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Implementation of Lean Six Sigma in the Yarn Manufacturing: a case study

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Abstract— The purpose of this study is to explore the implementation of Lean Six Sigma (LSS) project in the textile industry as a case study. Meanwhile, the literatures in the field of Lean Six Sigma and its implementation in the manufacturing industry and especially in the Textile industry have been explored. The lean techniques have been utilized to maximize winding speed, reduce variation between individuals production positions (The process speed) and provide tools for analyzing process flow and delay times, the setup delay has been minimize from 30 minutes to 5 minutes. These two achievements result in reduction of the WIP by 50%. While, Six Sigma emphasizes the need to recognize opportunities and eliminate defects in the produced cones (final product of the yarn manufacturing) as defined by customers, which improve the quality of end product significantly and improve the productivity by reducing the waste yarn with percentahe more than 20% according to the yarn type and raw material.

Index Terms— DMAIC approach, Lean Six Sigma, Textile industry, Yarn Manufacturing, TQC implementation, Lean Implementation, Winding Process.

1 Introduction

THE textile industry is one of the largest industrial sectors in the world and the challenges facing the textile industry with regards to providing sustainable growth with acceptable quality and profitable production are huge. As increasing population and greater use of such products in technical and industrial applications has led to a remarkable growth in demand for textiles; the development of innovative design, processes and raw materials are of paramount importance. After the quality revolution, the textiles industry has started implementing the modern manufacturing paradigms like Lean, Six Sigma, Total Quality Management, etc. However, textile manufacturers should adapt more implementation for such tools.

Lean Six Sigma consists by the integration of two parts [1]. The first part is the Lean, which rose as a method for optimizing auto manufacturing (Toyota production system) by focusing on the reduction of wastes and costs which requires a fundamental shift in the way of stakeholders' thinking and in the nature of the relationship between them [2]. Moreover, the second part is Six Sigma, which evolved in the semiconductor industry (Motorola) as a quality initiative to eliminate defects by reducing process variation using statistical methodology industry and focusing on those process performance characteristics that are of critical importance to customers [3] [4]. According to [5] the highest factors studied in LSS are the time, which represent the cycle and stop time in our project and the defects, which represent the cuts/100Km in our project. Therefore, we will focus on the most important factors.

The spinning mill is the first section of the textile industry, the output of the spinning mill is the yarn wound on paper or plastic conical- shaped packages called cones. The spinning mill consists of six stages, mixing, carding, drawing, roving, spinning and winding. There are two manufacturing systems. Pull system: System for moving work where a workstation pulls output from the preceding station as needed. Push system: System for moving work where output is pushed to the next station as it is completed. Our project in spinning mill is working as push system moving work where output is pushed to the next station as it is completed; the finished bobbins are pushed to winding step after finished in spinning machine [6].
All the goals in our project have been achieved by the DMAIC approach of Lean Six Sigma [7], which has been structured with disciplined, precise way to process improvement. DMAIC consisting of five phases: Define, Measure, Analyze, Improve and Control. Each phase is linked logically to the previous phase as well as to the next phase. Reducing variability is a magic solution to solve our quality problem in our project, using six sigma tools; we guarantee reducing the variation in significant range and achieve the required quality level.

2 Literature review

The implementation of Lean Six Sigma in the textile industry has not been reported in details yet. A systematic review of Lean Six Sigma for the manufacturing industry has been done in [8]; the research is based on a review of 37 papers that were published on LSS in the top journals in the field and other specialist journals. However, no paper in the field of textile industry has been mentioned in the research. A promising study has been done in [9] concerning the implementation of Lean Six Sigma in manufacturing indicating that the practices such as DMAIC, Kaizen team, Visual Control, SMED, 5S, etc. of LSS support to increases companies performance regardless the company size. In addition, the study revealed that use LSS in all departments supportive of improving quality and creating a safe environment and improved employee involvement within the organization. The history and future of LSS has been illustrated in [10], indicating that the future of Lean Six Sigma will be demanding and exciting due to the globalization and its associated competitive pressures, customers demanding more in terms of quality. The researcher in [11] add the Selection phase, Value Stream Mapping Phase and Replication phase to overcome the problems in the traditional roadmap DMAIC which could be taken in consideration for the implementation of LSS in the textile industry.

A few research works have been published highlighting the application of Lean manufacturing or Six Sigma in this industry, in [12] the lean manufacturing principles has been adapted in a composite textile mill which having weaving and wet processing and elaborated about the application of value stream mapping. They mentioned that the lean manufacturing principles are new to the textile industry.

A case study in a spinning mill sector of the textile industry has been illustrated in [13], which the application of the Six Sigma's DMAIC improvement methodology has been utilized to reduce the cone weight variation due to its big effect in the waste for the downstream process. Different Six Sigma tools like Pareto Diagram, Repeatability Chart and Analysis of Variance have been used in this study.

In [14] the DMAIC methodology has been implemented to reduce the shade variations in the manufacturing of Linen fabrics and used certain Six Sigma tools like SIPOC diagram, Pareto Diagram, Cause-and-Effect Diagram and Analysis of Variance. After adopting the disciplined Lean Six Sigma methodology, the yield of the overall dyeing process has improved to 82% from the earlier level of 47% indicating an improved sigma level of 2.34.

Two projects have been implemented in [15] with Lean Six Sigma through ISO 9001 : 2008 based QMS without any difficulty with the full cooperation of the shop floor team and top management involvement. Sliver waste reduction project and training lead-time reduction project were carried out in the spinning mill. They achieved an increased in Sigma level to 3.47 and 4.32 in the production lines repectevly.

The DMAIC methodology, together with appropriate tools, were used effectively in [16]. The projects reduced the changeover times on two different product lines and reduced contamination on a third line. In addition, the case study provided a look behind the scenes at how the LSS program was positioned and supported within the company, through an interview with the company's lead Master Black Belt.

As a result, over the last decade, Lean Six Sigma has become one of the most popular and proven business process improvement methodologies in many industrial branches. However, implementation of the LSS in the field of textile industry still in its primitive stages. More searches, case studies and practical trials can be done in this field with very promising results of solving current problems and improving the quality and productivity of the spinning mills.

3 Case Study

We made our case study in modern spinning factory located in 10th of Ramadan, Egypt. The factory are producing denim and fabric yarn with high quality for local and international market. It consists of two mills; the first mill is 100% new mill with modern established automated material handling and transportations. The second mill is divided between new machines with the automated material handling and old used machines with traditional material handling for all stages.

We will work in the final stage of the yarn manufacturing which is the winding process (Fig. 2). In this process, the finished bobbin (Fig. 1) from the previous stage spinning process is converted from bobbin to cone (Fig. 3). At the same time any defective in the yarn is cut and replaced by controlled splice, the tension on the yarn in the cone is adjusted in order to aceive the required density for next stages (dying or weaving)

4 Six Sigma Methodology (DMAIC Cycle)

Each applied step and technique of the Six Sigma methodology in our project has been clarified in details in the next subsections.

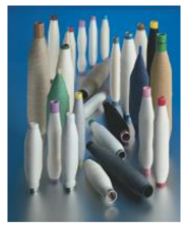
Fig1. The bobbins


Fig2. The Winding Machine


Fig3. The cones

4.1 Define Phase

In the define phase, we will select Customer Critical Process, define Project and develop implementation plan, define goals of improvement, define Project and operation objective, define expected outcomes from the project and define communication plan.

4.1.1 Select the Project – Problem Statement & Goals

The most important critical factors in winding process is the quality of produced cones which measured by:

1. Number of good and bad splices which done using splicer.
2. Number of remaining faults in the cone which controlled by yarn clearers (Fig. 4) and clearing limits.
3. The package length and weight which controlled by machine speed and process cycle time.
4. The package density, which adjusted using tensioner (Fig. 5).

Our project has two objectives, first to check and adjust the remaining faults in cone by control the number of cut in winding machine using yarn clearers and to control the tension of the produced cones. Second, readjust the winding machine speed and reduce the setup time in order to reduce the WIP bobbins waiting to enter the winding process after finishing spinning. However, increasing the winding speed above a certain limit caused quality problem by creating faults in the yarn and affecting the final package shape.

The Problem Statement can be defined as the following: High number of WIP bobbins waiting for winding will reduce the productivity of both winding machine and spinning machine and increase the lead-time. In addition, the quality of produced yarn after the winding process is not meeting the customer requirements regarding number of faults/100km produced yarn.

