International Journal of Innovation, Creativity and Change. www.ijicc.net
Volume 15, Issue 3, 2021

Productivity Improvement in the Denim Industry by DMAIC Methodology

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The aim of this paper is to boost productivity improvement by reducing the rejection rate and finding ways to improve the quality of the textile (denim) industry. The methodology used here is based on Six Sigma, which aids as a catalyst for lowering the rejection rate in the denim industry. Six Sigma in this paper serves as a systematic tool for continuous quality process improvement and for achieving desired targets and quality. The DMAIC model provides a framework that ultimately decreases the variation in the process, and executes a central plain that would be readily accepted by the organisation and which encourages people to adapt it. In the defining phase, the root causes of the problem and faults were recognised. As a result, a broken end was found to be the main cause of the rejection of defective products. The root causes were analysed using a cause and effect diagram. In the improvement phase, the design of the experiment (DOE) was implemented, and key parameters of the process were set up. This revealed that high concentrations of acid and hydrogen peroxide are the core origin of the diminishing yarn strength in the back process. A factorial design, with two replications, was performed. Hydrogen peroxide and acid were used in the dyeing department as chemical oxidation for indigo dye. After the implementation of Six Sigma, the productivity of the company improved and the rejection rate was reduced.

Key words: *Six Sigma, DOE, CED, PDCA Cycle, Pareto Chart*

INTRODUCTION

Productivity improvement is the main consideration in this work. Every resource used in denim productivity is desired and focused, whether it is manpower, machinery, money or methods. By using process improvement techniques in the system, the organisation promptly met its desired quality target. The aim was to follow a specific methodology that directly affects the output (Bristi & Mamun, 2019). Denim is very popular and for emerging fabrics in the fashion business, the quality of denim products matters a lot, and its attractive shades are highly welcomed by the customer. Denim has to be well adopted within the product range of a certain capsule of each seasonal collection (Khalil, 2015; Csanák, 2014).

Six Sigma is a process-based, data-driven, customer-centric approach used for the tactics of improvement. The Six Sigma methodology is widely used for reducing the variability of either process or product, or both. The birthplace of Six Sigma is the Motorola mobile company USA. During 1980, Motorola was facing a higher rejection rate in its product and suffering from a poor-quality process. Motorola was losing its large portion of business because of poor quality issues. A Motorola engineer, Bill Smith (founder of Six Sigma) came up with the concept of the Six Sigma process, which was associated with measuring defective parts per million (DPM) (Antony, 2014). The Six Sigma program has the foremost advantage in that it eliminates the subjectivity in decision-making; it creates a system that facilitates everyone within the organisation to collect, analyse and display data in a uniform way. As Six Sigma could also be a project-driven methodology, the prioritisation of missions which will offer the absolute best financial profit to the organisation is crucial (Cima et al., 2011).

Six Sigma offers a methodology to hunt out, quantify and "translate that knowledge into opportunities for business growth," as well as power over the tactic (Brun, 2011). The Six Sigma could also be an enormous umbrella that carries many tools and techniques thereunder. As all tools and techniques have different applications, supporting the character of the problem, the tool and technique are selected for the tactic of improvement (Raisinghani et al., 2005; Mast, & Lokkerbol, 2012). The tools are divided into three categories, such as basic Six Sigma (concerned with understanding the matter and solving it through seven QC tools); intermediate Six Sigma (concerned with few enumerative statistical methods like control charts, data analysis, etc.); and advanced Six Sigma (this includes DOE, the Taguchi method, statistical method, ANOVA, etc.). A comprehensive plan, provided by Six Sigma, assists companies to integrate appropriate statistical tools and techniques enabling a "comprehensive" environment that improves the process significantly. Often these tools are applicable in individual phases that define, measure, analyse, improvea and control (DMAIC) a methodology; in this way an efficient process quality improvement system is determined. The plan, do, check, act (PDCA) cycle is the basis for this structured method, but the tools and techniques to be used within each step are specified by the Six Sigma, and which are exclusive to Six Sigma. The Six Sigma achievement is also dependent on the assembly age. Six Sigma is not an accreditation scheme for quality like the ISO9000. There is no organisation that claims to have Six Sigma certification, and no such internationally recognised body exists which could certify or register companies that comply with Six Sigma (Chen & Lyu, 2009; Camgoz-Akdag, 2007).

