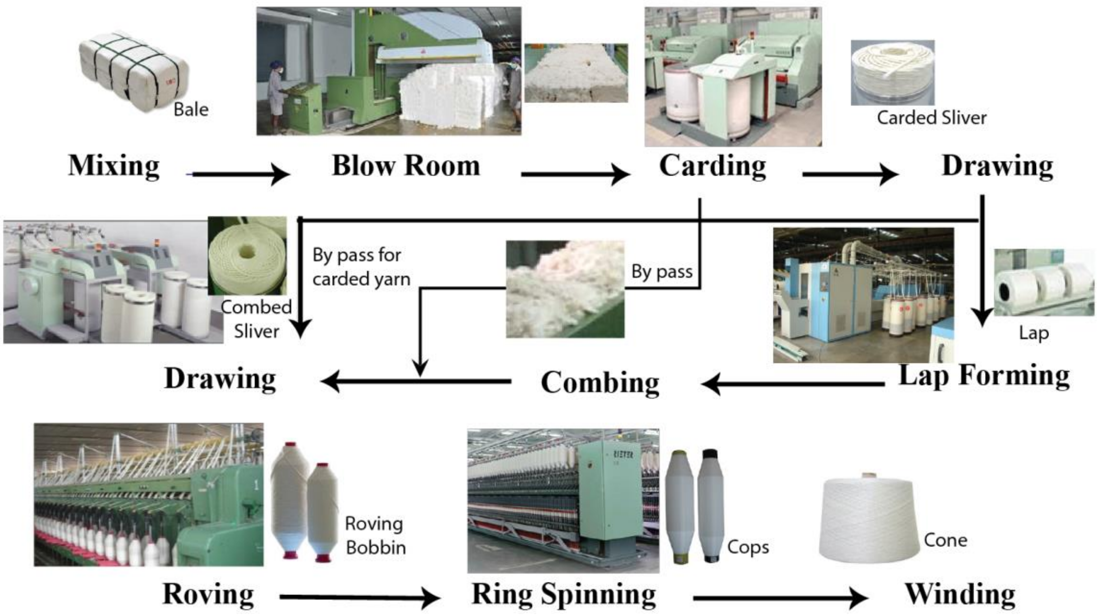


Figure 2.2: Ring Spinning Process Flow

Source: Researcher, 2019

2.3.1 Blow Room

Blow room is the first machinery for opening and cleaning cotton and comprises of set of lattices with spikes and perforations which open cotton into tufts and cleans it using air flow. It is also used in the cleaning and transfer of material during the process with the tuft size of cotton becoming smaller and smaller.

2.3.2 Carding Machine

The Carding machine opens the cotton tuft of fibres from blow room into a single fiber, which aids further removal of impurities and neps. Carding is referred as the heart of spinning mill due to importance of the role the carding process plays in yarn spinning. Air flow chute feed system is used to feed carding machines at Sunflag spinning mill to ensure even and uniform supply of fibres materials.

2.3.3 Drawing Frame

The fiber slivers produced in carding are taken to the draw frame in sliver cans. The draw frame drafts the sliver using sets of pairs of rollers running at different speed to blend, double and level the fiber slivers thus systematically reducing the size of sliver to a size suitable of being fed to the speed frame. In order to improve fiber control auto levelers are fitted on the draw frame to automatically adjust and improve the linear density of the sliver.

2.3.4 Comber

The comber is an optional machine, which is only used when high quality fine yarn is to be produced. Slivers from the draw frame are passed through the combing process where short fibers are removed and further cleaning is done to remove dirt from the sliver lap. Closely spaced-out sharp wires are combed into fibers projecting from holding jaws to remove shorter fibers. Yarn from combed sliver is stronger, more uniform and is referred as combed yarn. The material from the comber is passed through the draw frame again to produce a sliver.

2.3.5 Speed Frame

This is an intermediate process to prepare a package suitable for final spinning on the ring frame. Cans with fibers sliver from draw frame are transformed into lea with low twist referred to as the roving. A small compact package called bobbins with roving sliver with reduced linear density and minimal twist suitable for the Ring Frame is prepared.

2.3.6 Ring Spinning Frame

The Ring Spinning Frame is the final machine used in conventional spinning system to transform the roving from the speed frame into spun yarn. Ring Frame is the most widely used machine for spinning short staple fibres due to significant advantages it has compared to other modern spinning technologies. Ring spinning is the system of choice for spinning cotton, wool and flax fibres into a yarn. Roving, the feed stock of the ring frame is drafted by use of drawing rollers, then spun and wound around a bobbin mounted on a rotating spindle.

The three main activities of ring spinning are:

(i) drafting the roving to required fineness,

(ii) imparting strength to fiber strand by twisting it to form the yarn and

(iii) winding-up the spun yarn into a suitable package for further processing.

2.4 Operating Principle of the Ring Frame

The feed material in form of roving bobbins is inserted in holders on the creel, the roving is threaded through the guide bars into the drafting system which draws the roving to the required count. A thin layer of uniformly set fibers emerges from the front roller and the high speed rotation of the spindle insert's twist on the fibres to provide strength to the yarn. As the traveler rotates around, the spinning ring twists is inserted on the yarn. The ring traveler also takes up the yarn onto the bobbin mounted on the rotating spindle. The traveler is moved around the ring by dragging of the yarn threaded through it. The rotation of the traveler around the ring lags behind that of the spindle due to the relatively high friction of the ring traveler on the ring and atmospheric resistance of the traveler and the thread balloon between yarn guide eyelet and traveler.

The rotating speed difference between the spindle and the traveler results to winding of the yarn on the bobbin. The yarn winding is from the top to the bottom of the cylindrical bobbin by up and down movement of the ring achieved by raising and lowering a continuous ring rail on which the rings are mounted. The ring rail is slightly shifted traverse after each layer of yarn to achieve systematic reduction in layers of yarn along the height of winding height of the bobbin. The side view and line diagram showing the arrangement of the operating parts of a ring frame is shown in Figure 2.3.

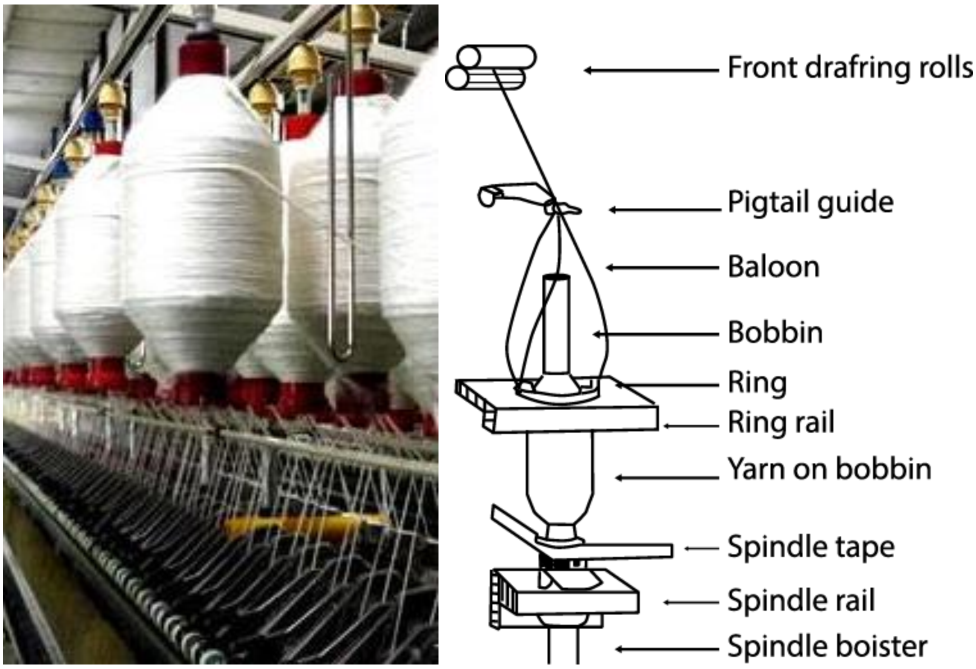


Figure 2.3: Side view and operating parts of the Ring Frame

Source: Researcher, 2019

2.5 Productivity Limitations of the Ring Frame

According to Ishtiaque (2004), ring frame constitutes a major proportion of cost of yarn production and productivity of the ring frame has considerable importance in the effort to maximize production, increasing ring spindle speed while maintaining the required yarn quality and running performance of the ring frame is the cherished goal consistently sought by spinning mills for minimizing the cost of yarn. The process of converting fibres to yarn at the ring frame is limited by the size of yarn package that can be built inside the ring size.

Limitations at the twisting zone of the ring frame is attributed to the traveler. The friction surface between the ring and the traveler generates high pressure of up to 35N/mm^2 during winding. The pressure generates heat which cannot be dissipated by the low mass traveler in short time resulting to limitation of the maximum possible operating speeds for the traveler. If the spindle speed is too high traveler temperatures reach 400 to 500 degrees Celsius which exceeds the thermal stress limit of the traveler leading to a drastic change in wear behavior of the ring and the traveler (Nilesh, 2011).

Comprehensive research and development has been carried out to improve the design feature of the ring–traveler featuring development of traveler from materials such as alloys and ceramics and use of surface coating to improve heat dissipation properties of the traveler and increase the speed of the traveler. Traveler speeds are limited to 40 meters per minute restricting the maximum rotational speeds of the spindle speeds and the production rates of the ring frame. Further limitation in the size of the bobbin which can be mount on the spindle while operating at the high spindle speeds increases the labor required for doffing and contributes to unwanted machine down-time during doffing stoppage reducing the machine productivity. Modern ring frame machines feature very advanced engineering improvements geared towards overcoming these drawbacks, such as automation of the doffing process and integration of a link to winding.

The productivity of the ring frame has increased by 40% since the late 1970s but the ring spinning technology used for yarn production has remained largely unchanged (Ishitiaque, 2004). The following refinements were significant to the survival of the ring frame:

i. Extension of the ring frame made them longer reducing the relative costs associated with automatic doffing.
ii. Integrating winding into the ring frame spinning process further enhanced the adoption of automation.
iii. Advancement of the ring frame to include automatic doffing mechanism minimized doffing stoppage time and reduced the effects of small ring and bobbin sizes.
iv. The use of autoconer with splicing mechanism in subsequent winding process eliminated the negative quality impacts of yarn knotting and improved the potential to use smaller bobbin package.
v. The use of smaller rings meant that higher rotational spindle speeds would be achieved within the limited traveler surface speed of 40m/s, which in turn increased the twisting rates.

The combinations of these factors improved maximum potential speed of the ring frame from about 15,000 to 25,000 rpm. There have also been other several proposed improvements in research, which can be developed to achieve further improvement of rings and travelers and use of automated take-off devices. For example, reducing the diameter of the ring allows increase of rotational speed of the spindle without change in traveler speed, cost savings equivalent to 7 Ksh./kg in yarn production cost can be achieved by use of a 42 mm ring instead of a 48 mm ring, despite a slight decline in efficiency. However, reductions in ring diameter assume the use of automatic doffers on the ring spinning machine, except in countries where wages are very low, and use of autoconer with piercers in winding otherwise the slub-free length is then of little importance (Reiter, 2014). Summarized comparison of yarn spinning methods based on existing literature has been tabulated in Table 2.1

Table 2.1: Summary comparison of yarn spinning methods and technology

	Spinning method/ technique				
	Convectional	**Open end**			
	Ring frame	Rotor	Friction	Voltex	Air jet
Fiber feed material used	All	Short	All	Medium long	Long synthetic
Production speeds (m/min)	20-30	200	300	400	120-300
Count range (Ne)	2^s -200^s	1^s -60^s	1^s -20^s	10^s -120^s	40^s -60^s
No. of preparation stages	6- carded 7- combed	3	5	5	5
No. of post spinning stages	1	-	-	-	-
Twist insertion mode	Ring and traveler	Turning of rotor	Rotation of drum	Use of air jets	Rotating vortex of high pressured air
Limitation of process due to twist insertion	Yes	Yes	No	yes	No
Limitation of process due doffing and transport mechanism	Yes	Partly	Yes	yes	Yes
End product application	All products	Coarse woven fabric	Heavy count technical core wrapped yarn	Woven outwear and beddings	Woven outwear and beddings

Source Literature Review, 2019

2.6 Productivity Improvement Measurement

2.6.1 Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is defined by Japan Institute of Plant Maintenance (JIPM) as a broad strategy to increase effectiveness of any manufacturing production through methods of increasing equipment effectiveness (Amasaka, 2009). The concept was adopted by the Japanese from the USA in 1951. TPM ensures production machines are kept in good working condition through systematic maintenance so that they fail less frequently and the production process continues without interruption. TPM integrates maintenance into manufacturing production as an essential and vitally important part of the industry. Maintenance is considered as an important factor that influences profitability of a mill, down time for maintenance is scheduled as a part of the manufacturing day to today activities. The goal of the TPM is to significantly increase production and at the same time improve employee morale and job satisfaction. Implementation of TPM is supported by implantation of well-defined steps for both production and maintenance (Ljungberg, 2000).

2.6.2 Overall Equipment Effectiveness (OEE)

Overall Equipment Effectiveness (OEE) is an integral part of total productive performance (TPM) concept launched by Seiichi Nakajima in the 1980s'. OEE is regarded as a measurement tool under TPM designed to identify production losses related to a machine used in production (Williamson, 2006). The quantitative measurement is used to determine the metric measure of productivity for an individual production equipment in an industry. OEE has become one of the most popular tool used to reveal and measure hidden or irrelevant costs related to a production machine (Nakajima, 1988).

According to Huang (2003), OEE concept has become increasingly popular and has been used as a quantitative tool to measure productivity in semiconductors manufacturing industries. In the textile Industry, OEE was applied in production department weaving tire cord in Indonesia. Factors influencing the low effectiveness of weaving were determined and corrective action to implement autonomous maintenance in accordance with TPM suggested (Akhmed 2015). OEE returns a percentage measure of how well a production equipment is utilized over a certain time period. An OEE rating of 100% means that the machine did not breakdown, did not run slower than the target time and no defective parts were produced. Although this is the goal of OEE, equipment used in manufacturing are not perfect, having a way to measure the performance of an equipment provides the opportunity to identify the most beneficial changes for improving its performance. Dal (2000) refers to OEE as a measure that attempts to reveal hidden costs.