Project Goals are: Reduce the WIP by 50% by increasing winding speed in specific range and reuce the variation beteen spindles without affecting the final quality, and reduce the setup time as possible in order to reduce the total lead-time. Readjust the tension and quality of removing the faults from the yarn to achieve the customer requirements. Reducing the cost of waste yarn with percentage 20% - 30% by improving the quality of yarn produced in the spinning process. Reducing the waste time of the spinning process waiting for the bobbins from the winding process with 40% - 50%, which increase the productivity of the factory.


Fig4. Yarn Clearers


Fig5. Tensioner

Project Team and Stakeholder have been identified early to have a communication plan for each of them. The project team, which will join the project from beginning, are Production Manager, Quality Manager and Quality control supervisor, Maintenance Manager and Maintenance Engineer, Winding Machines operators and supervisors and Spinning Machines operators and supervisors. While the Stakeholder included all the above project team, mill Manager, warehouse, Finance Mangers, previous Stages Supervisors. They included also the downstream process, the weaving mille quality control manager.

To collect the data, we use the interface of the winding machine and yarn clearers, operators have counted some production data like WIP, and some measurements have been done for the density of the produced cones and the number of remaining faults in the produced cone after winding (The details of Data Collection are in the Measure Phase).

4.1.2 Process Map (SIPOC)

A SIPOC is a high-level process map (Fig. 6) that includes Suppliers, Inputs, Process, Output, and Customers which will be used to identify all relevant elements of our process improvement project before work begins.

4.1.3 Voice of the Customer

The "Voice of the Customer" is a process used to capture the requirements/needs/feedback from the customer (internal or external) to provide them with best-in-class service/product quality. Table 1 lists the internal and external customers with their complaints, results and action to do in our project.

4.1.4 Kano Model

The Kano model is a theory of product development and customer satisfaction, which classifies customer preferences into four categories. Fig. 7 shows the three current problems in the winding step of our project.

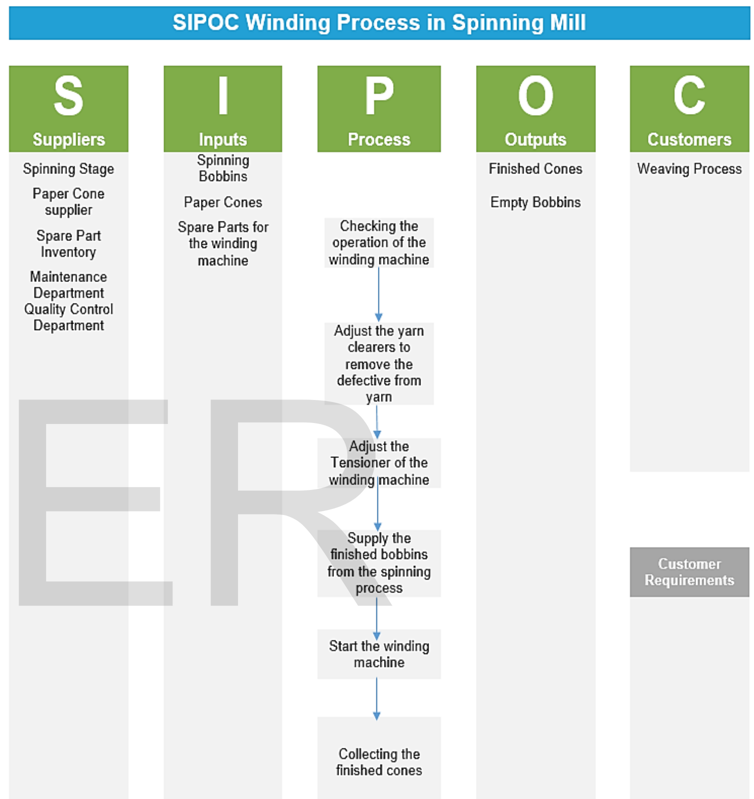

Fig6. SIPOC Winding Process

4.1.5 Critical-To-Quality (CTQ) tree

The purpose of Critical-To-Quality trees is to convert customer needs/wants to measurable requirements for the business to be implemented in our project as illustrated in Fig. 8. By the end of the Define phase, we cleary clarify the action to do in the next step.

TABLE 1: Internal and External customer complaints

Customer	Internal or External	Complaint	Result of the complaint	Action to Do
Weaving Factory	External	High number of faults in the Cones	Each Thin places and thick places can cause stoppage for the weaving machine for 5 min	Improve and Control the mean value and standard deviation for number of fault/100km of produced bobbins
		The tension of the package is not adjusted	The produced fabric has lower quality	Improve and Control the mean value and standard deviation for the tension of each cone
Spinning Sector	Internal	Long setup and production time at the winding machine	Stoppage of the spinning machine for high WIP bobbins	Reduce the setup time and increase the machine speed without affecting the quality

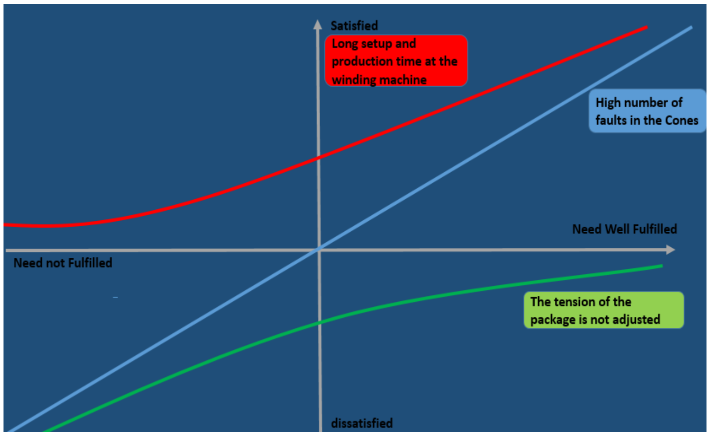

Fig7. Kano model of the project

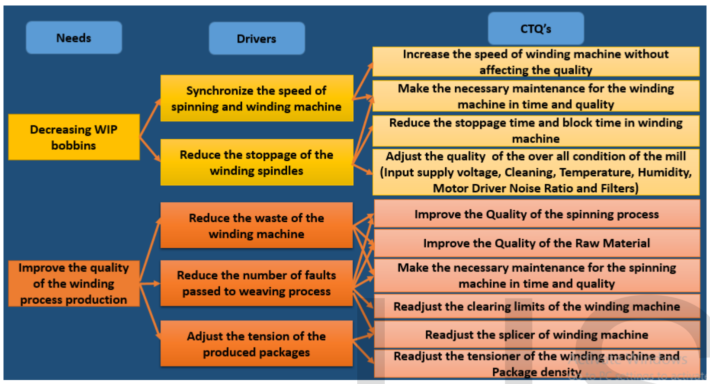

Fig8. Critical-To-Quality of the project

4.2 Measure Phase

The current state of the process will be analyzed by collecting and analyzing data, identifying the vital few that have greatest impact. We will use multiple tools input Output X-Y Analysis, Pareto Analysis, Sampling Techniques, Process Capability, Spaghetti Diagrams, Value Stream Mapping and Estimate Process Capability.

4.2.1 Data Collection

Data collection has been done using a special software called Uster Quantum Expert 3 (Fig. 9 and Fig. 10). It is a data collection software installed on a high capability server computer and connected through local area network to the winding machines for 24 hours and collect all the necessary data such as Number of cuts/100 Km, Production data for each machine, speed, stoppage time and idle time of each winding position and average speed of each machine …. Etc [17].

In addition, we did a manually data collection at the end of each shift for the Work In Process between the spinning process and winding process, the Quality data for the tension and shape and remaing faults of the produced cones from the winding machines. The Measurement of the environmental condition of the mill for 24 hours/day have been measured also. We will work on 15 winding machines (from U1-QPRO-8 to U1-QPRO-22 supplied from 15 spinning machines in the new mill. The produced yarn is carded with yarn count Ne 30. Each spinning machine will produced from 2-3 lots each shift with 1632 bobbins/lot. Each winding machine will produced from 2 – 3 lots / shift with 60 cones / lot.

4.2.2 Input Output (X-Y) Analysis

Table 2, shows the goal of the analysis which is to find Xs (Process and Input Measures) that are leading indicators of the critical output (Y). Such Xs are also key to find root causes (the focus of the Analyze phase) and to catch problems before they become serious (Control phase).