The Shainin techniques are well known to supply breakthrough improvements in order to eliminate chronic quality problems. These techniques effectively identify the basic cause and its validation (Steiner et al., 2007). Shainin DOE is an industrial operation. Acccording to this study 'the Shainin methodology is suggested to be extremely practical and it may easily be executed in numerous settings, making it one among the foremost approachable quality techniques still available. A substitute to the classical, the Taguchi experimental design is much simpler but lesser known. A Dorian Shainin consultant and advisor proposed and improved the Shainin DOE approach to over 750 companies in America and Europe. Shainin's philosophy has been, "don't let the engineers do the guessing; let the parts do the talking." Shainin recognised that in order to solve real-world problems, the empirical data is of great worth (Prashar, 2016). The Shainin system is quite often used in combination with the production facilities in order to perform traceability. Current information system technology is capable enough to utilise the process database in order to observe, investigate and compare data instantly with ease, without the need to perform the experimental factor screening by performing many observations (Kosina, 2015; Steiner et al., 2007).

The t-test is employed to check the differences between two different conditions that possess interval/ratio data. Hypothesis testing includes two conflicting conditions, namely H_0 representing the absence of any significant differences between the two tested conditions, and H_1 representing that there is a big difference between the two conditions being tested. The choice to simply accept or reject H_0 or H_1 is decided by the worth of the t-test calculated against the t-table, where the following provisions apply:

If the t-count is less than from the t-table, then the null hypothesis (H_0) is accepted and the alternate hypothesis (H_1) is rejected.

If the t-count is greater than from the t-table, then the alternate hypothesis (H_1) is a accepted and the null hypothesis (H_0) is rejected.

Hypothesis acceptance decisions are seen from the comparison of the p value to the α value, where the other provisions applying from the worth of t-count are:

If the p-value is less than of the α value, then the alternate hypothesis (H_1) is accepted and thus rejects the null hypothesis (H_0).

If the p-value is greater than of α value, then the null hypothesis (H_0) is accepted and thus the rejects alternate hypothesis (H_1) (Kadam et al., 2018).

This work has a higher regard for the Six Sigma strategy. It is employed to analyse the statistical data of the back-process department. Further, the DMAIC methodology enables us to define the problem and find the main root causes of the problem. After analysing the problem, the root causes are eliminated through effective Six Sigma strategies, and finally, the process is continually controlled and in phases containing various tools and techniques for minimising the rework rate.

METHODOLOGY

The methodology of this research work involves investigating the factors that may produce a defect in Article A (Ice Blue), whose configurations are a 3/1 RHT weave pattern, yarn count 10/s Ring Slub, and 30 ropes dipped in a series of dye boxes of vat dye that is used in back-process departments. Back-process plays a major role in increasing the rejection rate in article A (Ice Blue) at the finishing stage. In this study, the Six Sigma method with a problem-solving approach DMAIC will be used with the design of experiment (DOE). DMAIC stands for define, measure, analyse, improve and control, in that order.

Define Phase

Define is the first phase of the DMAIC methodology of Six Sigma. This phase defines the problem, the project goal, and the process that needs to be upgraded in order to achieve a higher sigma level. A variety of Six Sigma tools are available for the define phase, such as the Supplier Input Process Output Customer (SIPOC). SIPOC is a process map which includes suppliers, inputs, process, outputs, and customers. Output of the process dictates the quality; the following table indicates the SIPOC flow of the back-process. It is used for understanding the clear relationship between customer and supplier. In the define phase, there are two activities: (a) SIPOC and (b) critical to quality (CTQ).