OEE assigns a numerical value to improvement opportunity. It factors in the availability, performance and quality of output of a given piece of equipment. It is best suited for environments of high volume based production where capacity utilization is one of the higher priority and stoppages are costly in terms of lost capacity (Dal et al, 2000). Therefore, OEE is best suited to analyze spindle utilization in ring frame short staple spinning according to Nakajima (1988).

OEE was applied in this research to identify losses that restricts ring frame from achieving recommended optimum spindle utilization of 98% and rank the various aspects of the machine/equipment for improvement of productivity.

2.6.3 Modelling of OEE for Analysis of Spindle Utilization in Ring Frame

2.6.3.1 Six Big Losses

Under OEE, it is essential to understand and quantify the disturbance and manufacturing processes that lead to stoppages of machines and loss in capacity. The six big loses are shown in Figure 2.4:

a) Down time losses – used to calculate availability of the machine

   The two big losses under down time losses and used to calculate availability of a machine are:

   (i) Machine failure: production time and quantity is lost when the ring frame breaks down. Broken down ring frame which is not used to produce yarn can lead to downtime leading to production loss and further contributing to low spindle utilization.

(ii) Set-up and adjustments: production loss occurs during change overs for one item to another. In the ring frame losses occur at the end of cycle when the machine is stopped to doff full bobbins manually and replace them with empty RF bobbins, in case of count change the process parameters of the ring frame has to be adjusted.

b) Speed losses – used to determine the performance efficiency of the machine

i. Idling and minor stoppages includes temporary interruption of production. In the case of ring frame end breakage where a spindle does not produce yarn until the operator pieces the broken end, creeling loss also occurs when the supply material is used up and the operator has to remove the used roving bobbin and replace it with a full one then piece it with the yarn for production to resume.

ii. Reduced speed: these are losses due to difference between machine design speed and the actual operating speed. At the ring frame different yarn specifications (count and twist) require different process parameters including speed adjustment and cycle time from the initial doff to the final doff

c) Quality losses used to evaluate the production of defects by the machine

i. Defectives/rework losses: when an end-breakage occurs the feed material for the roving bobbin continues to be sacked as pneumafil waste, hence wastage.

ii. Reduced yield; there is reduced yarn production due to inefficiencies in piecing when an end breaks or when the roving bobbin gets used up, the operator has to patrol the entire ring frame to identify and piece broken ends.

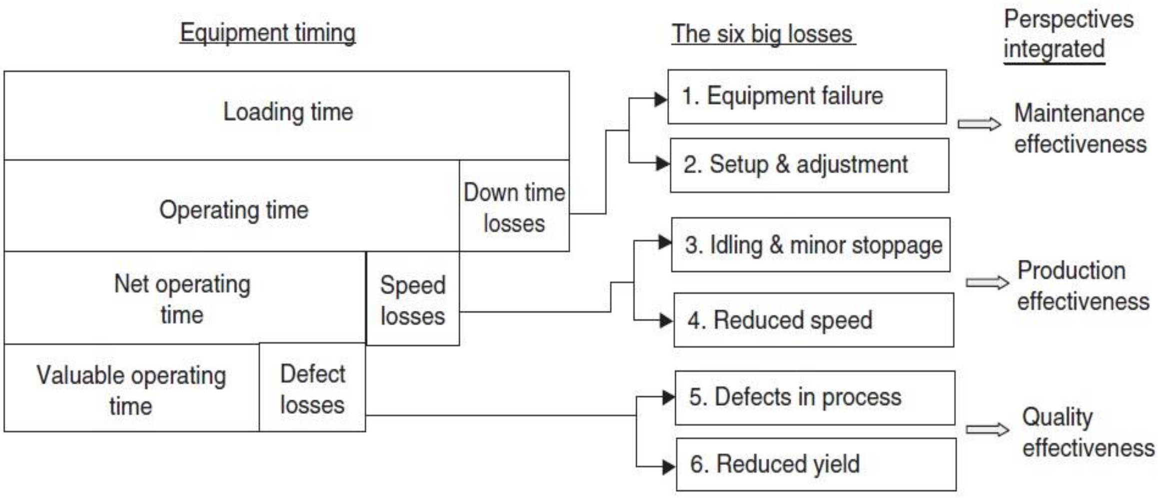


Figure 2.4*:* OEE measurement tool and the perspectives of performance integrated in the tool

Source: Muchiri & Pintelon, 2008

The OEE tool was modified in the perspective of the ring frame to identify losses that contribute to spindle utilization in ring spinning. The modified OEE provided a tool to evaluate all the loss factors in the utilization of the Ring Frame.

OEE components calculation procedures

OEE formulation is a function of the availability, performance rate and quality as formulated:

$$OEE\ (\%) = Availability\ (\%)\ \text{x}\ Perfoamance\ \ rate\ (\%)\ \text{x}\ Quality\,rate\ (\%) \quad \text{Eq. 1}$$

$$Availability\ (\%) = \frac{\text{Operating time x 100}}{\text{Planned Production time}} \quad \text{Eq. 2}$$

Where: Planned production time (PPT) = *Total duration of the shift*

Operatizing time = *total duration of the shift – doffing time –idle spindles**

** Idle spindles refer to Spindle tape and apron breakages and other spindle related breakdown that do not produce yarn from initial doff to full doff*

$$Performace\ (\%) = \frac{\text{Actual production rate x 100}}{\text{Ideal production rate}} \quad \text{Eq. 3}$$

$$Quality\ (\%) = \frac{\text{Good quality bobbin per ring frame x 100}}{\text{Total Number bobbins per ring frame}} \quad \text{Eq. 4}$$

2.6.4 Seven Basic Tools of Quality Control

The Seven Basic Tools for Quality Control (7 QC) were first proposed by Dr. Kaoru Ishikawa in 1968 for management of quality through techniques and practices for Japanese industries. The tools were designed for application in conducting self-studies, training of employees by supervisors or for use by quality control reading groups in Japan (Omachonu & Ross, 2004). According to Ishikawa these 7 tools can be used to solve 95% of all problems and have been the foundation of Japan's strong post world war industrial resurgence.

The seven basic quality control tools are tally sheets, graphs, histograms, pareto charts, cause-and-effect diagrams, scatter diagrams and control charts. Application of the tools and the relationships among the seven tools can be utilized for the identification and analysis of improvement of quality (Kerzner, 2009). The 7 QC tools are important tools used widely in manufacturing to monitor the overall operation and continuous process improvement by finding out root causes and eliminating them, also modes of defects on production lines are investigated through direct observation on the production line and statistical tools (Varsha, 2014).

2.6.5 Root Cause Analysis

Root Cause Analysis (RCA) is a systematic process for identifying “root causes” of problems or events and an approach for responding to them (Latino, 2011). Ishikawa Diagram is one of the tools, processes, and philosophies of accomplishing RCA.

Ishikawa Diagram was derived from the quality management process. It is an analytical tool under RCA that provides a systematic way of looking at effects and the causes that create or contribute to those effects. A diagram is drawn for each problem, with arrows showing the possible causes in each category. The causes and effects in a RCA are usually categorized according to six elements; man, materials, machine, measurement, method and environment. Potential causes are indicated by arrows that point to the main cause arrow (Neyestani, 2017).

2.6.6 Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis **(**FMEA) was developed for application in the naval aircraft control system by the Grumman Aircraft Cooperation in 1950 and 1960's (Kumar, 2011). FMEA is a systematic, proactive technique used to evaluate a process with a view of identifying where and how it might fail and also provide assessment of the effect of the of different failures, the technique is applied in identification and prioritization of the process parts with the highest need of change.

The starting point in FMEA is construction of a process map in order to come up with the activities and sub-activities of the process, potential failure modes are then identified and given the Risk Priority Number (RPN). Oldenholf (2011) explored the consistency of FMEA in the validation of analytic procedures by using different teams to carry out analysis.

2.7 Ring Spinning Process Parameters and Production

Production per spindle in a ring frame is influenced by the operating speed, fibre material, spinning process parameters and the number of idle spindles. Generally, the higher the yarn count, the lower the production per spindle, and the higher the twist per inch, the lower the production per spindle. Operational deficiencies such as poor machinery condition, bad housekeeping, improper material handling and inefficient labour may also affect productivity. Yarn production ring spinning is influenced by the spindle utilization of the ring frame.

2.8 Production Improvement Techniques

2.8.1 Single Minute exchange of a Die (SMED*)*

SMED technique is used to reduce a machine setup time. Machine set up time can be classified as either internal or external. Internal setup activities are those that are carried out when a production equipment has stopped, while external setup activities are those that are performed while the equipment is still running. SMED is an important lean tool used to reduce time wastage and improve flexibility in manufacturing production. The tool has been used in improving production by reducing losses related to lot size losses and improvement of manufacturing process flow. SMED reduces the non-productive time by streamlining and standardizing the operations for exchange tools, using simple techniques and easy applications (Ana Sofia Alves et.al, 2009).

2.8.2 Five (5) Ss

'5S' is one of the Japanese techniques which was introduced by Takashi Osada in the early 1980s. Five Ss is an abbreviation for the Japanese, which translates to mean: sorting, straighten, shine, standardize and sustain. It is basically a workplace management approach that helps to achieve a structured clean and orderly work place by fixing a location for everything, therefore improving working environment, human capabilities and thereby enhancing productivity by minimizing the loss of time and unnecessary movements as well (Mohd Nizam, 2010).

2.8.3 Continuous Improvement (CI)

Continuous improvement was adopted by Deming and Juran from a Japanese word Kaizen, which originated from Japanese work method of continuous improvement of work. The Demning concept of Plan Do Check and Act (PDCA) cycle was referred as a Shewhart cycle and consisted of four phases; the activities involved were Plan, Do, Check and Act.

In recent years, Kaizen has become more and more prevailing and extended to broader areas with new methodologies, advanced techniques and significant successes in many industries, such as steel, aerospace, furniture, as well as product design and human resource management, and many others (Morton et al. 2006; Kumarand Wellbrock, 2009).

2.9 Review of Evaluation of Performance Improvement Techniques

None of the production improvement methods or tools is better than the other, different methods and tools have both positive and negative aspects and the situation and where it is used affects the applicability. Some methods and tools are more suitable in particular industries than others. Their application also depends on the needs to be accomplished with a specific method, adoption of a method is therefore based on dominant conditions in a particular industry.

2.9.1 Ljungsrom Evaluation of Improvement Methods

The Ljungsrom evaluation of improvement methods uses the criteria of number of structural change, easy to understand, usable directly in daily work, fast results, possibility to evaluate economic results and involvement of all personnel to evaluate the performance improvement technique's attributes of 5s, TPM, Six Sigma and CI (Ljungsrom, 2004). The techniques were scored as strong, medium or weak; weak score did not imply that the technique was bad for the criteria, it meant it was more difficult to use in that particular criteria.

2.9.2 The Performance Improvement Method

The Performance Improvement Method (PIM) evaluation of methods was developed by Grunberg (2007) as an improvement of Ljungsrom evaluation criteria to promote structured production performance, improvement in manufacturing and easiness of use at operative level.

The PIM scoring criteria was designed for the manufacturing sector to assist in formulation and selection of the most suitable improvement technique to support improvement of implementation where the methods are applicable. The PIM compared 16 methods of Performance improvement among them Five S, SMED and CI, the evaluation criteria for PIM was based on the following:

(i) Ease of use by non-specialists
(ii) Competence enhancing
(iii) Implementation supportive
(iv) Performance measurements
(v) Supportive regarding choice of improvement object and that
(vi) Would not act against organizational resistance

The advantage of PIM approach was that the problem owner was involved in selection and supporting the implementation of performance improvement. PIM also proved to meet more criteria than other methods, especially on the important criterion of specialist independency. PIM is an organized and sustainable productivity improvement program and was used as a guideline to develop a method that supports productivity improvement in textile manufacturing firms in Ethiopia.

2.10 Factors Affecting Spindle Utilization in Ring Spinning of Fine Cotton Yarns

According to Rengasamy (2004), performance of the ring frame is determined by productivity, end breakage and quality of yarn produced. Spindle utilization is influenced by various factors, which may be categorized into two; idle running spindles and frame stoppages. Controlling ends down and stoppages of the ring frame can increase production per spindle to a great extent and also has an impact on yarn quality which is improved under the same conditions of cost and labor charges.

2.10.1 End breakages

One of the limitations of the modern ring frame is end breakage, decreasing end breakage of ring frame in consideration of running performance minimizes the cost of yarn. End breakage rate is directly related to the percentage of pneumafil wastages and cost of yarn production (Khan, 2015). End breaks occur when the yarn has less strength compared to the speed of the spindle. End breaks cause a loss in production because the spindle produces no yarn after an end-break until it is repaired. An operator usually serves up to a thousand spindles in a spinning mill and in some occasions an end break may remain unpieced for a couple of minutes. When an end breaks the feed material, the fibers in form of a roving, keep flowing and is sucked away by pneumafil system as waste fibers.

The operator manually repairs the breakage by retrieving the end from the bobbin and threading it through the traveler and the pigtail guide before inserting it into the nip of the front drafting roll. An experienced operator may take just a second to do the piecing but much of the time is spent patrolling to find the end-break. If an end break would occur on every spindle the production efficiency would be low resulting to significant loss in production.

End-break should be minimized in order to achieve high optimal production efficiencies. Attempts to automate piecing of end breaks and installation of roving stop systems to prevent fibre wastage have been hampered by the capital cost involved, most mills prefer to operate a conventional ring frame but it involves the expense of dealing with about a 2% fiber loss (Lord, 2002). Over all, when ends break there is a significant rise in the amount of fibers wasted at the ring frame leading to deterioration of the overall mill performance and the quality of the yarn spun.

2.10.2 Other Causes of Idle Spindles

Fiber material is supplied to the ring spinning machine in the form of roving bobbin, when the roving is exhausted, the operator removes the empty roving bobbin by replacing it with a new full roving bobbin, this process is referred to as creeling. Creeling time should be as short as possible to minimize productivity loss. Mills should have a standard procedure designed on the concept (SMED).

2.10.3 Spindle Breakdowns

Broken spindle tapes and drafting roller aprons results to idle spindles in addition to contributing to loss of roving material in form of soft waste. Ideally, broken spindles and aprons should be repaired immediately. The missing parts further increases idle spindles resulting to poor yarn realization and energy loss. Broken and missing machine parts should be replaced immediately. The best practice is implementation of TPM within spinning mills.