Fig9. Data Collection Software

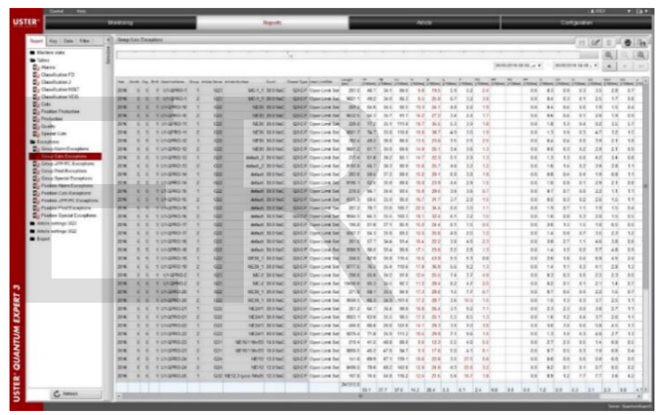

Fig10. Sample of the collected data from all winding machines

4.2.3 Pareto Analysis

Pareto charts are a type of bar chart in which the horizontal axis represents categories rather than a continuous scale, by arranging the bars from largest to smallest; a Pareto chart can help to determine which categories will yield the biggest gains if addressed, and which are only minor contributors to the problem. For each observation, the number of occurrence has been determined as in Table 3 and sorting in Table 4. Then they are plotted in Pareto Chart (Fig. 13).

TABLE 3: Occurance of each observation

Observation Criteria	Number of occurrence outside the specification
YF [/100km]	2
YB [/100km]	0
T [/100km]	6
Tension [cN]	5
Density g/cm3	3
AEF [%]	8
Run Time/Watch Time	8
Block Time/Watch Time	1
Stop Time/Watch Time	8

TABLE 2: Input Output (X-Y) Analysis

Responses or Outputs (Ys)				Factors (Xs)			
Dependent Variable	USL	LSL	Target	Independent Variables	USL	LSL	Target
Part Quality (Number of remaining faults / 100km)	3 / 100km	--	0 / 100km	Number of cut faults in bobbins / 100 km	70 / 100km	50 / 100km	60 / 100km
				Bobbin Yarn Count	31 Nec	29 Nec	30 Nec
				Process Speed	1250 m/min	1190 m/min	1200 m/min
				Number of Yarn Breaks / 100 Km	40 / 100km	25 / 100km	35 / 100km
Responses or Outputs (Ys)				Factors (Xs)			
Dependent Variable	USL	LSL	Target	Independent Variables	USL	LSL	Target
Part Quality (Number of wrong tension cones/shift/)machine	5	--	0	Tension for each cone	26 cN	34 cN	30 cN
				Bobbin Yarn Count	31 Nec	29 Nec	30 Nec
				Process Speed	1250 m/min	1190 m/min	1200 m/min
				Package Denisity	0.38 g/cm3	0.32 g/cm3	0.36 g/cm3
				Number of weak places . 100 km	7 / 100km	0 / 100km	3 / 100km
Responses or Outputs (Ys)				Factors (Xs)			
Dependent Variable	USL	LSL	Target	Independent Variables	USL	LSL	Target
Number of WIP / shift / machine	1800	150	1632	Number of cut faults in bobbins / 100 km	70 / 100km	50 / 100km	60 / 100km
				Bobbin Yarn Count	31 Nec	29 Nec	30 Nec
				Process Speed	1250 m/min	1190 m/min	1200 m/min
				Number of Yarn Breaks / 100 Km	40 / 100km	25 / 100km	35 / 100km
				Actual Effeceincy	90%	60%	70%
				Run Time/Watch Time (Production Time)	0.9	0.6	0.7
				Stop Time/Watch time (Idle time due to operator)	0.3	0	0.15
				Block Time/Wath time (Idle time due to machine)	0.01	0	0

TABLE 4: Pareto Analysis

Obsrvation Chrateria	Number of occurance outside the specification limits	Percantage	Cumulative Percentage
AEF [%]	8	19.51%	19.51%
Run Time/Watch Time	8	19.51%	39.02%
Stop Time/Watch Time	8	19.51%	58.54%
T [/100km]	6	14.63%	73.17%
Tension [cN]	5	12.20%	85.37%
Denisty g/cm3	3	7.32%	92.68%
YF [/100km]	2	4.88%	97.56%
Block Time/Watch Time	1	2.44%	100.00%
YB [/100km]	0	0.00%	100.00%
	41		

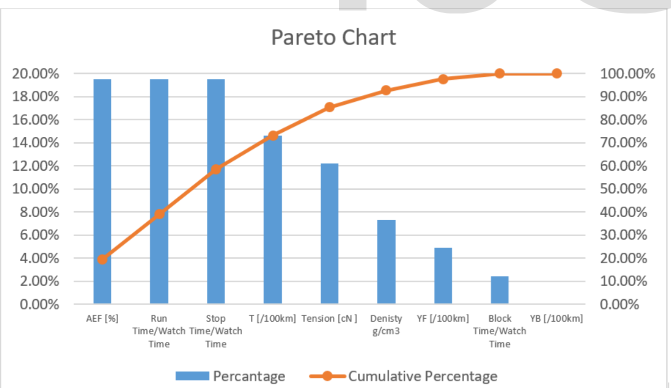

Fig11. Pareto Chart

According to the Pareto Chart, the variation in AEF percentage, Run Time, Stop Time and Number of Thin places cut/ 100km are the most categories, which must be controlled, however the number of cuts / 100 km and Density of the produced package are very important categories to be controlled.

4.2.4 Sampling Techniques

For all the required measurements, we used the on-line data collection, which collect the results for 100% of production, no need for data sampling.

4.2.5 Cp, Cpk Process Capability indices

Process capability compares (1) and (2) the output of an in-control process to the specification limits by using capability indices. The comparison is made by forming the ratio of the spread between the process specifications to the spread of the process values, as measured by six process standard deviation units.

Process Capability:

$$C_P = \frac{USL-LSL}{6\sigma} \quad (1)$$

Process Capability Index:

$$C_{PK} = \min\left(\frac{USL-\mu}{3\sigma}, \frac{\mu-LSL}{3\sigma}\right) \quad (2)$$

By analyzing the collected data and the process limits for each variable, and calculate the Process Capability and Process Capability index:

For number of faults/100Km, the USL is 70/100Km and LSL is 50/100Km, the Mean value is 62.16/100km and Standard deviation is 8.96. By applying the capability calculations, C_P = 0.372 and C_{PK} = 0.293 which indicate that the process is not capable and not centered.

For the process speed, the USL is 1250 m/min and LSL is 1190 m/min, the Mean value is 1220 m/min and Standard deviation is 12.3. By applying the capability calculations, C_P = 0.8 and C_{PK} = 0.8 which indicate that the process is not capable but centered.

For number of weak placess/100Km, the USL is 7/100Km and LSL is 0/100Km, the Mean value is 4.6/100km and Standard deviation is 2.66. By applying the capability calculations, C_P = 0.438 and C_{PK} = 0.3 which indicate that the process is not capable and not centered.

For the tension of each cone, the USL is 26 cN and LSL is 34 cN, the Mean value is 30.4 cN and Standard deviation is 2.95. By applying the capability calculations, C_P = 0.452 and C_{PK} = 0.4 which indicate that the process is not capable but centered.

As we notice from the above calculations, our process needs to be improved to be cabable and centered as possible.

4.2.6 Workflow diagrams

Fig. 12 shows the workflow of our project which arranged very well in the new mill and new delivered machines. There is no need to be modified; because each spinning machine is connecting and supply the winding machine on the same line.

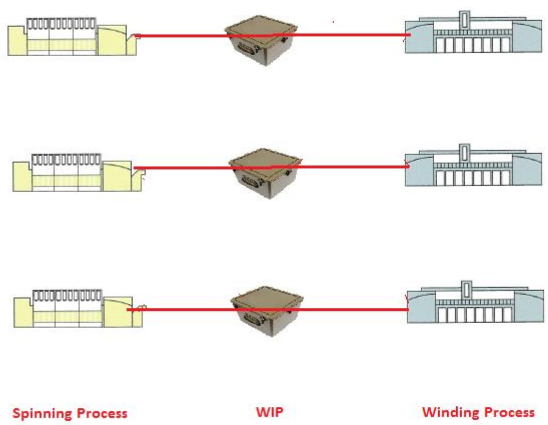

Fig12. Workflow Diagram

4.2.7 Value stream maps

The Value Stream Map is used to capture all key flows (of work, information, materials) in a process and important process metrics. We used iGrafx Process for Six Sigma software. Fig. 13 shows the current situation of our mill (as-is version) focused on spinning and weaving process indicating WIP of 60 bobbins per each winding position and with Lead Time of 223 hours.