1. *SIPOC*

The aim of a SIPOC diagram is to summarise the inputs and the outputs of the production process so that identification of defective products can be carried out in the step/process. The SIPOC building process diagram is as shown in Table 1.

International Journal of Innovation, Creativity and Change. www.ijicc.net
Volume 15, Issue 3, 2021

Table 1. Supplier Input Process Output Customer (SIPOC) of Back-Process

Suppliers	Inputs	Process	Output	Customers
Spinning	Yarn Cones	Transferring multiple yarn from individual Rope yarn packages onto ball log	Ball Formation	Dyeing machine
Dyeing Department	Warped Ball	Dyeing of rope without shade variation	Dyed rope in drums	Re-beaming machine
Re-Beaming Department	Dyed yarn in drum	Open the dyed rope and separate the yarn from each other	Parallel yarn warped on beam	Sizing machine
Sizing Department	Warp beam	Application of sizing chemicals	Sized beam	Weaving looms

Table 1 shows different suppliers, which may provide different raw materials. For instance, one raw material might be of high quality and the other of poor raw material, which may impact highly on the final product. For this reason, the SIPOC will help us in differentiating the variability point, whether that arises from the supplier, input, process, output, or customer, and it will be easy then to take corrective action.

Critical to Quality (CTQ)

A Pareto diagram of Article A (Ice Blue) defects can help in determining CTQ, as shown in Figure 1.

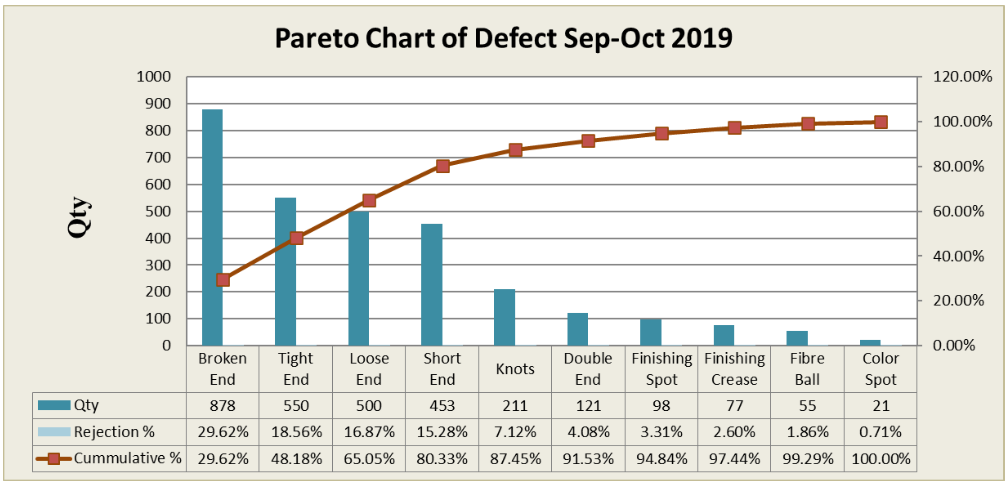


Figure 1. Pareto chart of defect, Sep-Oct 2019

Figure 1 explains that BE (Broken End) defects are the largest metered number to rejection percentage of the finished fabric. In this study, BE defective became a pilot project stemming from the decline of defective finished fabric. The magnitude of defective metres due to BE is 29.62 percent.

Measure Phase

The measure phase is the second phase of the DMAIC cycle of Six Sigma. This phase is when the measurement process is used to determine the current condition, before improvement. In this stage, the p chart, baseline performance measurement (sigma level) and the four-block diagram have been used. In the performance baseline measurement of the two months, in back process (September-October 2019) the sigma level is shown in Table 2.