2.10.4 Doffing Frame stoppages

Doffing is the process of removing the filled up bobbin packages from the spindle of the ring frame and replacing with the empty ones. When the bobbin gets filled up with yarn, the entire ring frame machine automatically stops. Doffing is carried out by skilled operators referred as doffers. The count number of the yarn being spun determines the time the machine takes before doffing. For coarse yarn counts of 7s, and 10s the doff time is less and for finer counts of 30s, to 40s the time is significantly higher. Yarn counts of 20s takes 90-110 min for a complete doff. The process of doffing should be carried out in the shortest time possible time.

2.11 Deduction from Literature

Ring spinning has been the most used but the least productive spinning system, the major limitation is occasioned by the traveler which generates high amount of heat at high speed running, it is extremely difficult to conduct this heat away in the short time available. The spindle speed has thus been limited to 25,000 Rpm. A study by Reiter (2015) revealed that the Ring Frame machine as the major cost factor in spinning mills accounting for 60% of the total cost of converting fibers to yarn.

SITRA publication "Norms for Productivity in Spinning" gives ring spinning spindle utilization standard norm of 98% to form medium counts of yarn. Higher production per spindle is a great advantage to the mill as it reduces costs per unit production leading to increase in marginal profits of the firm. Research conducted in India by SITRA, indicate that a 1% increase in production per spindle would lead to a saving of US$ 15,000 per annum for a 30000 spindle mill (Shanmuganandan, 2010).

ITC 2015 estimates the average spindle utilization at 67% for the eight operational spinning mills in Kenya. Sunflag had the highest spindle utilization in Kenya of approximately 85% based on the weight of the yarn produced, previous surveys on spinning mills in Kenya focused on the yarn realization.

No study has been undertaken on a spinning mill in Kenya to determine and analyze the factors affecting the low spindle utilization and therefore this study seeks to fill the existing knowledge gap.

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

This Chapter covers the research design that was followed in conducting the study. A mix of descriptive, qualitative and quantitative techniques were applied to address the objectives of the study. A systematic research methodology was designed to study ring spinning process, parameters and production with a view of identifying production losses. Production 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. The summary of the methodology applied in the study is shown in Figure 3.1.

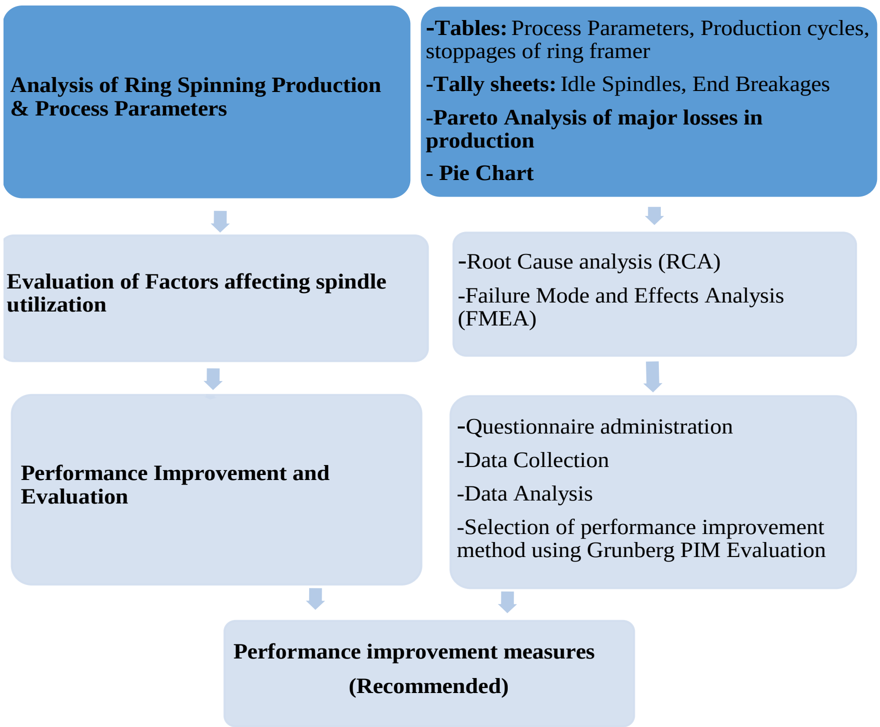


Figure 3.1: Methodology of the study

3.1 Ring Frame Process Analysis and Production

The study used quantitative and qualitative research techniques to investigate process parameters, machine settings and yarn production in cotton short staple ring spinning. Ring frame spinning process in place was analysed and detailed analytics of production carried out using applicable basic tools of Quality Control (7 QC tools) methodology to identify and create opportunities for mapping out process inefficiencies. The tools are widely used in manufacturing to monitor the overall operation for continuous improvement and can be used to solve 95% of all the problems. The seven QC tools include; stratification, histogram, tally sheets, cause and effect diagram, pareto chart and control charts. The tools were applied to carry out study of machine operating settings, analysis of machine running cycles, product being proceed and study of production levels.

3.1.1 Analysis of Ring Frame Process Parameters

A preliminary study of the ring frame settings and process parameter that had influence on production was carried out for the ring frames of the spinning mill. Basic data collection tables as proposed by basic 7 QC tools was used to collect data related to the ring frame and spindles spinning medium to fine count cotton yarns. Analysis of the table was used to analyse the feed materials, yarn counts being produced, the machine settings and production levels of the mill.

3.1.2 Ring Frame Analysis Running and Stoppages Cycles

Data on stoppage durations automatically recorded on the Ring frame machine memory was retrieved and recorded using tally sheet against the cause of each of the stoppage for two ring frames for two weeks to analyze the various causes of ring frame stoppage and determine the spinning and doffing cycles. The spinning and doffing cycle times for the shifts was found to be stable and predictable. The spinning cycle was timed from the start of the running of the ring frame when yarn starts building up on the bobbin up to the time when the bobbins get filled with the yarn and the frame automatically stops. Spinning cycles of the two ring frames was timed from the start to the full doffing time, in a week of 5 days with 8 working hours.

3.1.3 Study of Idle Spindles and End Breakages

A snap study was carried out of all ring frames by using tally sheets, which were used to investigate causes of idle spindles. Data on the number of spindles per frame not making yarn at various intervals of the machine spinning cycle was collected. The numbers of end breakages in two ring frames were studied by observing the number of end breaks/100 spindle/hour. The number of breaks at the start of the study, number of ends pieced during the study and number of breaks at the end of the study were recorded and used to determine the end breakage rate of the Ring frame.

3.1.4 Pareto Analysis

Pareto analysis time loss due to stoppages was conducted and used to determine production loss based on six major productions on OEE. Pareto analysis is the most widely used to identify, sort and display causes of a particular problem. It graphically illustrates all the factors that influence a given outcome thus identifying the possible root causes. Pareto analysis was used to identify and classify the reasons that are responsible for production loss contributing to low spindle utilisation in ring frame spinning.

3.2 Evaluation of factor affecting Ring Frame Spindle Utilization

The study used descriptive and qualitative techniques to understand the factors that influenced ring frame spindle utilization in ring spinning. Analysis of the impact of various factors was carried out to prioritize the factors.

3.2.1 Root Cause Analysis

Ishikawa diagram was used to conduct a Root Cause Analysis through focused group discussions to identify production losses in the ring spinning doffing process. RCA is a structured approach used in identifying causes of production with techniques designed to provide focus for identifying and resolving problems. Causes of production loss, which were considered to have high effect on production, were classified on the level of their significance. The loss factors were fed on Ishikawa diagram on the basis of man, machine, materials, environment and management.

3.2.2 Failure Mode and Effects Analysis (FMEA)

FMEA was carried out to detect the possible failure modes related to the ring spinning process and prioritize them. It is an effective method and tool for analyzing a procedure and risk assessing with capability of offering critical assistance to analysis and improvement in manufacturing process such as ring frame spinning. A team of operators was used to develop a process map for the ring spinning process. The main processes of spinning, doffing and set-up were discussed to come up with all the detailed sub-activities of the spinning process. The failure modes under each sub activity were discussed and given the Risk Priority Number (RPN) using the FMEA Criteria (Appendix 3).

Potential failure causes with the highest RPN were identified in order to prioritize performance improvement measures in ring spinning.

3.3 Performance Improvement Design and Evaluation

The study used quantitative and qualitative approach to collect data through questionnaire and interviews related to productivity improvement and to understand the operational structure of the mill for identification and selection of a performance improvement technique.

3.3.1 Sampling Procedure

The researcher used purposeful sampling to identify eighteen (18) responded composed of the engineer, technician, operators and other staff working directly on the Ring Frame. According to Blair (2015), purposeful sampling technique is used in quantitative research to ensure representativeness in identification and selection of the respondents well versed in the subject of the study for the most effective use of limited resources. Purposeful sampling involves identifying and selecting individuals or group of individuals that are especially knowledgeable about or experienced with a phenomenon of interest (Cresswell & Plano Clark, 2011). The mill had one engineer, one technician, thirteen operators and three support staff working directly on the ring frames who were selected for the study. The study therefore employed stratified purposeful sampling where employees working directly on the Ring Frames at various levels were selected as respondents as shown in Table 3.1.

Table 3.1: sample size of employees working directly on the ring frame compared to total employee of the mill

Employee Level	Mill employees	Sample Size *(Employees working on Ring Frames)*
Engineers	4	1
Technicians/artisans	10	1
Operators	136	13
Others	30	3
Total	**180**	**18**

Source: Field Data, 2019

3.3.2 Questionnaire Survey

A detailed questionnaire was structured based on the Grunberg (2007) method to support performance improvement in industrial operations (PIM) and sent to the various categories of the mill workforce. The PIM based questionnaire was designed on Grunberg criteria of specialist independence, competence supportive, implementation supportive, measurement based, objective supportive and organizational supportive. The questionnaire was used to collect unique information related to performance improvement in ring spinning. The six level criteria were scored at four levels indicating the extent to which the responded agreed with the statements given, the questionnaire is attached in appendix 1.

3.3.3 Data collection

3.3.4 Respondents Response Rate

The researcher issued 18 questionnaires representing 10% of the target population of 180 employees of the Sunflag Textile mills spinning plant located along Lunga Lunga road, Industrial area, Nairobi. The response rate of the respondents is shown in Table 3.2

Table 3.2: Response Rate of the Respondents

Responses	Frequency	Percentage (%)
Completed usable questionnaires	16	88.8
Unreturned and disqualified questionnaires	2	11.2
Total	**18**	**100**

Source: Field Data, 2019

3.3.5 Data Analysis

Data collected was analyzed by using excel statistical tools and modeled to descriptive statistic using industrial engineering overall equipment effectiveness (OEE) and Performance Improvement Method (PIM) model along with inferential statistics. Various factors which directly affect the ring frame productivity such as end breakage rate, idle spindles, doffing loss and pneumafill waste were analysed and their effects on overall spindle utilization evaluated.

3.3.6 Validity and Reliability

The validity of a test is a measure of how well a test measures what it is supposed to measure (Kombo & Tromp, 2006). According to Mugenda and Mugenda (2003), validity is the accuracy and meaningfulness of inferences which are based on the research results. It's the degree to which the results obtained from the analysis of data actually represent the variables under study. Mugenda (2008) points out that validity is used to estimate how accurately the data obtained in the study represents a given variable or construct in the study. Content validity through expert and supervisor opinion was used.

According to Mugenda (2008) reliability is a measure of the degree to which a research instrument yields consistent results or data after repeated trials. Reliability in research is influenced by random error, as the error increases; reliability decreases (Mugenda & Mugenda, 2003). Random error is the deviation from a true measurement due to factors that have not effectively been addressed by the researcher. Statistical Analysis System, known as SAS statistical software, is one of the most widely used, flexible data processing tools. SAS software version 9.4 was used to carry out analysis of variance (ANOVA), the means were compared by least square means (Ls-means) at alpha = 0.05. A significant level of 0.05 had a 5% risk of concluding that there was a difference when there was none. P values were considered significant or insignificant at confidence levels of 95%. A small P values of 0.05 or less indicated there was statistical difference. Large P values of more than 0.05 indicated there no statistical difference in the values.

3.4. Performance Improvement Evaluation

The PIM Tool developed by Grunberg (2007) shown in Table 3.3 was used to come up with improvement measures for the potential failure causes. It is used to come up with organised and sustainable productivity improvement, which is flexible to apply at the operational level of the mill. The 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.

Table 3.3: The PIM Method to Support Performance Improvement in Industrial operations (source Grunberg 2007)

	Specialist Independent	**Competence Supportive**	**Implementation Supportive**	**Measurement Based**	**Object Supportive**	**Organisational Supportive**
TPM	1	1	3	3	3	1
JIT	1	1	1	1	2	1
TQM	1	1	2	3	1	2
Lean	1	1	1	1	1	1
BPR,BPI	1	1	2	3	1	2
6 Sigma	1	3	3	3	1	2
DFT	1	1	1	1	1	1
SCM	1	1	1	1	1	1
TOC	1	1	3	1	3	2
RPA	1	1	N/A	2	N/A	N/A
Simulation	1	1	N/A	3	1	1
Mapping	2	1	N/A	2	1	1
SMED	2	1	1	2	3	2
Five S	2	1	3	1	1	2
CI	2	1	1	2	1	2
Decision	2	1	N/A	2	N/A	N/A

Source: Field Data, 2019

CHAPTER FOUR: RESULTS, FINDINGS AND DISCUSSIONS

4.1 Introduction

In this chapter analysis was done to establish the impact of production management practices on the ring frame spindle utilisation. A detailed study on production loss was conducted and an evaluation of production management practices for the mill carried out. The data was analysed using statistical tools and interpretations made on responses received and available literature.

4.2 Impact of Frame Spinning Process Parameters and Production Performance on Spindle Utilisation

The mill operated 16 ring frame machines to produce short staple cotton yarns; 4 Laxmi LR6, 4 Rieter and 8 Rieter Laxmi G51 models of ring frames. The mill operated 24 hours daily on a day and night shift of 11 hours and 13 hours respectively. The study was conducted on the 16 ring frames producing yarn count of 20, 24, 30 and 38 Ne to analyze the process parameters, ring frame production per shift. Bobbin yarn content weight in a production cycle of a ring frame was also evaluated. The trends of production cycles of the ring frame, the mass of yarns produced and all the stoppages of the ring frame were investigated using data collection tools developed.