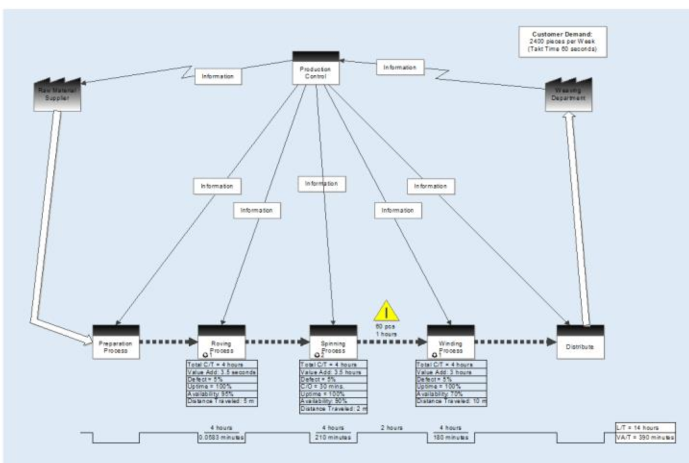

Fig13. Value Stream Map before reducing WIP

Fig. 14 shows the same value stream map with the target situation (Future Version) after reducing the WIP between spinning process and winding process to 5 bobbins per winding positions which resulting in decreasing the total Lead Time to 30.5 hours.

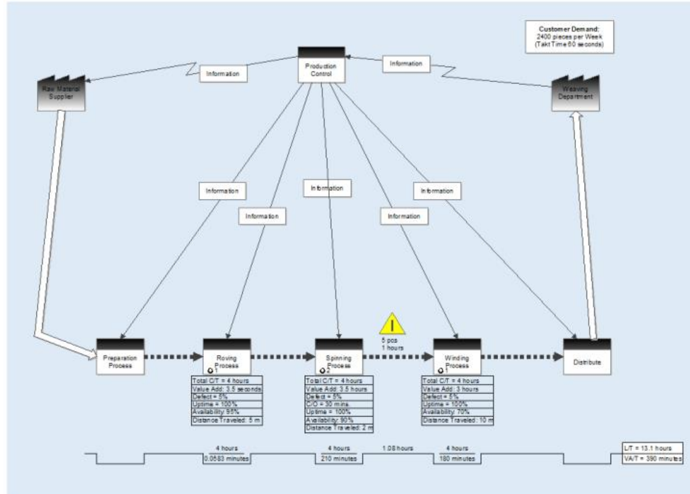

Fig14. Value Stream Map AFTER reducing WIP

4.3 Analyze Phase

In the analyze phase, we will analyze the cause and effects, create Multi-variable analysis, determine variance components, and assess correlation using Cause and effect diagrams, 5 Why's analysis, Correlation and Regression analysis and finally Variation Analysis.

4.3.1 Cause and Effect Diagrams

In order to ensure that a balanced list of ideas have been generated during brainstorming or that major possible causes are not overlooked and to explore all the potential or real causes (root causes or inputs) that result in a each single effect (or output) in our project, we will study the root cause for two main problems: Fig. 15 shows the Cause and Effect Diagram of the Low Quality problem due to high number of remaining faults in the produced cones. While Fig. 16 shows the Low Production Efficiency problem due to high WIP. We will utilize these diagrams to answer the questions in the next section of 5 Whys and proceed to the improve phase.

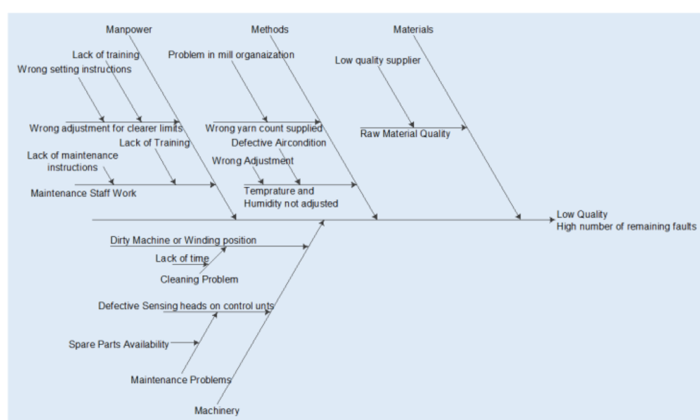

Fig15. VSM of the Low Quality problem

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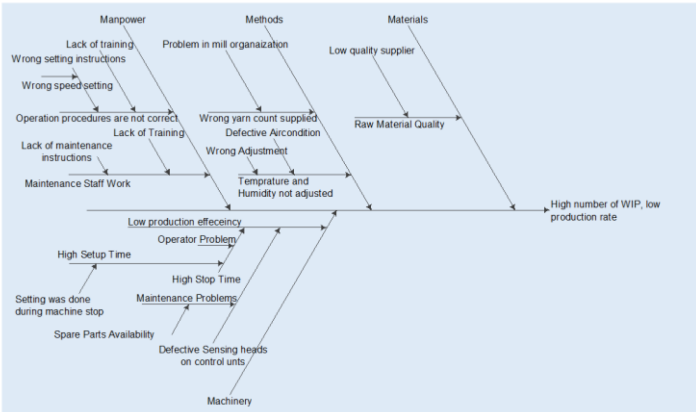

Fig16. VSM of the Low production efficiency

4.3.2 Five Whys

5 Whys Analysis is a problem solving technique that allows us in addition with the Cause and Effect Diagram to get at the root cause of a problem fairly quickly. We will analyze our two main problems in our project in details with the 5 Whys analysis:

The Cause: High number of remaining faults in produced cones:

- ➢ Why there is High number of remaining faults in produced cones?
- • Because: there is high variation in the number of cut faults, the number of thin places and the number of yarn breaks.
- ➢ Why there is high variation in the number of cut faults, the number of thin places and the number of yarn breaks?
- • Because: The clearing limits are not adjusted well, the quality of bobbins from spinning process is not under control and there is a lot of fiber accumulation on the spinning machine.
- ➢ Why the clearing limits is not adjusted well, the quality of bobbins from spinning process is not under control and there is a lot of fiber accumulation on the machine?
- • Because: The operator does not clean the machine well and does not adjust the clearing limits as the manual, the maintenance of spinning machine is not done according to the given table from machine manufacture.
- ➢ Why the operator does not clean the machine well and does not adjust the clearing limits as the manual, the maintenance of spinning machine is not done according to the given table from machine manufacture?
- • Because: The operator and maintenance team have not trained well on the machine operation and maintenance.
- ➢ Why the operator and maintenance team have not trained well on the machine operation and maintenance?
- • Because: The management does not apply the Total Quality Management and does not involve the operators and maintenance in Quality issues.

The Cause: High number of WIP before winding process:

- ➢ Why there is High number of WIP before winding process?
- • Because: there is high variation in the machine speed, the setup time is high and there is variation in number of cut faults.
- ➢ Why there is high variation in the machine speed, the setup time is high and there is variation in number of cut faults?
- • Because: the machine speed and clearers limits are not adjusted well, the setup time is done during the stoppage of machine, and the spindles stop time is high without reason.
- ➢ Why the machine speed and clearers limits are not adjusted well, the setup time is done during the stoppage of machine, the spindles stop time is high without reason?
- • Because: The operator does not adjust the machine well and does not adjust the clearing limits as the manual and leaves the stoppage spindles without start them, the maintenance of spinning machine has not been done according to the given table from machine manufacture.
- ➢ Why the operator does not adjust the machine well and does not adjust the clearing limits as the manual and leaves the stoppage spindles without start them, the maintenance of spinning machine has not been done according to the given table from machine manufacture?
- • Because: The operator and maintenance team have not trained well on the machine operation and maintenance.
- ➢ Why the operator and maintenance team have not trained well on the machine operation and maintenance?
- • Because: The management does not apply the Total Quality Management and Lean Six Sigma and does not involve the operators and maintenance in Quality issues.