Table 2. Performance baseline (sigma level) of back process, September and October 2019

Month	Production (metres)	BE	Defects Per Unit (DPU)	Defects Per Million Output (DPMO)	Yield	Zst
September	54215	678	0.012506	12506	98.78	3.75
October	79995	777	0.009713	9713	98.78	3.75
Average	67105	727.5	0.011109	11109	98.78	3.75

Table 2 shows that the average sigma level (Zst) of the months of September and October 2019 is 3.75. The ongoing process capability (Z) is shown by mapping into four block diagrams.

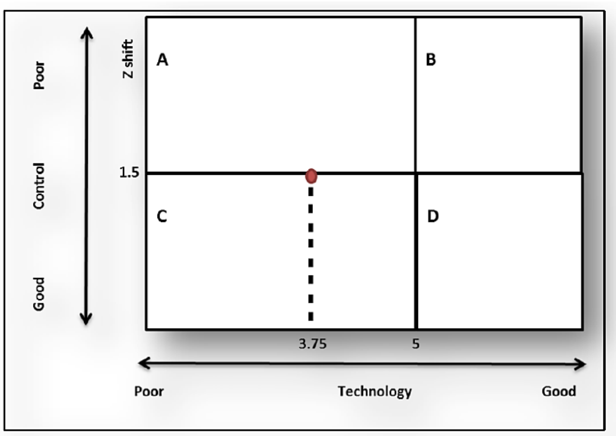


Figure 2. Four block diagram of current performance

Analyse Phase

The third sequential stage of the DMAIC Cycle is the analyse phase. This phase is analytical in nature in comparison to earlier-discussed phases. In this stage, the Shainin system has been implemented to gain information regarding the prime reasons (or vital factor) for the defective product (BE). After that and by help of the t-test, a vital factor analysis is performed, in order to determine to leading source of the defective product (BE).

Shainin System Method (SSM)

The Shainin System is a technique that initiated from creating evidences of problem definition by performing several types of comparisons, such as the worst value to the best one. The comparison parameters of this research work are the process, product and design parameters. Each parameter uses 30 data from each group, with the objective of attaining the prime causes of the defective product (with BE fault) by using a t-test with the following conditions:

If the p value is greater than the α value, the alternate hypothesis (H_0) is accepted, that it is not a vital factor (NVF).

If the p value is less than the α value, the alternate hypothesis (H_1) is accepted, that it is a vital factor (VF).

Table 3 summarises the outcomes of the Shainin's System evaluation. The t-test is utilised in the calculation to determine the VF that are the sources of BE defective products.

Table 3. List of factors causing the BE defective product by SSM

S. No.	Cause Factor	Possible Cause	ρ Value	α Value	Finding
1	Ball warping Process	Tenacity	0.472	0.05	NVF
2		Residual Elongation	0.169	0.05	NVF
3	Rope Dyeing Process	Tenacity	0.001	0.05	VF
4		Residual Elongation	0.022	0.05	VF
5	Re-Beaming Process	Tenacity	0.437	0.05	NVF
6		Residual Elongation	0.175	0.05	NVF
7	Sizing Process	Tenacity	0.376	0.05	NVF
8		Residual Elongation	0.145	0.05	NVF

Table 3 shows the results of the Shainin system. It is clearly evident from the table that the tenacity and the residual elongation after rope dyeing is the vital factor that is the main source of the BE defective product. We have determined the vital factor of the BE defective product. The next step is to determine the root cause of the problem by using a CED (cause effect diagram) analysis, as shown in Figure 3.