4.2.1 Ring Frame Process Parameters and Production

This section sought to determine the process parameters that the mill used on the 16 ring frames. Table 4.1 was used to study the process parameters and production of the ring frames. All the ring frames were producing cotton yarns and applied a break draft of 1.21 to attenuate the supply roving material. The mill was spinning coarse to medium count yarns of 20, 24, 30 and 38, higher counts of yarn required higher twist per metre (TPM) to impart strength on the yarn, TPM was also influenced by end use of the yarn. Yarns, which were, used for high strength applications such warp yarns required more TPM compared to hosiery yarn. The operating spindle speed of the ring frame were moderate and ranged from 10 rpm, 500 rpm to 13,000 rpm, higher spindle speed had influence on end breakage rate of the yarn which affected productivity of the ring frame and the quality of the yarn. Thirteen of the ring frames had 960 spindles and three had 864 which amounted to installed capacity of 15,072 ring frame spindles, the daily production was 6800 Kgs daily which translated to 0.451kgs per spindle compared to daily rotor production of 6.94 kg per rotor which spun an average count of 8 Ne. This was in line with the study conducted by Klein (2012) which estimated the yarn production of rotor at 4-6 times compared to the ring frame. Table 6 presents data on ring spinning process parameters of the mill.

Table 4.1: Ring Frame Settings and Process Parameters

RF/ Mc No.	Model	Max. Spindle Speed in (Rpm)	No. of spindles	Process Parameters		
				Yarn Count	**TPM**	**Operating Spindle speed (Rpm)**
1.	Laxmi LR6	20000	960	24	670	13000
2.	LaxmiLR6	20000	960	24	670	13000
3.	LaxmiLR6	20000	960	30	776	13800
4.	Laxmi Rieter G51	15000	960	38	925	12000
5.	Laxmi Rieter G51	15000	960	38	925	12000
6.	Laxmi Rieter G51	15000	960	30	774	11500
7.	Laxmi Rieter G51	15000	960	30	774	11500
8.	Laxmi Rieter G51	15000	960	30	774	11500
9.	Rieter	16000	960	20	625	12000
10.	Rieter	16000	960	20	625	10500
11.	Rieter	16000	960	20	625	12000
12.	Rieter	16000	960	20	625	12000
13.	Laxmi LR6	16000	960	20	625	12000
14.	Laxmi Rieter G51	16000	864	20	625	10500
15.	Laxmi Rieter G51	16000	864	20	625	10500
16.	Laxmi Rieter G51	16000	864	24	801	12000

Source: Field Data, 2019

4.2.2 Ring Frame Spinning and Doffing Cycles times

The study also collected information on the production cycles of the ring frame. The machine automatically records the cycle process parameters such as spinning and doffing cycles times which were retrieved, recorded and analyzed. The spinning and doffing cycle times for the shifts were found to be stable and predictable. The spinning cycle was timed from the start of the running of the ring frame and yarn starts building up on the bobbin to the time when ring frame automatically stops due to bobbins being filled up with yarn. The spinning cycles of the ring frame was timed from the start to the full doffing time in the 11 hours' day shift. Six (6) spinning and doffing cycles were completed for each of the six ring frames.

The spinning cycle mean time was 125.0533 minutes, analysis of variance was done using SAS software and the means were compared by least square means (Ls-means) at alpha = 0.05, the results of the SAS Glimmix procedure are indicated in Appendix 5 of this report. The P value for the spinning cycle time was found to be 0.5420, there were no significant differences were found between the mean time at the different cycles (Figure 10). The doffing cycle mean time was 12.1867 minutes, analysis of variance was done and the means were compared by least square means (Ls-means) at alpha = 0.05. The P value for the doffing cycle time was found to be 0.9245, there were no significant differences were found between the mean time at the different doffing cycles. The spinning and doffing cycles are presented in Figure 4.1 and Figure 4.2 respectively.

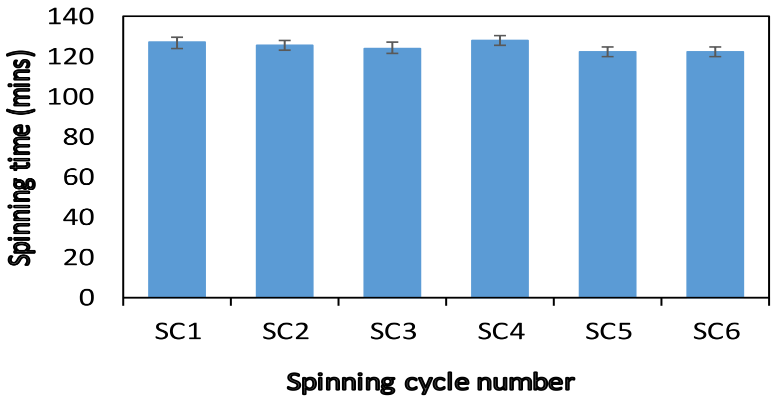


Figure 4.1: Ring Frame spinning cycle time

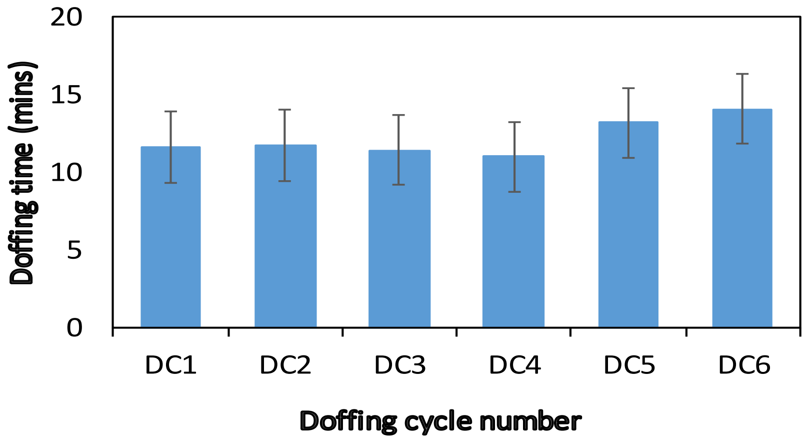


Figure 4.2: Ring Frame Doffing Cycle time

4.2.3 Analysis of Mass of Yarn Produced per Cycle of Ring Frame

A study of the mass of yarn produced by the ring frames at full doff per cycle of a ring frame in a shift was carried out. Analysis was undertaken to determine production loss resulting from difference in mass of yarn produced by the ring frames. Weight variations at full doff resulted from end breakages, idle spindles, exhaustion of roving bobbin and subsequent piecing delay by machine operators which lead to difference in the weight of yarn produced. The mean mass of yarn produced by the ring frames was found to have a mean of 49.7 kgs. Analysis of variance was done using SAS software and the means were compared by least square means (Ls-means) at alpha = 0.05, the results of the SAS Glimmix procedure are indicated in Appendix 5 of this report. The P value for the mass of yarn produced by the Ring Frames in a doff was found to be 0.5152, there were no significant significant differences were found between the mean mass of yarn produced by different ring frame machines. Figure 4.3 shows the weight of yarn produced by ring frames spinning 20s Ne count yarn.

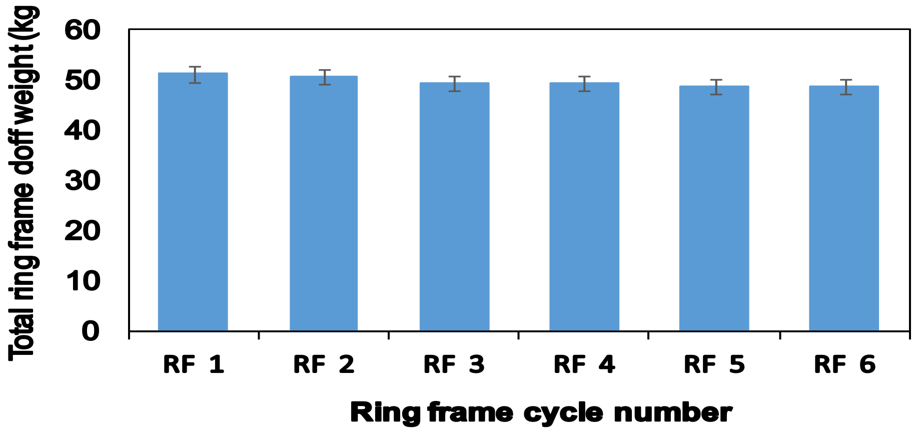


Figure 4.3: Variation in yarn weight per production of cycle ring frame

4.2.4 Analysis of Mass of Yarn Bobbins Produced by the Ring Frame

The ring frames had 960 spindles which were fitted with empty bobbins on which the spun yarn was wound. A further study to determine weight of the bobbins produced by the spindles within a ring frame was carried out. Ten (10) bobbins were randomly selected from six (6) ring frames spinning 20s and weighed to determine the production loss occurring due to under filling of yarn on the bobbins from the spindles of the ring frame. Lower weight of bobbins meant less yarn content on the doffed ring bobbins, the maximum bobbin weight recorded from the ring frames during the study was 64.3 grams. The mean mass of yarn bobbins at full doff was found to have a mean of 56.71525 grams representing a loss of 7.5847 grams per bobbin, analysis of variance was done using SAS software (Appendix 5) and the means were compared by least square means (Ls-means) at alpha = 0.05. No significant differences were found between the mean mass of bobbins produced by different ring frame machines in different cycles. The average weight of the bobbins produced by the ring frames is shown in Figure 4.4.

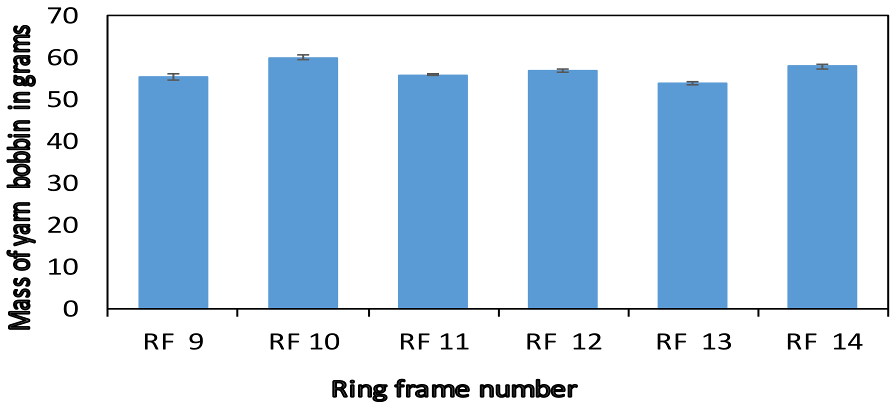


Figure 4.4: Average weight of ring frame yarn bobbin in grams from 6 different ring frames spinning 20s Ne

4.2.5 Ring Frame Stoppages

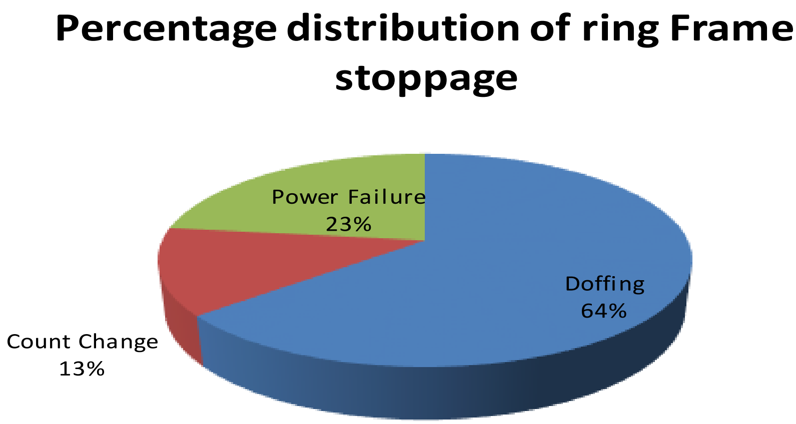
This section sought to investigate the causes and frequency of ring frame stoppages during the production shift of the mill, tables were used to collect data related to stoppages of the ring frame. Stoppages of the ring frame in two shifts were recorded in the order in which they occurred giving the reasons for stoppage. The causes of the stoppage were classified into production losses of OEE as they occurred in Table 4.2**.** Doffing was the highest cause of ring frame stoppages accounting for 64% of time loss in ring frame stoppages as shown in Figure 4.5.

Table 4.2: Two Shift Ring frame stoppages

Stoppage No.	Reason for the stoppage	Loss classification	Time loss in Mins
1.	Doffing	Idling and minor stoppages	15
2.	Doffing	Idling and minor stoppages	13
3.	Count Change	Set up and adjustments	20
4.	Doffing	Idling and minor stoppages	18
5.	Doffing	Idling and minor Stoppages	21
6.	Power Failure	Breakdown	35
7.	Doffing	Idling and minor Stoppages	15
8.	Doffing	Idling and minor Stoppages	15
		Total time loss	137

Source: Field Data, 2019

Figure 4.5: Distribution of Ring Frame Stoppages



4.2.6 Investigation of spindle production loss due to idle spindles and end breakage

A further study was carried out to investigate the production loss which occurred within the spindles during the running time of the machine due to idle spindles and end breakage. Production loss of 727 spindle minutes was lost due to idle spindle which was attributed to missing spindle drive tapes, broken bottom apron, roving exhaust and delay in creeling of roving bobbin by the ring frame operators as shown in Table 4.3. End-breaks in 100 spindles observed over a period of hour was 5.62 as shown in Table 4.4, standard mill operating procedure was that an end break would be pieced within 5 minutes of breakage. The loss in ring frame spindle hours arising from idle spindles and end breakage was computed based on the mill standard operating procedure and was found to be 863.68 spindle minutes of ring frame stoppage in two shifts. Analysis of the causes of spindle loss during the spinning cycle are shown in Figure 4.6.