4.3.3 Correlation statistics (coefficients)

In order to emphasize the cause of the lower production efficiency, we use the Pearson correlation coefficient (designated as r) which reflects the strength and the direction of the relationship between two variables. Fig. 17 shows a high correlation between the Actual efficiency, which reflect on the WIP number, and the stop time, which represent the stoppage due to operator problem or setup time of the machine. The regression calculation output are $R^2 = 0.934$ and adjusted $R^2 = 0.933$.

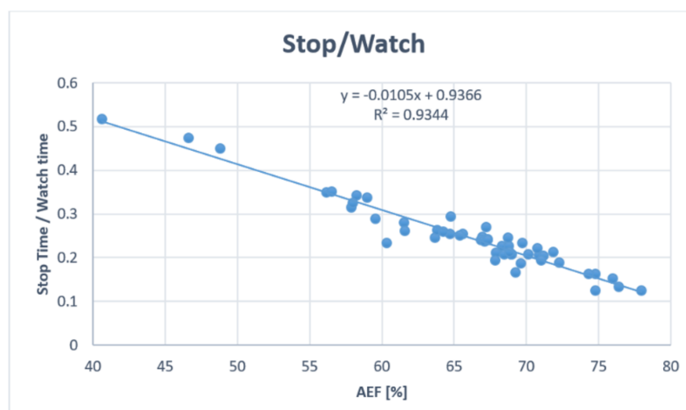

Fig17. The Stop/Watch time and AEF[%] correlation

4.3.4 Time series plots (Run charts)

In order to analyze the collected data for the three shifts, 7 days using the Quantum Display Unit and track the order in which the data were generated by the process, we summarize a part of these data in the table 5 and use them to generate a several Time Series Plots (Run Charts). We mark off the data units on the vertical (y) axis and mark the sequence, plot the data points on the charts (Weak Places / 100 km, Speed and Yarn Faults /

100 km) and draw a line connecting them in sequence. Determine the median and draw a line at that value on the chart.

TABLE 5: Data analysis for time series chart

Sequence	Weak Places / 100km	Speed	Yarn Faults / 100km
1	4.37	1216	65.6
2	3.63	1212	69
3	4.28	1220	61.9
4	3.63	1215	64.9
5	4.03	1215	67.5
6	10.39	1203	77.87
7	3.92	1230	73.43
8	6.11	1201	81.36
9	3.17	1220	61.15
10	9.09	1210	67.9
11	3.29	1225	59.36
12	5.12	1214	67.4
13	11.41	1193	85.2
14	13.1	1190	89.3
15	3.56	1218	62.7
16	2.9	1223.7	64.43
17	2.88	1220	59.13
18	3.94	1216	65.9
19	7.59	1214	66.3
20	7.67	1210	71.3
21	7	1219	60.7

The wak places and yarn faults analysis (Fig. 18 and Fig. 20) show that the number of points, which are not in the median, are 19, and number of runs are 11. The speed analysis (Fig. 19) shows that the number of points, which are not in the median, are 19, and number of runs are 12.

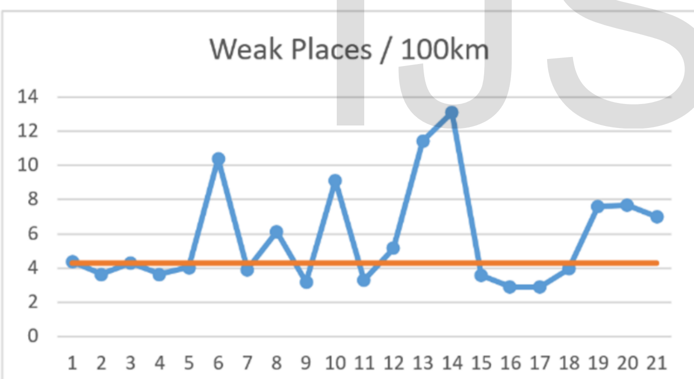

Fig18. Weak Pleaces Run Chart

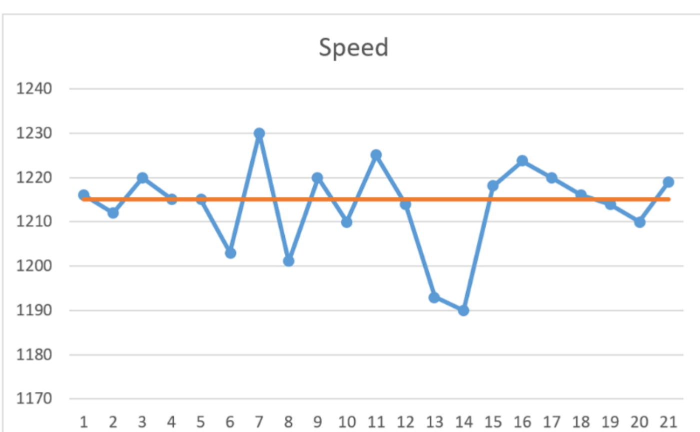

Fig19. Speed Run Chart

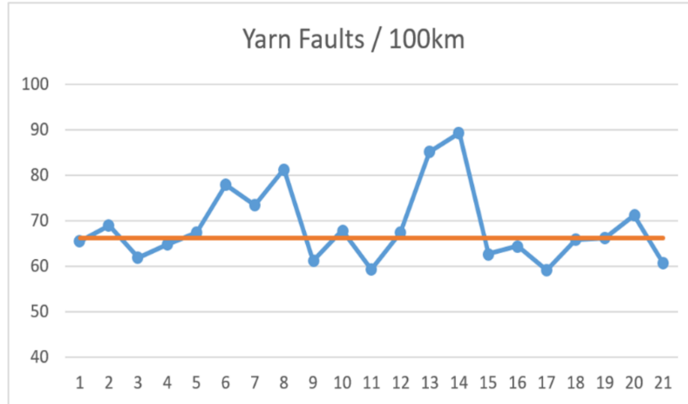

Fig20. Yarn Faults Run Chart

4.3.5 Causes of Variations

Common Causes of variation in our project are inappropriate procedures in machine adjustment and setup, floor maintenance of machines and clearers, quality control error in either fault elimination or tension adjustment and ambient temperature and humidity. While the Special causes of variation are poor adjustment of equipment (Machine speed, clearers setting, splice setting …), operator falls asleep, faulty controllers and operator absent.

4.4 Improve Phase

In this phase, we will try to improve the process and evaluate solutions, implement variation reduction, standardize process and assess risk factors using different tools like Process Lean Metrics, Setup Reduction, Total Productive Maintenance, Visual Process Controls and FMEA.

4.4.1 Process Lean Metrics

First, we calculate the Cycle Time and throughput rate, which is the interval of time between two successive outputs coming out of a workstation or process. Every winding position produce one cone in around 3 hours with capacity of 2 output lots / shift and it is the throughput rate of the machine 2 lots / shift. The bottleneck in our project is the winding process, and by improving the quality and production rate of this step, the whole mill production rate will be improved. The Lead Time is the sum of the Cycle Time, which is about 3.5 - 4 hours, and the Waiting Time, which is between 0.5 – 1 hour (stoppage time and setup time). The calculated Process Utilization is Cycle Time / Lead Time = ¾ = 75%. The actual utilization from the collected data is 72.65%.

4.4.2 Setup Reduction

Setup reduction is the process of reducing changeover time. Since setup activities add no form, fit, or function to the product, they are by definition non-value adding. The benefits are included reducing lead-time which resulting in improved delivery. There are two types of setup; Internal and external setup. Internal setup is an activity that must be performed by the process operator during machine stoppage, the operator was adjusting the clearers limit (Fig. 21) and the machine settings (Fig. 22) (speed, tension, package size,…) during machine stoppage, and this adjustment was taken from 30 – 60 min. In addition,

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the external setup is an activity that could be performed while the equipment is producing parts or the process operator is conducting other value-add work.