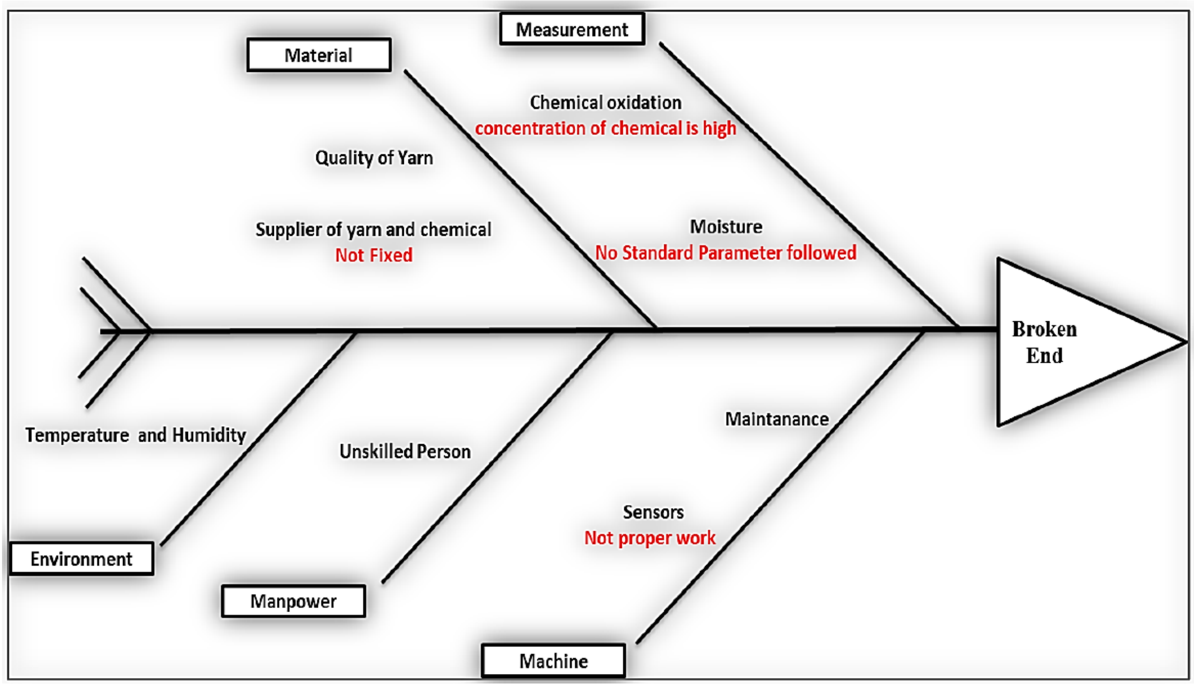


Figure 3. Cause and effect diagram of Broken End (BE)

Improve Phase

The fourth sequential stage of the DMAIC Cycle is the improve phase. In this stage the corrective action for the root cause (that was identified in the analyse phase) is carried out. In this work, a DOE (Design of Experiment) is used in the improvement phase. With the help of a Plan-Do-Check-Act (PDCA) cycle, the "full factorial design" is used to randomly create the run order for each set of treaetments. The experimental resuts are statistically analysed by using analysis of variance at a level of significance of 0.05. After that, the experimental results are interpreted and the optimal combination of factors are set.

PDCA (Plan-Do-Check-Act) Cycle

In a central process, a comparision is drawn between the actual results of an action and a target set point. After that, the noticed difference is mentioned and the corrective measures are adopted if the disparity becomes large. The continual nature of continuous improvement follows this usual definition of control, and is expressed by the PDCA (Plan-Do-Check-Act) cycle, as shown in Figure 4.