Table 4.3: Two Ring Frame spindle production loss due to various idle spindles identification

Cause of Idle spindle Stoppage	Loss Classification	Rate of loss	Spindle minutes (mins)	Time loss (mins)
Missing Spindle tapes	Reduced speed	4 spindles per cycle	139	556
Roving exhaust and delay in creeling of roving bobbin	Yield loss	2 Roving bobbin exhausts	15	30
Bottom apron break	Yield loss	1 spindle per cycle	139	139

Table 4.4: End Breakage Rate Yield Loss on 100 Spindle Hour of the Ring Frame

End breaks at start	Ends pieced	Break at end	Total breaks	No of breaks per 100 spindle Hour
12	56	10	54	5.62

Source: Field Data, 2019

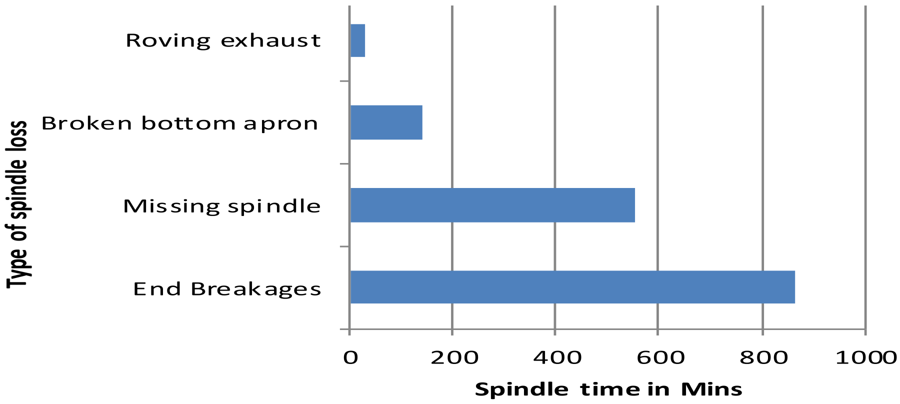


Figure 4.6: Analysis of loss in ring frame spindle hrs due to idle spindles in spindle-Mins

4.2.7 Pareto Analysis of Major Losses in Production

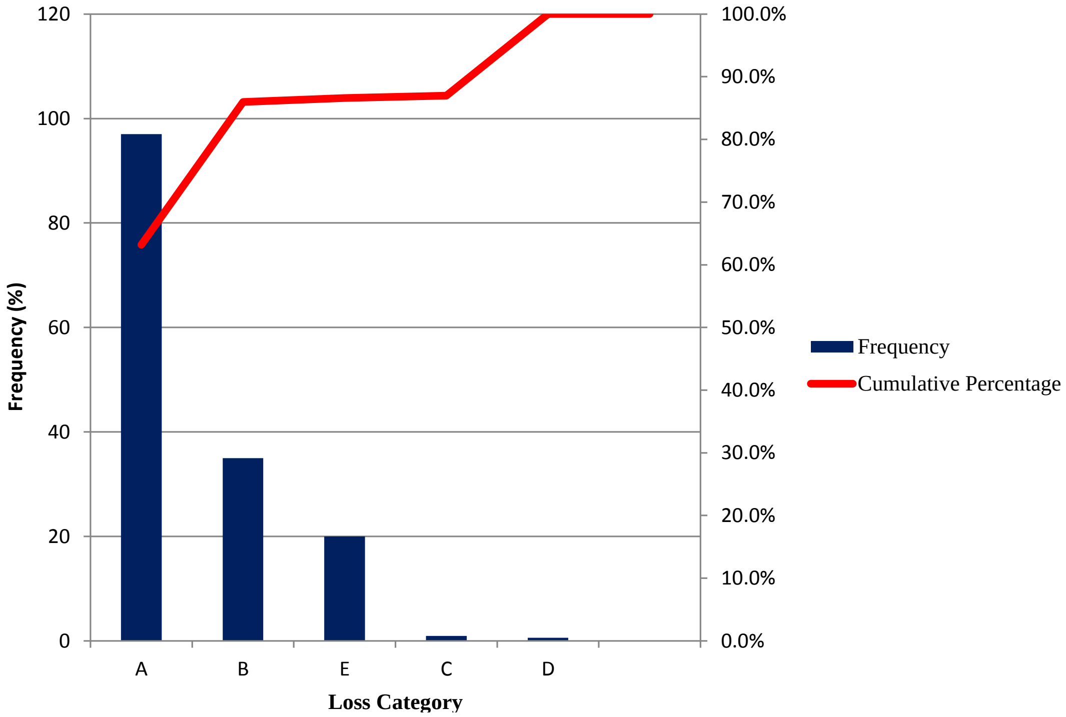
Analysis of production loss at the ring frame level and within the individual spindles of the ring frame was carried out using Pareto analysis to identify significant causes of production loss in ring spinning. All the ring frame stoppage losses and idle spindles were categorized into OEE five major classes of production loss as shown in Table 4.5 and analyzed using pareto analysis in Figure 4.7. 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.

Table 4.5: 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

Source: Field Data, 2019

Figure 4.7: Pareto Analysis of major losses in ring spinning



4.3 Evaluation of factor affecting Ring Frame Spindle Utilization

4.3.1 Root Cause Analysis

Ishikawa Diagram was applied to find problems related to the Ring Frame doffing process through discussions with the mill management and engineers on the causes of production loss. The main question used for Root Cause Analysis (RCA) was; what factors of the ring frame doffing process contributes to low spindle utilization in ring spinning? Ishikawa diagram was constructed considering the influence of five categories; man, material, management, environment and measurement. All the factors identified were analyzed on the basis of level of significance to the ring frame doffing process. The analysis of the ring frame doffing time loss factors is shown in Figure 4.8.

The significant factors identified to the ring frame doffing were due to:

(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

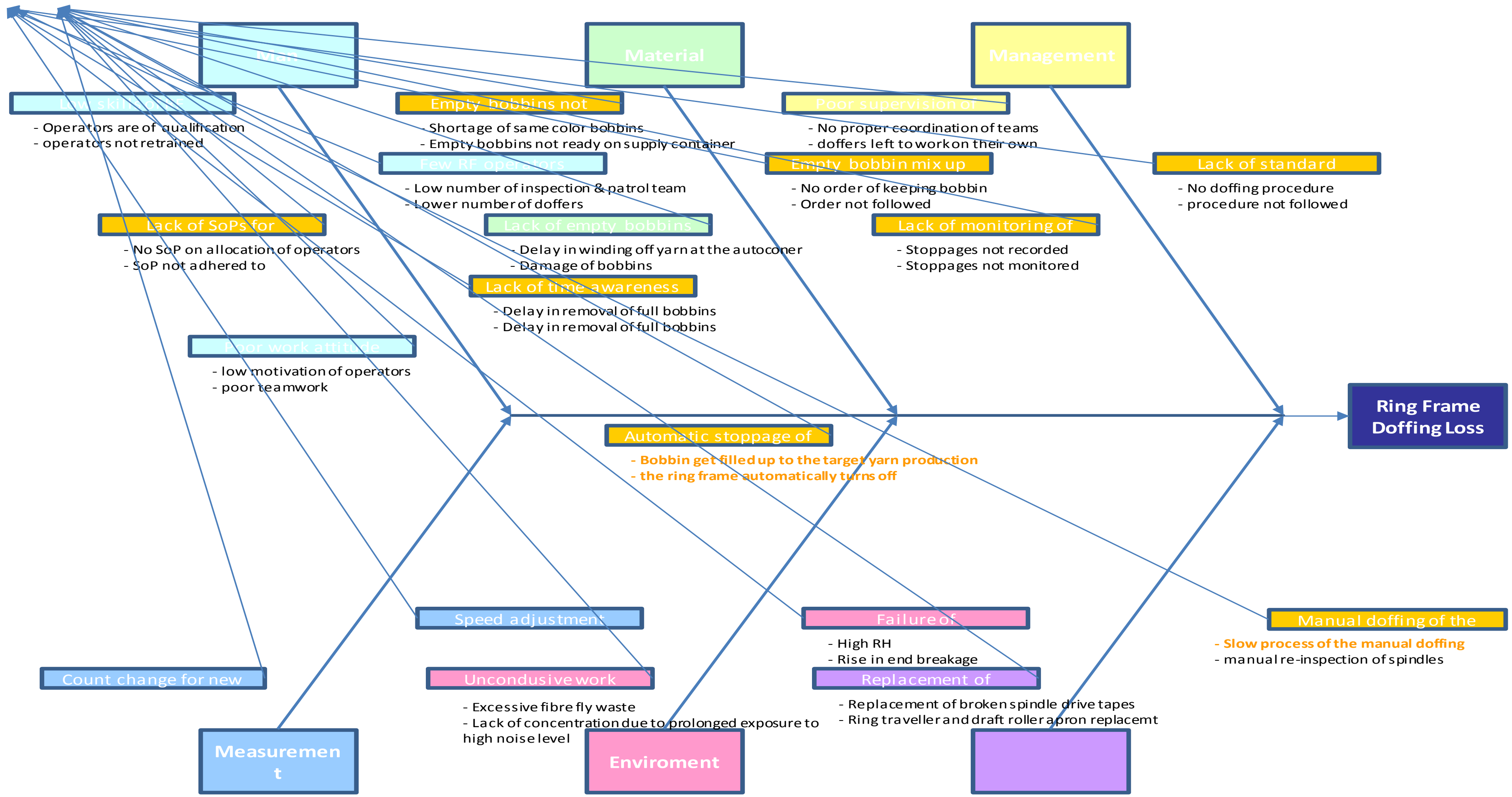
(iv) Delay in completion of the preparation of empty codded bobbins for the ring frame delayed the process of starting replacement of the of the filled up bobbins as the bobbins were not ready due to delay in completion of preparation of bobbins,

(v) Shortage of bobbins or mix up of bobbins for counts, lots and codes.

(vi) 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.

These causes were chosen as the inputs to the Ring Frame Doffing FMEA process after being identified as the significant causes of ring frame doffing loss.

Figure 4.8: Root Cause Analysis of ring frame doffing process time loss



4.3.2 Process Failure Mode and Effects Analysis (FMEA*)*

Failure Mode and Effects Analysis (FMEA) for ring frame doffing process was carried out to find out the possible failure modes and rank them in order of priority. The process map from when the ring frame automatically stops was outlined and each sub activity which was to be undertaken for each process was identified. Each failure modes, cause and effect of these doffing processes, activities and sub-activities were tabulated and assigned the Risk Priority Numbers (PRN).

The Ring Frame Doffing operation processes with the RPN is tabulated in Table 4.6.

Table 4.6: Ring Spinning Doffing process FMEA

No.	Operation in Ring frame spinning Doffing	Potential Failure Mode (s)	Potential Failure Cause	Potential Failure Effect	Occurrence	Severity	Detectability	Risk Priority Number (O)*(S)*(D
1	Empty bobbin cop identification for next doff	Mix in bobbin size, color and code	Lack of segregation of cops	Mix up in yarn counts and lots	6	7	3	126
2	Cleaning of empty bobbin cops	Empty bobbin with yarn remnant	Poor cleaning of empty cops	Contamination of yarn	3	5	3	45
3	Inspection of empty cops to ensure they are in good working condition	Use of damaged bobbin cops	Bobbin cannot be fit on the spindle	Fitting not held in place	3	4	5	60
4			Poor buildup of yarn bobbin	Damaged during installation or transportation	1	2	2	4
5	Loading of the right numbers empty cops in the bobbin tray	Lack of enough bobbins for the ring frame	Fewer number of bobbins cops	Delay in replacement of full bobbins	8	7	7	392
6	Arrangement of cops on bobbin tray	Unorderly arrangement of bobbin cops	Longer retrieval time for bobbin cops		8	2	3	48
7	Transportation of empty bobbin tray to the ring frame where doffing activity is to be undertaken	Lack of empty bobbins to start doffing	Delay in moving and arranging empty bobbin tray	Time loss	8	8	5	320
8	Operation of overhead blower	Damaged overhead blower	cannot blow fly fibers	Damaged during operation	3	5	2	30
9	Raising of lappet rail to upward position	interference with removal and loading of bobbins	lappet rail not raised	Increased doffing time	4	3	3	36
10	Proper material handling of empty cops and full cops	Deformation of cops	Damaged yarn cops	Increase in rejected yarn cops	5	7	7	245

No.	Operation in Ring frame spinning Doffing	Potential Failure Mode (s)	Potential Failure Cause	Potential Failure Effect	Occurrence	Severity	Detectability	Risk Priority Number (O)*(S)*(D
11	Replacement of full cops with empty cops	Breakage of yarn during bobbin change	Poor handling by doffers	Increased start end breakage	8	7	6	336
12	Arrangement and transportation of full cops	full cops not placed in the cop trolley	Damaged yarn cops during at full bobbin cop trolley	Loss in yarn bobbin cops	4	3	4	48
13	Covering of the doffed ring cops	Exposure yarn bobbins to contamination	Contamination	Rejection of the batch	3	3	3	27
14	Gaiting for all the spindles in a proper manner	Gaiting done with yarn which is not running	Mix match gaiting of yarn	Mix-up of different lots and counts of yarn	6	6	7	252
15	Roving bobbin change for filling, filling activities and piecing in the event of a count change	Mix up of speed frame lots Filling filling activities and piecing in the event	Count change and Lot change	Fabric defect in weaving and dyeing	8	5	8	320
16	Traveler change traveler as instructed by superiors during count change	Unchanged traveler	Count change	Formation of defective yarn	2	4	5	40
17	Inspection of the machine is ready to start	machine not ready to start	Poor bobbin change	Extended stoppage of entire ring frame.	3	4	3	36
18	Lowering of lappet rail are lowered to its position properly	lappet rail not lowered	Uncontrolled balloon formation	Increased end breakages	3	3	2	18
19	Patrol of the entire ring frame	Extended high end breakage	unpierced/ broken ends during doffing	Lost production due to idle spindles	3	2	4	24

Table 4.7: 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

Source: Field Data, 2019

Table 4.7 shows potential failure causes and effects with highest RPN. Short and frequent production cycles in ring frame spinning, frequent lot of change overs to be done even when the same yarn count and lot is being processed contributed to high time loss during doffing stoppages. If external preparation activities for these change over were not completed before the ring frame stopped doffing period extended resulting to loss in production time. Though the procedure for the doffing was known, it was not standardized and sequenced to minimize the time for doffing. Different fibres, counts and lots were processed on the same spinning ring frames which not only further increased the change over time but also increased the possibility of contamination at weaving and dyeing stage.

4.4 Performance Improvement Evaluation using Descriptive Statistics

Data on mill management and production practices collected using a PIM based questionnaire and was analysed using excel. The findings of descriptive analysis are presented and discussed below. The analysis was based on the criteria proposed in the PIM method to support performance improvement in industrial operations (Grunberg, 2007). The responses for the four questions in the six level criteria were on a scale of 1 – 5 where: 1= Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree.