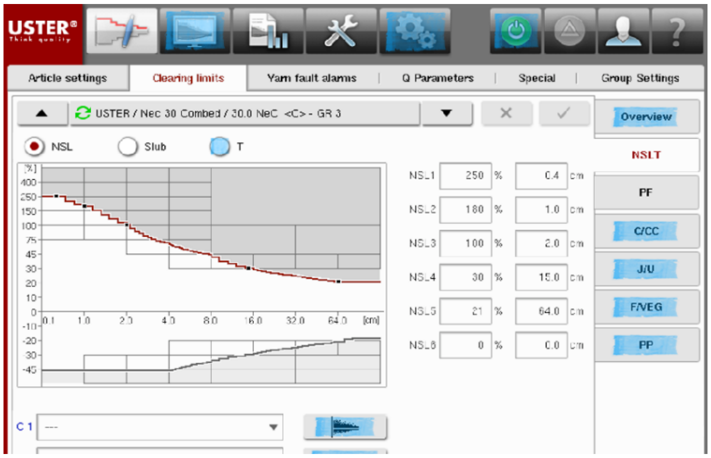

Fig21. Clearer Limits Adjustment

After a good training for the operators and maintenance team from the machine manufacture, the management changed the setup procedures to do all the necessary settings for machine and clearers during the running of machine and save them in database, then the operator stops the machine for only 5 min to recall these setting before start the new lot. Additional action, the production and quality manager start to use a synchronization adjustment (which is a new feature in the yarn clearers central unit) for the yarn clearers for the new lots and material types to reduce the setup time.

Fig22. Winding Machine Spindle Adjustment

4.4.3 Total Productive Maintenance (TPM)

Total production maintenance (TPM) is a system of maintaining and improving the integrity of production and quality systems through the machines, equipment, processes, and employees that add business value to an organization. The main problem in the mill of our case study is the separation of production and quality and lack of training of the operator. Therefore, as TPM, the operators have been trained to adjust the machine to maintain the high quality and high productivity at same Time. In addition, the required maintenance has been done in cooperation between maintenance department and production department, the operators and maintenance staff have been involved in the quality and production. TPM focuses on keeping all equipment in top working condition to avoid breakdowns and delays in manufacturing processes.

Improve Phase #1: Return equipment to reliable condition through clean machine thoroughly and perform repairs.

Improve Phase #2: Eliminate breakdowns through eliminate factors contributing to failure such as clean the tensioner and splicer before entering the fibers inside nozzles, adjust the belts well, supply only cleaned and dry air to the machine and lubricate the moving parts according to machine manufacture's instruction. In addition, we try to improve accessibility to the part or area so you can regularly clean, lubricate, adjust, inspect.

Improve Phase #3: Develop TPM database by forming the necessary document for all preventive and predictive maintenance procedures.

Improve Phase #4: Eliminate defects through install visual controls, help prevent future failures by training maintenance staff in proper techniques implement 5S housekeeping and organization, regularly review and improve machine performance by perfect adjust for machine speed and splicer and tensioner and readjust the yarn clearers and clearing limits probably.

4.4.4 Visual Process Control

Visual controls include a variety of displays and visual markers in the workplace, which includes the safety indicators, and check boards. Three check boards have been designed and used; the first check board used to monitor production and stop time for each machine in each shift (Fig. 23), the second check board used to monitor adjustment for each machine in each shift (Fig. 24), the third check board used as personal training board (Fig. 25)

Machine	Date	Shift	Operator	Maintenance	Production	Run Time	Stop Time
U1-QPRO-1	5/1/2019	1	Ahmed Morsi	Amir El-Sayed	186.8 Kg	6:35	1:25
U1-QPRO-1	5/1/2019	2	Yiusef Awad	Karim			
U1-QPRO-1	5/1/2019	3					
U1-QPRO-1	5/2/2019	1					
U1-QPRO-1	5/2/2019	2					
U1-QPRO-1	5/2/2019	3					
U1-QPRO-1	5/3/2019	1					
U1-QPRO-1	5/3/2019	2					
U1-QPRO-1	5/3/2019	3					
U1-QPRO-1	5/4/2019	1					
U1-QPRO-1	5/4/2019	2					
U1-QPRO-1	5/4/2019	3					

Fig23. Check board for production and stop time

Machine	Date	Shift	Adjustment	Operater	Work Done	Stppage Time	Notes
U1-QPRO-2	5/1/2015	1	Clearer Limits	Ahmed Morsi	Readjust the Thin places limit to -40% 12 cm	5 min	
U1-QPRO-4	5/2/2016	1	Splicer Adjustment	Ahmed Morsi			

Fig24. Check board for machine adjustment in each shift

As a result of the previously improvement tools, a remarkable reduction in the weak places, cleaer cuts and their variations has been achieved, which imrove the quality of produced yarn.

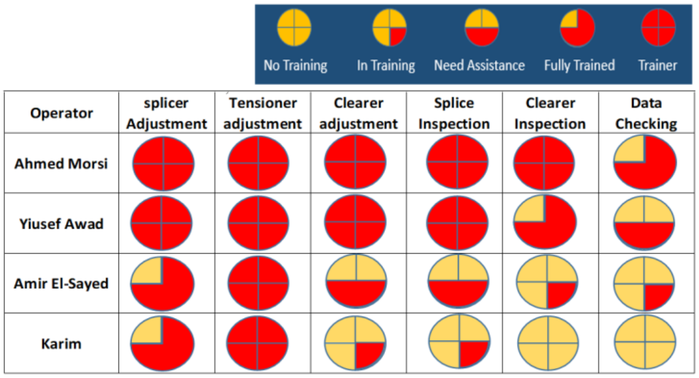

Fig25. Personal training check board

4.4.5 Failure Mode & Effects Analysis (FMEA)

The purpose of this step is to design a structured approach to Identify the ways in which a product, service, or process can fail, estimate risk associated with specific failure causes, prioritize the actions to reduce risk of failure and evaluate design validation plan (product/service) or current control plan (process). Prior to developing the PFMEA, a team should be selected and a process map developed for the process in question. Then the following steps have be done:

1. List the process steps in the first column of the PFMEA form.
2. For each process step brainstorm a list of the potential failure modes - ways in which the product or service might fail.
3. Identify the potential effects of each failure mode and rate the severity of the effects.
4. Identify the potential causes of the failure modes and rate their likelihood of occurrence.
5. List current controls in place and rate the ability of the control to detect or prevent the failure mode or cause.
6. Multiply the three ratings to get the Risk Priority Number (RPN).
7. Identify improvement actions to reduce or eliminate the risk associated with high RPN's.
8. Recalculate the RPN to verify it is below the economically feasible threshold.

Table 6 shows complete PFMEA for winding machine with high variation in the cuts per 100 km. Moreover, table 7 shows complete PFMEA for winding machine with high WIP before winding. While table 8 shows complete PFMEA for wrong package density produced by winding machine.

TABLE 6: Complete PFMEA for winding machine with high variation in the cuts per 100 km

#	Process Function (Step)	Potential Failure Modes (process defects)	Potential Failure Effects (KPOVs)	SEV	Potential Causes of Failure (KPIVs)	OCC	Current Process Controls	DET	RPN	Recommend Actions	Responsible Person & Target Date	Taken Actions	SEV	OCC	DET	RPN
1	Winding Process	Variation in the cuts / 100 km in the clearers	Remaining faults in the produced Cones	7	Wrong adjustment of yarn Clearers	5	Check Clearers Control Unit	5	175	Operator Training	Operator and Manager	Yes	7	2	2	28
2	Winding Process	Variation in the cuts / 100 km in the clearers	Remaining faults in the produced Cones	7	Clearer is defective	2	Check the clearer functionality	8	112	Make the schedule Maintenance and check clearers frequently	Maintenance Engineer	Yes	7	1	2	14
3	Winding Process	Variation in the cuts / 100 km in the clearers	Remaining faults in the produced Cones	7	The winding machine is dirty	3	Visual Check	1	21	Clean the winding machine	Operators	No				
4	Winding Process	Variation in the cuts / 100 km in the clearers	Remaining faults in the produced Cones	7	The quality of raw material is bad	1	Check samples from raw material	9	63	Purchase a good raw material	Purchasing Department and Quality Control	No				
5	Winding Process	Variation in the cuts / 100 km in the clearers	Remaining faults in the produced Cones	7	Supplied bobbins have too many faults	2	check samples from produced bobbins	9	126	Adjust the quality of bobbins in spinning process an check it regularly	Quality Control	Yes	7	1	3	21

TABLE 6: complete PFMEA for winding machine with high WIP before winding.

#	Process Function (Step)	Potential Failure Modes (process defects)	Potential Failure Effects (KPOVs)	SEV	Potential Causes of Failure (KPIVs)	OCC	Current Process Controls	DET	RPN	Recommend Actions	Responsible Person & Target Date	Taken Actions	SEV	OCC	DET	RPN
1	Winding Process	The speed of winding machine is not adjusted	High WIP before Winding	6	The machine setting is wrong	5	Check Winding machine settings	5	150	Adjust the machine correctly	Operator and production manager	Yes	6	2	2	24
2	Winding Process	There is high number of cuts in winding machine	High WIP before Winding	6	Cleaer is defctive	2	Check the cleaer functionality	8	96	Make the schedule Maintenance and check clearers frequently	Maintenance Engineer	Yes	7	1	3	21
3	Winding Process	There is high number of cuts in winding machine	High WIP before Winding	6	Wrong adjustment of yarn Clearers	3	Check Clearers Control Unit	5	90	Operator Training	Operator and Manager	Yes	7	1	2	14

TABLE 8: complete PFMEA for wrong package density produced by winding machine

#	Process Function (Step)	Potential Failure Modes (process defects)	Potential Failure Effects (KPOVs)	SEV	Potential Causes of Failure (KPIVs)	OCC	Current Process Controls	DET	RPN	Recommend Actions	Responsible Person & Target Date	Taken Actions	SEV	OCC	DET	RPN
1	Winding Process	The tension of winding position is not adjusted	The package density is wrong	7	The machine setting is wrong	5	Check Winding machine settings	5	175	Adjust the machine correctly	Operator and production manager	Yes	6	2	2	24
2	Winding Process	The winding speed is not djusted	The package density is wrong	7	The machine setting is wrong	5	Check Winding machine settings	5	175	Adjust the machine correctly	Operator and production manager	Yes	6	2	2	24
3	Winding Process	The input bobbins have wrong yarn count	The package density is wrong	7	Supplied bobbins are wrong	3	check samples from produced bobbins	9	189	Adjust the quality of bobbins in spinning process an check it regularly	Quality Control	Yes	7	2	3	42

4.5 Control Phase

In the control phase, we control the process, implement control charts for key variables, mistake proof processes and evaluate results. We will use the tool of Control Chart in this phase. During the Improve phase, the solution is piloted, plans are made for full-scale implementation and putting a solution in place can fix a problem for the moment, but the activities in the Control phase are designed to insure that the problem does not reoccur and that the new processes can be further improved over time. The control charts is used for establishing a measurement baseline, detecting special cause variation, ensuring process stability and enabling predictability, monitoring process over time and confirming the impact of process improvement activities.

The data of cuts / 100 km pirior to the improve phase have been collected as individual measurement in sequence per shift and arranged in Table 9. Fig. 26 and Fig. 27 show the control charts of XmR of the number of cuts / 100 km. All points are locating inside the limits, which indicate that the process now is under control and no special cause of variation.

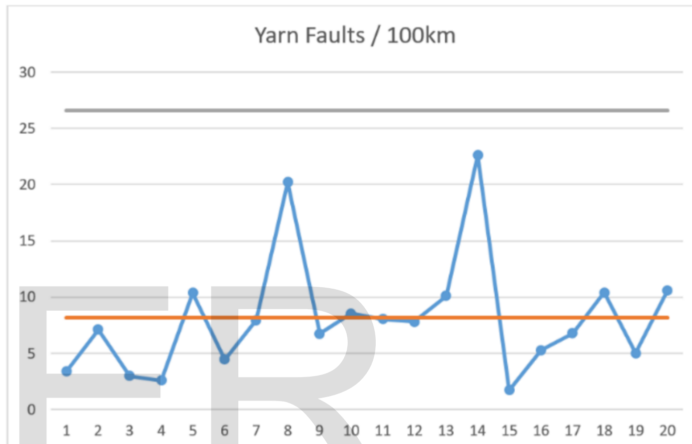

Fig26. Control charts of XmR of the number of cuts / 100 km

TABLE 9: Cuts /100 km in sequence per shift

Sequence	Yarn Faults / 100km	Moving Range	Average Line of X	UCLx	LCLx	Average Line of mR	UCLmR
1	65.6		68.49190476	90.12834476	46.85546476		
2	69	3.4	68.49190476	90.12834476	46.85546476	8.134	26.581912
3	61.9	7.1	68.49190476	90.12834476	46.85546476	8.134	26.581912
4	64.9	3	68.49190476	90.12834476	46.85546476	8.134	26.581912
5	67.5	2.6	68.49190476	90.12834476	46.85546476	8.134	26.581912
6	77.87	10.37	68.49190476	90.12834476	46.85546476	8.134	26.581912
7	73.43	4.44	68.49190476	90.12834476	46.85546476	8.134	26.581912
8	81.36	7.93	68.49190476	90.12834476	46.85546476	8.134	26.581912
9	61.15	20.21	68.49190476	90.12834476	46.85546476	8.134	26.581912
10	67.9	6.75	68.49190476	90.12834476	46.85546476	8.134	26.581912
11	59.36	8.54	68.49190476	90.12834476	46.85546476	8.134	26.581912
12	67.4	8.04	68.49190476	90.12834476	46.85546476	8.134	26.581912
13	75.2	7.8	68.49190476	90.12834476	46.85546476	8.134	26.581912
14	85.3	10.1	68.49190476	90.12834476	46.85546476	8.134	26.581912
15	62.7	22.6	68.49190476	90.12834476	46.85546476	8.134	26.581912
16	64.43	1.73	68.49190476	90.12834476	46.85546476	8.134	26.581912
17	59.13	5.3	68.49190476	90.12834476	46.85546476	8.134	26.581912
18	65.9	6.77	68.49190476	90.12834476	46.85546476	8.134	26.581912
19	76.3	10.4	68.49190476	90.12834476	46.85546476	8.134	26.581912
20	71.3	5	68.49190476	90.12834476	46.85546476	8.134	26.581912
21	60.7	10.6	68.49190476	90.12834476	46.85546476	8.134	26.581912
Average	68.49190476	8.134					

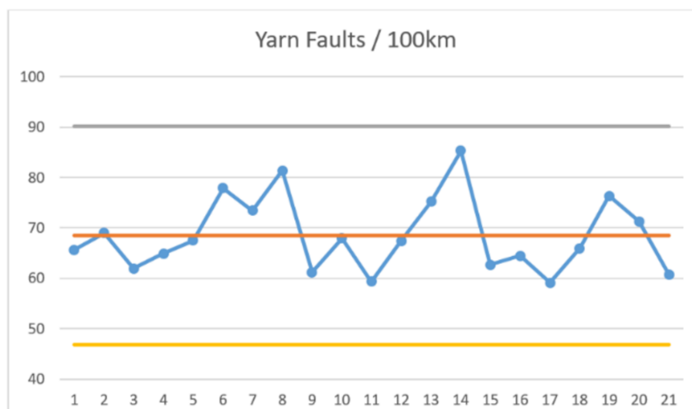

Fig27. Control charts of XmR of the number of cuts / 100 km

The data of winding speed have been collected as individual measurement in sequence per shift and arranged in Table 10. Fig. 28 and Fig. 29 show the control charts of XmR of the winding speed with all points are within the limits, which indicate that the process now is under control and no special cause of variation.

The data of weak places / 100km have been collected as individual measurement in sequence per shift and arranged in Table 11. Fig. 30 and Fig. 31 show the control charts of XmR of the weak places / 100km with 2 out of 3 successive values in Zone A. In addotion, 4 out of 5 Successive values in Zones A and B, which indicate that the process is tot ally lack of control in the number of weak places and there is a special cause of variation in the weak places and further improve over the time must be done.