4.4.1 Performance Improvement Specialist Independence of the Mill

This section sought to find out how production management and improvement was carried out within the mill and ascertain whether the mill had capacity to implement performance improvement.

The responded strongly disagreed with the statements that productivity specialist or consultant was a priority of the mill and recognition for performance improvement staffing. The respondents disagreed that the mill had prioritized production management and improvement. Overall, the respondents rated the mill specialist independence for performance improvement low as indicated in Figure 4.9. Therefore, for a performance improvement method to be successfully implemented and sustained at the mill it would have to be easy to use by non-specialists.

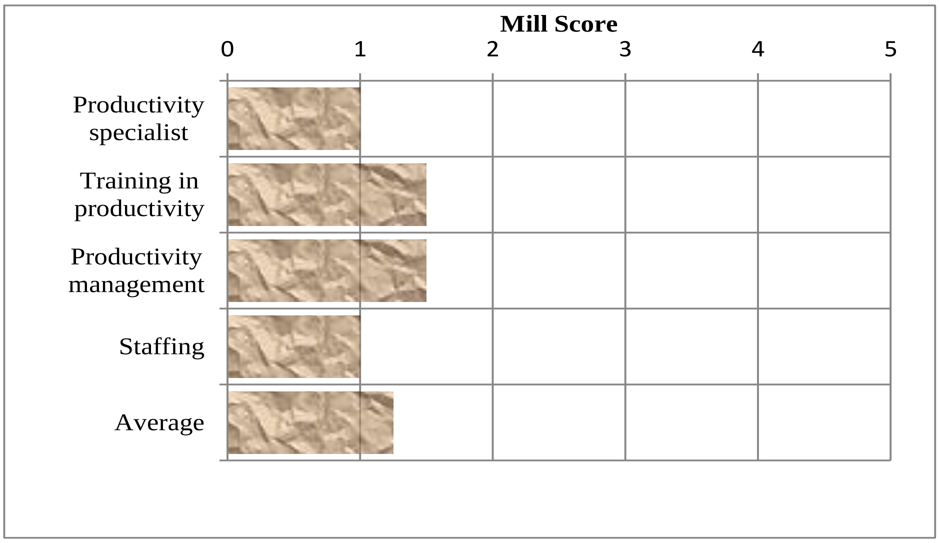


Figure 4.9: Specialist Independence score for the mill on performance improvement

4.4.2 Competency Supportive effects on Ring Frame Productivity

This section sought to determine the competencies that enhanced productivity in ring spinning production in relation to the practices of the mill. The respondents strongly agreed that employees had the right competencies (M = 4.9, SD = 2.6) required in operation and management of mills using ring frames which included being in possession of the job specific skills, job experience, team work and interpersonal skills as indicated in Figure 4.10.

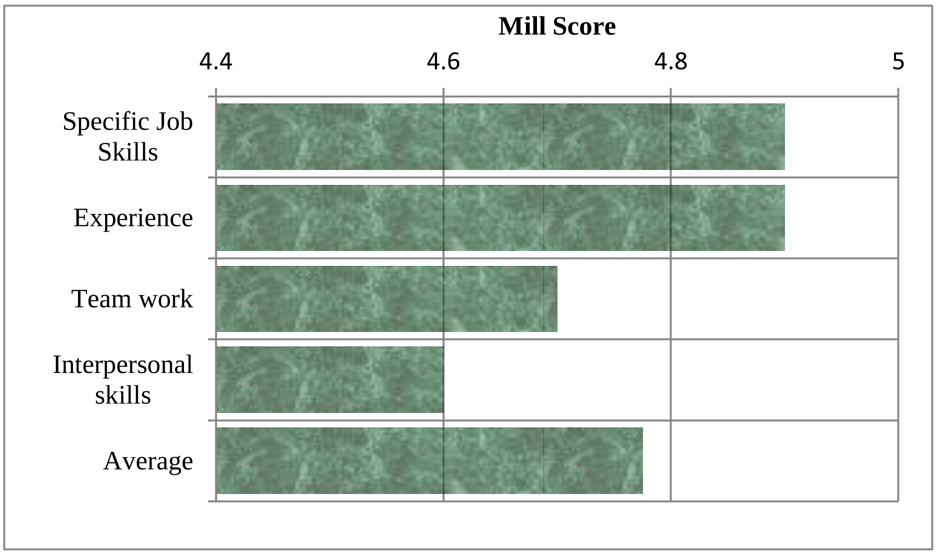


Figure 4.10: Employee Competency Supportiveness effects on ring spinning productivity

4.4.3 Implementation Supportive of Mill Production Management Practices

This section sought to find out the level of management supportiveness and engagement to promote productivity and improve production at the mill. The respondents were neutral on provision of the necessary resources (M=3.9) to support production performance improvement. The respondents agreed that the tasks information required was available, the mill demonstrated high level of safety and indicated that they were generally satisfied with the work environment as indicated in Figure 4.11.

Figure 4.11: Management Implementation Supportiveness to mill productivity

4.4.4 Performance Measurement and Monitoring Effects on Ring Frame Productivity

This section sought to determine the level of tracking and monitoring of production in ring spinning and to promote productivity and performance. The respondents disagreed that the mill had a monitoring system to truck production performance and productivity, the respondents strongly disagreed that the mill had clear and visible system for monitoring production. Production targets were also not cascaded to all levels of the mill staff establishment to promote accountability. Most of the respondents however agreed that the mill undertook snap studies and end breakage rate analysis to keep the unproductive spindles at the minimum. The results of how the mill supported the criteria of measurement are as indicated in Figure 4.12.

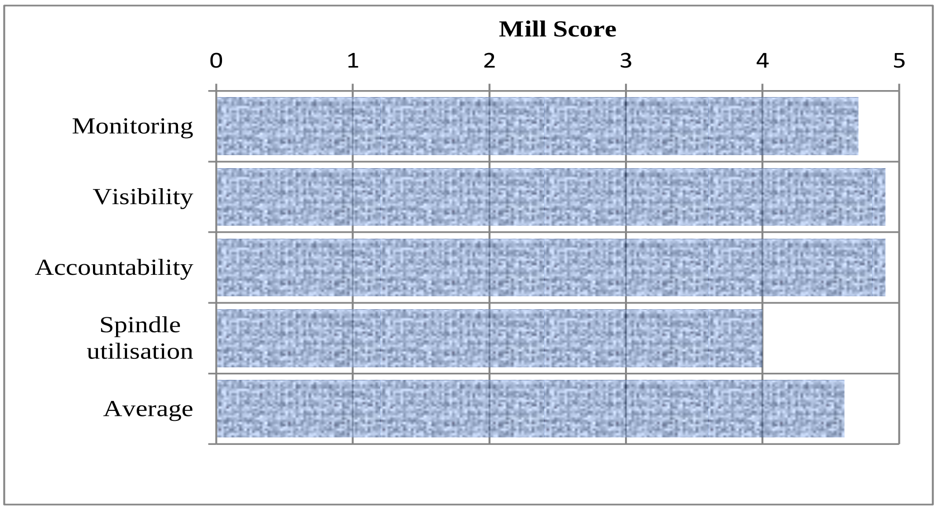


Figure 4.12: Mill score on criteria measurement based approach to productivity

4.4.5 Production Management Supportiveness to Ring Spinning Processes

This section sought to know the effects of the ring spinning process parameters on productivity of the ring frame. The respondents disagreed that the mill was using modern and up-to-date technology and equipment in yarn production but strongly agreed that the roving material supply to the ring frame was adequate and of good quality. The responded also strongly agreed that the humidification system for maintaining the ambient temperature and humidity was stable. However, the respondents were neutral that the assignment of duties to ring spinning operators was supported by a work study. Overall, the respondents rated the supportiveness regarding choice of ring frame as the production improvement object at mean of 3.4. The analysis on production management supportiveness to ring frame spinning process is shown in Figure 4.13.

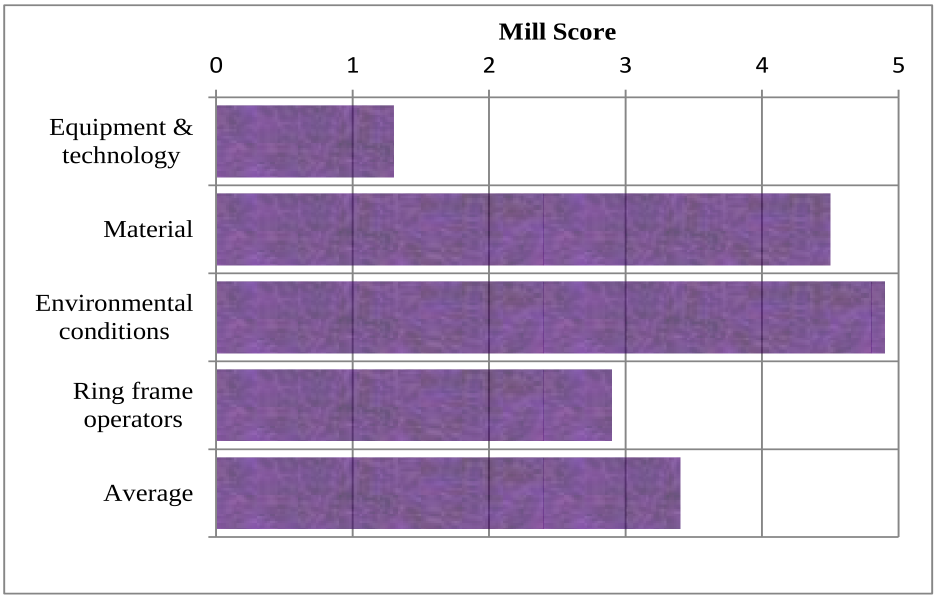


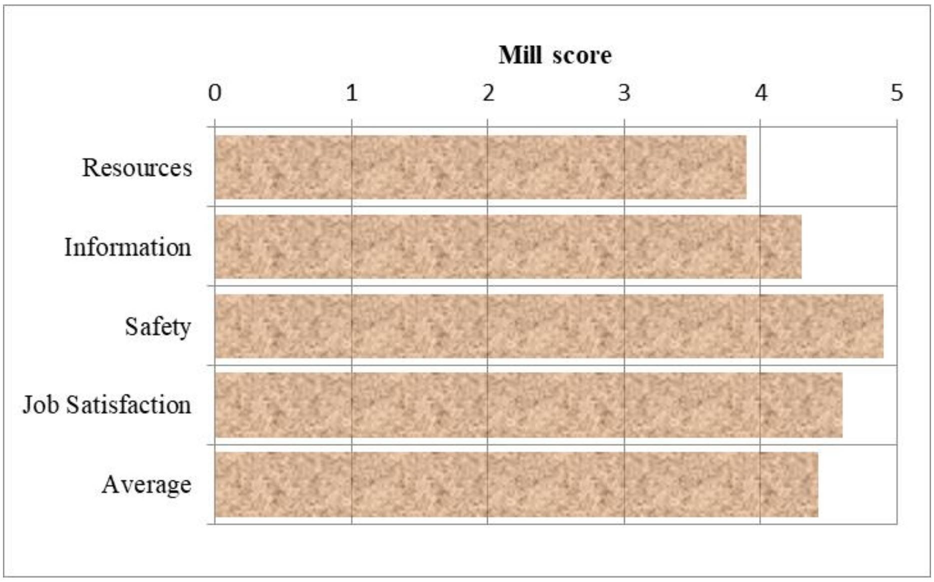
Figure 4.13: Analysis of object supportiveness to choice of ring frame as the production improvement object.

4.4.6 Organizational Arragement Supportiveness to Ring Frame Productivity

This section sought to establish the supportiveness of performance improvement by the spinning mill by finding out the availability of resources and information for performance improvement which was rated at 3.9 and 4.3 respectively. The evaluation also considered employees' safety and satisfaction, which were rated high with a mean score of 4.9 and 4.6 respectively as shown in Figure 4.14.

-+

Figure 4.14: Organizational Supportiveness of the Mill



4.5 Overall PIM Evaluation of Performance Improvement of Ring Frame Spindle Utilisation Performance

Comparison of all the six PIM criteria of performance improvement evaluation was made with competence, implementation and organizational supportiveness giving the highest importance rating score for the spinning mill as shown in Figure 4.15.

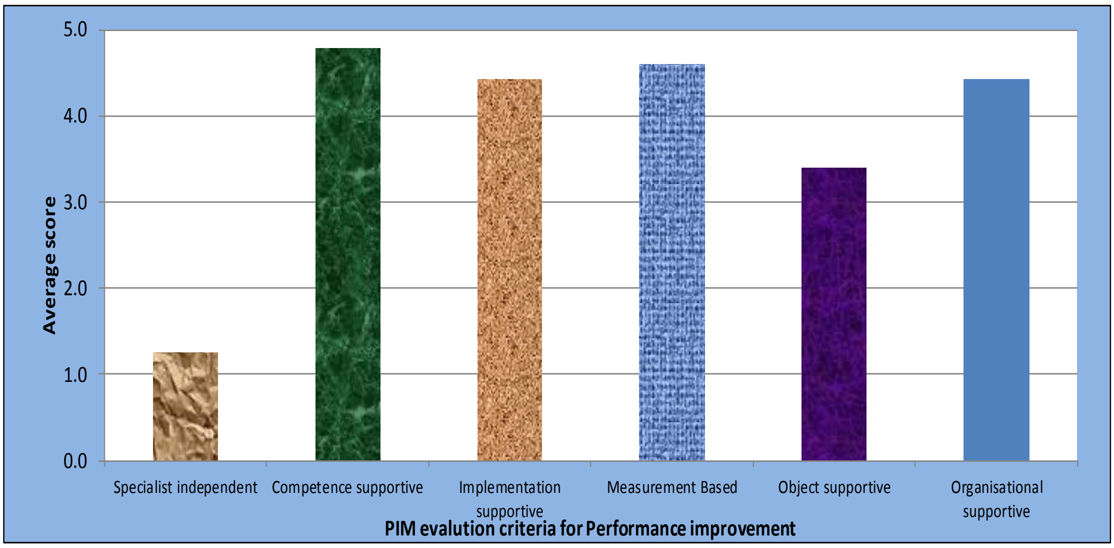


Figure 4.15: Overall PIM Performance Evaluation of the mill based on PIM

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 fulfill 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, track and monitor performance which would form a basis for further improvement. To increase support for measurements, the PIM premade forms and instructions to be used to promote further understanding when promoting the system. The average scores for overall PIM performance evaluation is shown in Table 4.8.