TABLE 10: Winding speed in sequence per shift

Sequence	Speed	Moving Range	Average Line of X	UCLx	LCLx	Average Line of mR	UCLmR
1	1216		1213.666667	1242.527667	1184.805667		
2	1212	4	1213.666667	1242.527667	1184.805667	10.85	35.4578
3	1220	8	1213.666667	1242.527667	1184.805667	10.85	35.4578
4	1215	5	1213.666667	1242.527667	1184.805667	10.85	35.4578
5	1215	0	1213.666667	1242.527667	1184.805667	10.85	35.4578
6	1203	12	1213.666667	1242.527667	1184.805667	10.85	35.4578
7	1230	27	1213.666667	1242.527667	1184.805667	10.85	35.4578
8	1201	29	1213.666667	1242.527667	1184.805667	10.85	35.4578
9	1220	19	1213.666667	1242.527667	1184.805667	10.85	35.4578
10	1210	10	1213.666667	1242.527667	1184.805667	10.85	35.4578
11	1225	15	1213.666667	1242.527667	1184.805667	10.85	35.4578
12	1214	11	1213.666667	1242.527667	1184.805667	10.85	35.4578
13	1205	9	1213.666667	1242.527667	1184.805667	10.85	35.4578
14	1205	0	1213.666667	1242.527667	1184.805667	10.85	35.4578
15	1218	13	1213.666667	1242.527667	1184.805667	10.85	35.4578
16	1210	8	1213.666667	1242.527667	1184.805667	10.85	35.4578
17	1220	10	1213.666667	1242.527667	1184.805667	10.85	35.4578
18	1210	10	1213.666667	1242.527667	1184.805667	10.85	35.4578
19	1214	4	1213.666667	1242.527667	1184.805667	10.85	35.4578
20	1205	9	1213.666667	1242.527667	1184.805667	10.85	35.4578
21	1219	14	1213.666667	1242.527667	1184.805667	10.85	35.4578
Average	1213.667	10.85					

TABLE 11: Weak places/100Km in sequence per shift

Sequence	Weak Places / 100km	Moving Range	Average Line of X	UCLx	LCLx	Average Line of mR	UCLmR
1	4.37		5.765714286	13.42784429	0		
2	3.63	0.74	5.765714286	13.42784429	0	2.8805	9.413474
3	4.28	0.65	5.765714286	13.42784429	0	2.8805	9.413474
4	3.63	0.65	5.765714286	13.42784429	0	2.8805	9.413474
5	4.03	0.4	5.765714286	13.42784429	0	2.8805	9.413474
6	10.39	6.36	5.765714286	13.42784429	0	2.8805	9.413474
7	3.92	6.47	5.765714286	13.42784429	0	2.8805	9.413474
8	6.11	2.19	5.765714286	13.42784429	0	2.8805	9.413474
9	3.17	2.94	5.765714286	13.42784429	0	2.8805	9.413474
10	9.09	5.92	5.765714286	13.42784429	0	2.8805	9.413474
11	3.29	5.8	5.765714286	13.42784429	0	2.8805	9.413474
12	5.12	1.83	5.765714286	13.42784429	0	2.8805	9.413474
13	11.41	6.29	5.765714286	13.42784429	0	2.8805	9.413474
14	13.1	1.69	5.765714286	13.42784429	0	2.8805	9.413474
15	3.56	9.54	5.765714286	13.42784429	0	2.8805	9.413474
16	2.9	0.66	5.765714286	13.42784429	0	2.8805	9.413474
17	2.88	0.02	5.765714286	13.42784429	0	2.8805	9.413474
18	3.94	1.06	5.765714286	13.42784429	0	2.8805	9.413474
19	7.59	3.65	5.765714286	13.42784429	0	2.8805	9.413474
20	7.67	0.08	5.765714286	13.42784429	0	2.8805	9.413474
21	7	0.67	5.765714286	13.42784429	0	2.8805	9.413474
Average	5.765714286	2.8805					

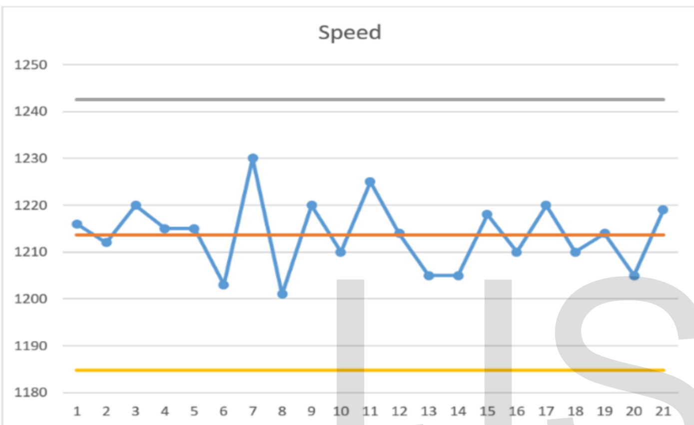

Fig28. Control charts of XmR of the process speed

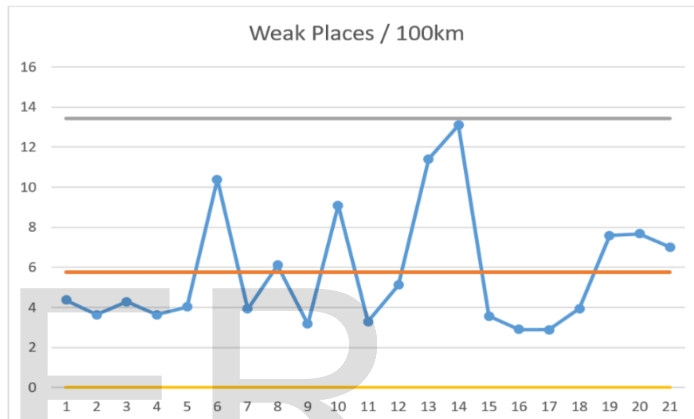

Fig30. Control charts of XmR of the number of weak places / 100 km

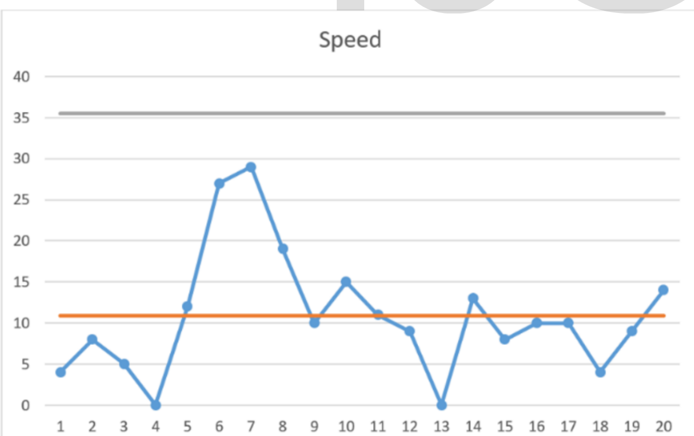

Fig29. Control charts of XmR of the process speed

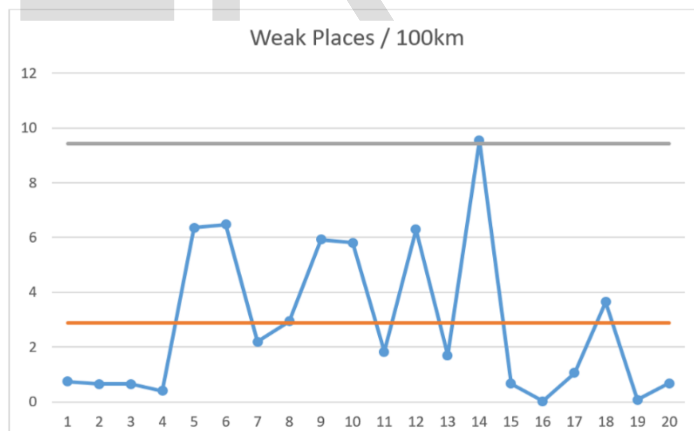

Fig31. Control charts of XmR of the number of weak places / 100 km

5 Conclusion and Future work

By implementing the Lean Six Sigma different techniques, a significant change and effect have been done and notice either in the quality level of the produced cones and satisfaction of the weaving mill or in the production of the whole spinning mill and the flow of the work process. In addition, a notice saving in the quality and production costs has been achieved by implementing the Lean Six sigma by reducing the waste and non-value added times and the low quality refused cones from the weaving process.

More control on the process over time should be done to maintain the achieved quality and production level. Training of the operators and maintenance staff should be continue in regular basis, involving both production and maintenance department in the quality control will help to keep the improvement of the process and keep the cleaned organized work place with correct climate conditions.

A remarkable notice has been recorded during the research that, there is a nig interference between the five DMAIC steps of LSS. Analysis for the process has been done during the Measure process, additional measurements and advantage analysis have been done during and after Improve process. In addition, Improve and Control Processes are very interfering.

During our project, we focused on the winding stage of the yarn manufacturing process, more research and case studies can be done in the implimintation of the Lean Six Sigma in the whole stages of the yarn producing mill simatinously in order to improve the factory production and quality, which affect the end product and customer statisfaction.

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