Table 4.8: Overall 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
	3.8

Source: Field Data, 2019

4.5.1 Performance Improvement Technique Selection

In this research five methods/ techniques for performance improvement were identified based on the results of PIM evaluation of Sunflag Spinning Mill Ltd. These techniques were Process mapping, SMED, Five S, CI and decision support

In order to select a suitable performance improvement technique for the spinning mill, comparison was done using the Grunberg (2007) PIM's criteria to support improvement methods which allocated applicable numeric values to the method on the basis of; 1= weak or low support, 2= partly supportive, strong support and N/A and as shown in Appendix III: The results of the evaluation (Table 4.9) 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.

Table 4.9: 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

Process Mapping	SMED	Five S	CI	Decision Support
8	13	10	9	5

Source: Field Data, 2019

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 could be applied for improvement production by converting internal set-up time to external set up time Five S had a score of 10 whereas Continuous improvement (CI) scored 9.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Review of Research Objectives

The objective of this research was to improve spindle utilization of the Ring Frame in cotton short staple ring spinning in Kenya, a case study of Sun flag Textile Mills, Kenya. A performance improvement method for mill has been recommended. The methods used to analyse ring spinning production, ring frame spindle utilization and to formulate a performance improvement method were based on literature review and the case study. The study was guided by three specific objectives.

The first objective was to analyse the ring spinning process, parameters and production per spindle in short staple cotton spinning. Data on production loss due to the ring frame stoppage and underutilization of the 960 spinning spindles within a ring frame was analysed using the six major stoppages used to calculate OEE and Pareto analysis of major losses in ring spinning production was conducted.

The second objective was to determine the factors affecting spindle utilisation in short staple cotton ring frame spinning. This was achieved through Failure Mode and Effects Analysis (FMEA) of the ring frame doffing process which was used find out the possible failure modes and rank them in order of priority. The analysis ranked seven (7) failure modes that had Risk Priority Numbers (RPN) in order of their priority.

The third objective was to formulate a production improvement method to be adopted for improving ring frame spindle utilisation which was achieved by evaluating the mill production practices using a PIM based questionnaire. The identified mill performance improvement techniques were compared using the PIM Criteria where SMED was selected as best method for the mill.

5.2 Key Findings

As per the first objective, a pareto analysis of major losses in production revealed that Idling and minor stoppages losses accounted for 63.2% and breakdown losses 22.8%. Doffing loss was highest cause of ring frame stoppages in the category accounting for 64% of ring frame stoppages of the ring frame. 5.62 end breaks were observed per 100 spindles per hour, which was the highest cause of production loss within the spindles of the ring frame.

For the second objective, manual doffing procedure, process of removal and replacement of bobbins on the spindle, lack of time awareness by doffers, delay in preparation of empty bobbins was identified as the main cause of doffing loss using Ishikawa Diagram. FMEA of the ring frame doffing process was used to find out the possible failure modes and rank them in order of priority. Top seven (7) failure modes that had the highest Risk Priority Numbers (RPN) were ranked in order of their priority. These include; lack of enough bobbins for the ring frame, breakage of yarn during bobbin change, lack of empty bobbins to start doffing, mix up of speed frame lots and counts during filling activities and piecing in the event, gaiting done with yarn which is not running, deformation of cops and mix in bobbin size, color and code.

As per the third objective, questionnaire was used to collect data on mill performance management and improvement using Grunberg (2007) PIM Criteria. The mill had a low score of 1.3 in mill independence to implement performance improvement techniques, which required support of specialists. Performance improvement technique would be supported in the mill if it was to be undertaken by non-specialists, was easy to understand and communicate to employees. The mill product monitoring and trucking for the ring frame was found to have negative effect on productivity of the mill. The mill also scored low in object supportiveness reflecting that the production process management had not taken into account the unique aspects of the ring frame doffing process. The Process mapping, SMED, Five S, CI and decision support methods were proposed for the mill, evaluation using the PIM criteria recommend SMED, which had the highest score of 13 for performance improvement of the mill.

5.3 Conclusions

Based on the results, the researcher therefore concludes that 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.

The choice of SMED as a performance improvement technique for the mill was supported by the elaborate process required for set-up during change over which occurred frequent in ring spinning process. SMED was an easy to use tool for large improvement attempts and can be supported within the mill practices and procedures for improvement of spindle utilisation of the ring frame.

5.4 Recommendations

A doffing process SMED procedure was recommended for highest performance improvement ring frames spindle utilisation at the mill. Important aspect of SMED of separating external activities was recommended to be modified for the ring frame doffing 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 where to be 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 using 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-up time into external set-up time.

5.5 Research Contribution

The Research has contributed to theory through development of a systematic methodology to prioritise the factors affecting efficiency and productivity of spinning mills using ring spinning at the frame and spindle levels, which can be used as a basis for formulating metric for ring frame spindle utilisation determination. The research also developed criteria for ranking and evaluating causes of production loss and production practices of the mill as a tool for identifying areas of performance improvement.

As contribution to practice, a methodology was developed for spinning mill using ring spinning system to use to evaluate ring frame spindle utilisation loss factors, evaluate them to improve their production management practices and select production improvement technique for optimal productivity and efficiency of the ring frame.

5.6 Recommendations for Further Research

Experimental research to determine the effect of the quality of the feed material on the spinning process need to be done to further improve the work already carried out on this thesis. This would include analysis of quality of cotton fibres and study of the preparation operations of the blow room, carding, drawing, combing and speed frame. Lastly, more research should be conducted to determine further loss of productivity at winding and weaving related to breakages at the ring frame.

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CHAPTER SEVEN: APPENDIXES

Appendix 1: Questionnaire

Questionnaire on Improved Ring Frame Spindle Utilization in Short Staple Cotton spinning Using OEE: A Case study of Sunflag Textile Mills, Nairobi, Kenya

PART A: COMPANY BACKGROUND INFORMATION
(Please Indicate as Appropriate)

1. Spinning Yarn Production Capacity in Kgs per day:

   Ring Spun ☐ Rotor Spun ☐

2. Total number of Employees in the spinning Mill ☐

   Assigned to Ring Frame ☐

3. What is the number of Employees under the following Categories of specialization?

   Engineers ☐ Technicians/Lab Technologist ☐
   Craftsmen/Artisan ☐ Operators ☐
   Others ☐

4. How many years have you worked in Sunflag Textile Mills?

   1 - 5 years ☐ 6 - 10 years ☐
   11 – 15 years ☐ 16 – 20 years ☐
   Over 21 years ☐

5. How did you acquire skills?

   Attended Training ☐ On the Job Training ☐

Part B: Dependence of performance improvement on Usability by Non- specialist in performance Improvement

(This section seeks to ascertain how performance improvement specialist/staff independence affects successes of production improvement in spinning. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: 1 = Disagree (DA) 2 = Agree (A) 4 = Strongly Agree (N) 5 = Not applicable (N/A)

Performance improvement specialist	**DA**	**A**	**N**	**N/A**
Having a performance specialist/consultant is the Priority of the Mill				
Training in Production Improvement \techniques is a core of the annual training plan				
Performance Management Staff is recognized within the mills staffing Structure				
Production are Periodically taken though performance improvement				

Part C: Employee Competency and Productivity in Ring spinning

(This section seeks to determine the relationship between employee competency and productivity of the ring frame. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: 1 = Disagree (DA)   2 = Agree (A)   4 = Strongly Agree (N)   5 = Not applicable (N/A)

Competence Supportive	**DA**	**A**	**N**	**N/A**
Operators posted at the ring frame must attained a certain levy of competence in the skills required				
Higher level of experience has effects on the performance of doffers				
Team work is important for performance improvement				
Good communication interactive skill is required for increased production				

Part D: Evaluation of Management Implementation Supportiveness to Production Improvement.
(This section seeks to establish the relationship between management implementation supportiveness and production in spinning mills. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: 1 = Disagree (DA)   2 = Agree (A)   4 = Strongly Agree (N)   5 = Not applicable (N/A)

Implementation Supportive	**DA**	**A**	**N**	**N/A**
Job satisfaction among workers leads to improved production				
Efficient supervision of employees leads improved productivity in yarn production				
Well structured Standard Operating procedures promotes productivity in spinning				
Formation of working teams improves the overall spindle utilization				

Part E: Production Measurement and Productivity in Ring spinning
(This section seeks to assess the relationship performance measurements and the production in ring spinning. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: 1 = Disagree (DA)   2 = Agree (A)   4 = Strongly Agree (N)   5 = Not applicable (N/A)

Staff Attitude	SD	D	N	A	SA
Monitoring of the yarn production improves overall spindle utilization of the Mill					
Snap study to control the number idle spindles undertaken to minimum production loss					
The mill monitors the number of end breaks to keep them at the minimal level.					
Production is analysed against targets per ring frame/ shift					

Part F: Comparative Advantage to Trends in Ring Spinning Ring Spinning
(This section seeks to establish effect of the operating conditions of the spinning mill staff in relation to production improvement in ring spinning at sunflag textile mills. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: **Key**: 1 = Disagree 2 = Agree 4 = Strongly Agree 5 = Not applicable
(DA) (A) (N) (N/A)

Implementation object specialization	SD	D	N	A	SA
Up-to date equipment - Sunflag uses up –to -date ring frames ng (Fall within recommended retooling of 10-12yrs)					
Material - The roving material supplied by the roving is the right quality for the ring frame					
Ambient Conditions - The humidification system for the maintaining ambient RH and temperature is maintained at good working conditions					
Motivation - employees are motivated to do their job					

Part D: Evaluation of Organizational Supportiveness to Production Improvement.
(This section seeks to establish the relationship between organizational supportiveness to performance improvement and production in spinning mills. Kindly indicate the extent to which you agree with the following statements by ticking the appropriate box)

Key: 1 = Disagree 2 = Agree 4 = Strongly Agree 5 = Not applicable
(DA) (A) (N) (N/A)

Implementation Supportive	DA	A	N	N/A
The mills has room to make suggestions for production improvement.				
The mill attaches high value Improvements in production.				
The mill has a policy for continuous improvement based on productivity.				
Lesson learnt are incorporated in production practices of the mill				

Appendix 2: Ljungstrom Evaluation of Some Improvement Methods

Criteria/Method	5S	TPM	Six Sigma	CI
No or small structural changes	Strong	Strong	Medium	Weak
Easy to understand	Strong	Medium	Weak	Medium
Usable directly in daily work	Strong	Medium	Weak	Weak
Fast results	Strong	Medium	Weak	Weak
Possibility to evaluate economic benefits	Strong	Strong	Strong	Medium
Involve all personnel	Medium	Medium	Weak	Medium

Appendix 3: The PIM (Grunberg Methods To Support Performance Improvement In Industrial Oprerations

	Specialist Independent	Competence Supportive	Implementation Supportive	Measurement Based	Object Supportive	Organizational Supportive
TPM	1	1	3	3	3	1
JIT	1	1	1	1	2	1
TQM	1	1	2	3	1	2
Lean	1	1	1	1	1	1
BPR,BPI	1	1	2	3	1	2
6 Sigma	1	3	3	3	1	2
DFT	1	1	1	1	1	1
SCM	1	1	1	1	1	1
TOC	1	1	3	1	3	2
RPA	1	1	N/A	2	N/A	N/A
Simulation	1	1	N/A	3	1	1
Mapping	2	1	N/A	2	1	2
SMED	2	1	3	2	3	2
Five S	2	1	3	1	1	2
CI	2	1	1	2	1	2
Decision	2	1	N/A	2	N/A	N/A

Appendix 4: FMEA RPN Scoring Criteria

Occurrence Ranking Index (Frequency):		Severity Ranking Index (problem?)		Detection Ranking Index (See Defect?)	
Rank	**Criteria**	**Rank**	**Criteria**	**Rank**	**Criteria**
1	Remote chance for failure	1	Undetectable effect on system	1	Almost certain detection of failure mode
2 3	Low failure rate based on previous designs with low failures	2 3	Low severity impact because failure will cause slight customer annoyance	2 3	Very high likelihood of detecting failure mode High likelihood of detecting failure mode
4 5 6	Moderate failure rates based on similar designs which have some occasional failures but not in major proportions	4 5 6	Moderate severity with some customer dissatisfaction and with performance loss which is noticable by customer	4 5 6	Moderately high likelihood of detecting failure mode Moderate likelihood of detecting failure mode Low likelihood of detecting failure mode
7 8	High failure rates based on similar designs which have been troublesome.	7 8	High severity with high degree of customer dissatisfaction	7 8	Very low likelihood of detecting failure mode Remote likelihood of detecting failure mode
9 10	Very high failure rates and the failures will be major occurrences.	9 10	Very severe problem involving potential safety problem or major non-conformity	9 10	Very remote likelihood of detecting failure mode Can not detect failure mode

Appendix 5: SAS System Glimmix Procedure for Least square means errror analysis

Model Information	
Response Variable	Spinning Cycle
Response Distribution	Gaussian
Link Function	Identity
Variance Function	Default
Variance Matrix	Diagonal
Estimation Technique	Restricted Maximum Likelihood
Degrees of Freedom Method	Residual

Class Level Information		
Class	**Levels**	**Values**
Cycle	6	SC1 SC2 SC3 SC4 SC5 SC6

Number of Observations Read	30
Number of Observations Used	30

Dimensions	
Covariance Parameters	1
Columns in X	7
Columns in Z	0

Dimensions	
Subjects (Blocks in V)	1
Max Obs per Subject	30

Optimization Information	
Optimization Technique	None
Parameters	7
Lower Boundaries	1
Upper Boundaries	0
Fixed Effects	Not Profiled

Fit Statistics	
-2 Res Log Likelihood	161.82
AIC (smaller is better)	175.82
AICC (smaller is better)	182.82
BIC (smaller is better)	184.07
CAIC (smaller is better)	191.07
HQIC (smaller is better)	178.01
Pearson Chi-Square	796.70
Pearson Chi-Square / DF	33.20

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Cycle	5	24	0.83	0.5420

Cycle Least Squares Means					
Cycle	Estimate	Standard Error	DF	t Value	Pr > |t|
SC1	127.06	2.5767	24	49.31	<.0001
SC2	125.88	2.5767	24	48.85	<.0001
SC3	124.48	2.5767	24	48.31	<.0001
SC4	128.02	2.5767	24	49.68	<.0001
SC5	122.48	2.5767	24	47.53	<.0001
SC6	122.40	2.5767	24	47.50	<.0001

Differences of Cycle Least Squares Means						
Cycle	_Cycle	Estimate	Standard Error	DF	t Value	Pr > |t|
SC1	SC2	1.1800	3.6440	24	0.32	0.7489
SC1	SC3	2.5800	3.6440	24	0.71	0.4858
SC1	SC4	-0.9600	3.6440	24	-0.26	0.7945
SC1	SC5	4.5800	3.6440	24	1.26	0.2209
SC1	SC6	4.6600	3.6440	24	1.28	0.2132

Differences of Cycle Least Squares Means						
Cycle	_Cycle	Estimate	Standard Error	DF	t Value	Pr > |t|
SC2	SC3	1.4000	3.6440	24	0.38	0.7042
SC2	SC4	-2.1400	3.6440	24	-0.59	0.5625
SC2	SC5	3.4000	3.6440	24	0.93	0.3601
SC2	SC6	3.4800	3.6440	24	0.96	0.3491
SC3	SC4	-3.5400	3.6440	24	-0.97	0.3410
SC3	SC5	2.0000	3.6440	24	0.55	0.5882
SC3	SC6	2.0800	3.6440	24	0.57	0.5734
SC4	SC5	5.5400	3.6440	24	1.52	0.1415
SC4	SC6	5.6200	3.6440	24	1.54	0.1361
SC5	SC6	0.08000	3.6440	24	0.02	0.9827

T Grouping for Cycle Least Squares Means (Alpha=0.05)		
LS-means with the same letter are not significantly different.		
Cycle	Estimate	
SC4	128.02	A
		A
SC1	127.06	A
		A
SC2	125.88	A
		A
SC3	124.48	A
		A
SC5	122.48	A
		A
SC6	122.40	A

Model Information	
Response Variable	Doffing Cycle
Response Distribution	Gaussian
Link Function	Identity
Variance Function	Default
Variance Matrix	Diagonal
Estimation Technique	Restricted Maximum Likelihood
Degrees of Freedom Method	Residual

Class Level Information		
Class	Levels	Values
Cycle	6	DC1 DC2 DC3 DC4 DC5 DC6

Number of Observations Read	30
Number of Observations Used	30

Dimensions	
Covariance Parameters	1
Columns in X	7
Columns in Z	0
Subjects (Blocks in V)	1
Max Obs per Subject	30

Optimization Information	
Optimization Technique	None
Parameters	7
Lower Boundaries	1
Upper Boundaries	0
Fixed Effects	Not Profiled

Fit Statistics	
-2 Res Log Likelihood	156.20
AIC (smaller is better)	170.20
AICC (smaller is better)	177.20
BIC (smaller is better)	178.45
CAIC (smaller is better)	185.45
HQIC (smaller is better)	172.39
Pearson Chi-Square	630.38
Pearson Chi-Square / DF	26.27

Type III Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Cycle	5	24	0.27	0.9245

Cycle Least Squares Means					
Cycle	Estimate	Standard Error	DF	t Value	Pr > |t|
DC1	11.6100	2.2920	24	5.07	<.0001
DC2	11.7780	2.2920	24	5.14	<.0001
DC3	11.4420	2.2920	24	4.99	<.0001
DC4	11.0000	2.2920	24	4.80	<.0001
DC5	13.1960	2.2920	24	5.76	<.0001
DC6	14.0940	2.2920	24	6.15	<.0001

Differences of Cycle Least Squares Means						
Cycle	_Cycle	Estimate	Standard Error	DF	t Value	Pr > |t|
DC1	DC2	-0.1680	3.2414	24	-0.05	0.9591
DC1	DC3	0.1680	3.2414	24	0.05	0.9591
DC1	DC4	0.6100	3.2414	24	0.19	0.8523
DC1	DC5	-1.5860	3.2414	24	-0.49	0.6291
DC1	DC6	-2.4840	3.2414	24	-0.77	0.4509
DC2	DC3	0.3360	3.2414	24	0.10	0.9183
DC2	DC4	0.7780	3.2414	24	0.24	0.8124
DC2	DC5	-1.4180	3.2414	24	-0.44	0.6657
DC2	DC6	-2.3160	3.2414	24	-0.71	0.4818
DC3	DC4	0.4420	3.2414	24	0.14	0.8927
DC3	DC5	-1.7540	3.2414	24	-0.54	0.5934
DC3	DC6	-2.6520	3.2414	24	-0.82	0.4213
DC4	DC5	-2.1960	3.2414	24	-0.68	0.5046
DC4	DC6	-3.0940	3.2414	24	-0.95	0.3493
DC5	DC6	-0.8980	3.2414	24	-0.28	0.7841

T Grouping for Cycle Least Squares Means (Alpha=0.05)		
LS-means with the same letter are not significantly different.		
Cycle	Estimate	
DC6	14.0940	A
		A
DC5	13.1960	A
		A
DC2	11.7780	A
		A

T Grouping for Cycle Least Squares Means (Alpha=0.05)		
LS-means with the same letter are not significantly different.		
Cycle	Estimate	
DC1	11.6100	A
		A
DC3	11.4420	A
		A
DC4	11.0000	A

Model Information	
Response Variable	Ring Frame Production Mass
Response Distribution	Gaussian
Link Function	Identity
Variance Function	Default
Variance Matrix	Diagonal
Estimation Technique	Restricted Maximum Likelihood
Degrees of Freedom Method	Residual

Class Level Information		
Class	Levels	Values
Ring	6	RFP1 RFP2 RFP3 RFP4 RFP5 RFP6

Number of Observations Read	30
Number of Observations Used	30

Dimensions	
Covariance Parameters	1
Columns in X	7
Columns in Z	0
Subjects (Blocks in V)	1
Max Obs per Subject	30

Optimization Information	
Optimization Technique	None
Parameters	7
Lower Boundaries	1

Optimization Information	
Upper Boundaries	0
Fixed Effects	Not Profiled

Fit Statistics	
-2 Res Log Likelihood	120.82
AIC (smaller is better)	134.82
AICC (smaller is better)	141.82
BIC (smaller is better)	143.07
CAIC (smaller is better)	150.07
HQIC (smaller is better)	137.01
Pearson Chi-Square	144.34
Pearson Chi-Square / DF	6.01

Type III Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Ring	5	24	0.87	0.5152

Ring Least Squares Means

Ring	Estimate	Standard Error	DF	t Value	Pr > |t|
RFP1	51.2400	1.0967	24	46.72	<.0001
RFP2	50.6600	1.0967	24	46.19	<.0001
RFP3	49.4200	1.0967	24	45.06	<.0001
RFP4	49.3400	1.0967	24	44.99	<.0001
RFP5	48.8200	1.0967	24	44.51	<.0001
RFP6	48.7200	1.0967	24	44.42	<.0001

Differences of Ring Least Squares Means

Ring	_Ring	Estimate	Standard Error	DF	t Value	Pr > |t|
RFP1	RFP2	0.5800	1.5510	24	0.37	0.7117
RFP1	RFP3	1.8200	1.5510	24	1.17	0.2521
RFP1	RFP4	1.9000	1.5510	24	1.22	0.2325
RFP1	RFP5	2.4200	1.5510	24	1.56	0.1318
RFP1	RFP6	2.5200	1.5510	24	1.62	0.1173
RFP2	RFP3	1.2400	1.5510	24	0.80	0.4319

Differences of Ring Least Squares Means						
Ring	_Ring	Estimate	Standard Error	DF	t Value	Pr > |t|
RFP2	RFP4	1.3200	1.5510	24	0.85	0.4032
RFP2	RFP5	1.8400	1.5510	24	1.19	0.2471
RFP2	RFP6	1.9400	1.5510	24	1.25	0.2231
RFP3	RFP4	0.08000	1.5510	24	0.05	0.9593
RFP3	RFP5	0.6000	1.5510	24	0.39	0.7023
RFP3	RFP6	0.7000	1.5510	24	0.45	0.6558
RFP4	RFP5	0.5200	1.5510	24	0.34	0.7403
RFP4	RFP6	0.6200	1.5510	24	0.40	0.6929
RFP5	RFP6	0.1000	1.5510	24	0.06	0.9491

T Grouping for Ring Least Squares Means (Alpha=0.05)		
LS-means with the same letter are not significantly different.		
Ring	Estimate	
RFP1	51.2400	A
		A
RFP2	50.6600	A
		A
RFP3	49.4200	A
		A
RFP4	49.3400	A
		A
RFP5	48.8200	A
		A
RFP6	48.7200	A

Appendix 5: Response to causes of Ring frame doffing (Discussion with mill staff on RCA)

Cause Categories	4) Causes - 2nd Level	5) Significant Factor?	6) Specific Causes - 3rd level	7) Significant Factor?
Man	Low skills of RF operators	N	Operators are of qualification	
			operators not retrained	
	Few RF operators	N	Low number of inspection & patrol team	
			Lower number of doffers	
	Lack of SoPs for operators	Y	No SoP on allocation of operators	
			SoP not adhered to	
	Lack of time awareness by operators	Y	Delay in removal of full bobbins	
			Delay in removal of full bobbins	
	Poor work attitude	N	low motivation of operators	
			poor teamwork	
Material	Empty bobbins not ready	Y	Shortage of same color bobbins	
			Empty bobbins not ready on supply container	
	Empty bobbin mix up	Y	No order of keeping bobbin	
			Order not followed	
	Lack of empty bobbins	N	Delay in winding off yarn at the autoconer	
			Damage of bobbins	
Management	Poor supervision of doffers	N	No proper coordination of teams	
			doffers left to work on their own	
	Lack of standard doffing procedure	Y	No doffing procedure	
			procedure not followed	
	Lack of monitoring of stoppages	Y	Stoppages not recorded	
			Stoppages not monitored	
Measurement	Count change for new order done within doffing stoppage	N		
	Speed adjustment done within doffing stoppage	N		
Enviroment	Uncondusive work environment	N	Excessive fibre fly waste	
			Lack of concentration due to prolonged exposure to high noise level	

Machine	Failure of Humidification Plant	N	High RH	
			Rise in end breakage	
	Automatic stoppage of RF at full doff	Y	Bobbin get filled up to the target yarn production	Y
			the ring frame automatically turns off	Y
	Replacement of machine parts	N	Replacement of broken spindle drive tapes	N
			Ring traveller and draft roller apron replacemt	N
	Manual doffing of the Ring Frame	Y	Slow process of the manual doffing	Y
			manual re-inspection of spindles	

Appendix 6: Response to questionnaire

	Part C					Part D					Part E					Part F					Part G			
	Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4		Q1	Q2	Q3	Q4
1	5.0	5.0	4	5		4.0	5.0	5	5		5.0	5.0	5	4		1.0	5.0	5	4		1.0	4.0	5	4
2	5.0	5.0	5	4		5.0	4.0	5	4		5.0	5.0	5	4		1.0	5.0	5	1		4.0	4.0	5	4
3	5.0	5.0	5	5		5.0	4.0	5	5		4.0	5.0	5	5		1.0	4.0	5	4		4.0	5.0	4	4
4	5.0	5.0	5	5		2.0	4.0	5	5		5.0	5.0	5	3		1.0	5.0	5	1		4.0	4.0	5	5
5	5.0	5.0	4	4		4.0	5.0	4	4		5.0	5.0	4	4		2.0	4.0	4	3		3.0	4.0	5	5
6	5.0	5.0	5	4		4.0	4.0	5	4		4.0	4.0	5	4		1.0	4.0	5	4		4.0	4.0	5	3
7	4.0	5.0	5	5		4.0	4.0	5	5		5.0	5.0	5	5		1.0	5.0	5	2		3.0	3.0	5	5
8	5.0	5.0	5	5		5.0	4.0	5	5		5.0	5.0	5	4		1.0	4.0	5	3		4.0	4.0	4	5
9	5.0	5.0	4	5		5.0	5.0	5	5		5.0	5.0	5	4		1.0	4.0	5	1		4.0	4.0	5	5
10	5.0	5.0	5	4		3.0	5.0	5	4		3.0	5.0	5	4		1.0	5.0	5	4		4.0	5.0	5	4
11	4.0	4.0	5	5		2.0	4.0	5	5		5.0	5.0	5	3		1.0	4.0	5	3		4.0	4.0	3	3
12	5.0	5.0	5	5		4.0	5.0	5	4		5.0	5.0	5	4		1.0	5.0	5	4		4.0	5.0	5	4
13	5.0	5.0	4	5		4.0	4.0	4	5		5.0	4.0	5	3		1.0	4.0	5	3		2.0	3.0	5	3
14	5.0	5.0	5	4		2.0	3.0	5	5		4.0	5.0	5	5		3.0	4.0	5	4		3.0	4.0	5	4
15	5.0	5.0	5	4		5.0	4.0	5	4		5.0	5.0	5	4		2.0	5.0	5	2		4.0	5.0	4	3
N	**15**	**15**	**15**	**15**		**15**	**15**	**15**	**15**		**15**	**15**	**15**	**15**		**15**	**15**	**15**	**15**		**15**	**15**	**15**	**15**
Mean	**4.9**	**4.9**	**4.7**	**4.6**		**3.9**	**4.3**	**4.9**	**4.6**		**4.7**	**4.9**	**4.9**	**4.0**		**1.3**	**4.5**	**4.9**	**2.9**		**3.5**	**4.1**	**4.7**	**4.1**
Variance	**0.12**	**0.07**	**0.21**	**0.26**		**1.27**	**0.35**	**0.12**	**0.26**		**0.38**	**0.12**	**0.07**	**0.43**		**0.35**	**0.27**	**0.07**	**1.41**		**0.84**	**0.41**	**0.38**	**0.64**
SD	**0.35**	**0.26**	**0.46**	**0.51**		**1.13**	**0.59**	**0.35**	**0.51**		**0.62**	**0.35**	**0.26**	**0.65**		**0.59**	**0.52**	**0.26**	**1.19**		**0.92**	**0.64**	**0.62**	**0.80**
SEM (standard error of the mean)	**0.09**	**0.07**	**0.12**	**0.13**		**0.29**	**0.15**	**0.09**	**0.13**		**0.16**	**0.09**	**0.07**	**0.17**		**0.15**	**0.13**	**0.07**	**0.31**		**0.24**	**0.17**	**0.16**	**0.21**