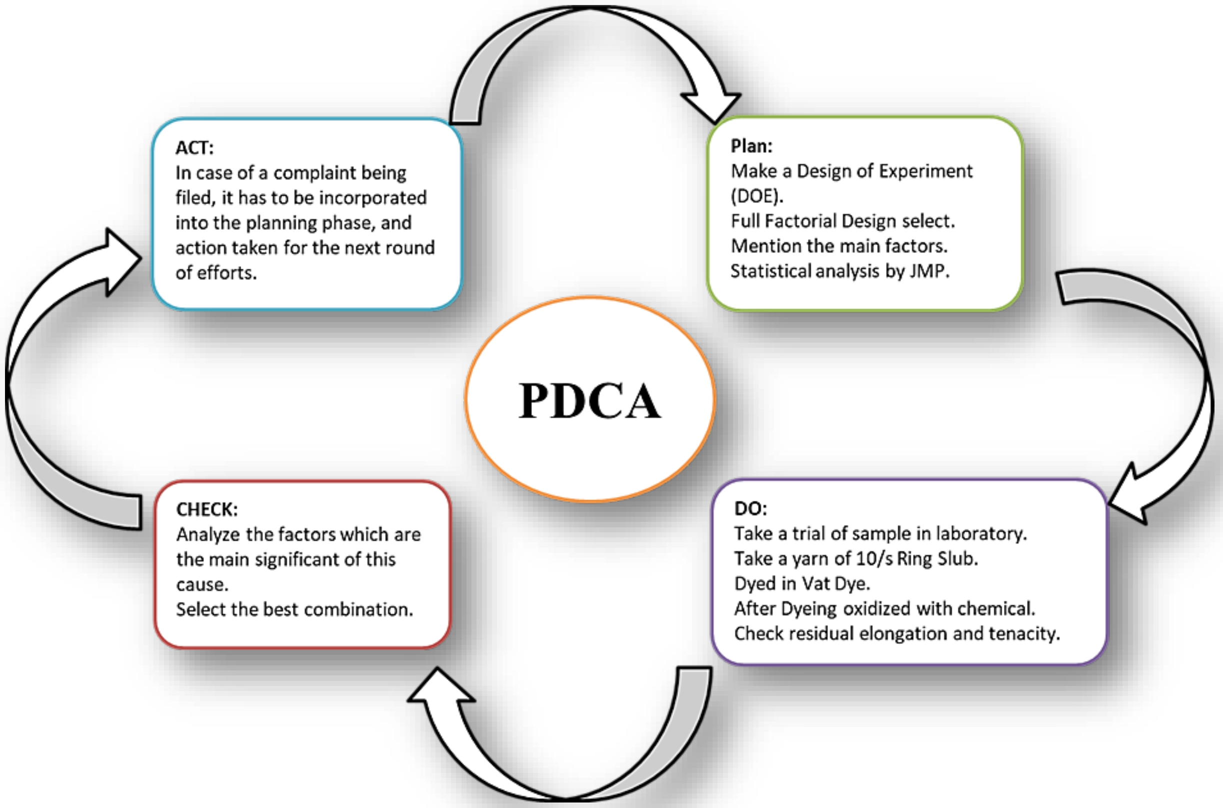


Figure 4. PDCA (Plan-Do-Check-Act) cycle

In the dyeing process, the main factors of yarn rupture during weaving process are shown in Table 4.

Table 4. Low level and high level values of the factors of Broken End defective product

S. No.	Factors	Low Level (-1)	High Level (+1)
1	Hydrogen Peroxide	10	35
2	Formic Acid	5	15
3	Temperature	24	65

The "full factorial design" is used to randomly create a run order for each set of treatments. The results obtained by the experimental were statistically analysed by using the analysis of variance at a level of significance 0.05. Further more, the optimal combination of factors is set for the results obtained from the experiment. Table 5 shows the response values against the different combinations.

Table 5. Response values of factors

S. No.	Pattern	Hydrogen/Oxide	Acid	Temperature	Residual Elongation	Tenacity (RKM)
1	- - -	-1	-1	-1	5.20	12.33
2	- - +	-1	-1	1	4.91	11.80
3	- + -	-1	1	-1	4.91	11.81
4	- + +	-1	1	1	4.88	11.75
5	+ - -	1	-1	-1	4.84	11.61
6	+ - +	1	-1	1	4.78	11.53
7	+ + -	1	1	-1	4.79	11.58
8	+ + +	1	1	1	4.77	11.51

After a response of all combinations of factors, the best combination is acid (10gm), hydrogen peroxide (5gm) and temperature (24 ºC), which enhanced the values of tenacity to 12.26 RKM and the residual elongation to 5.17 percent, as shown in Figure 5.

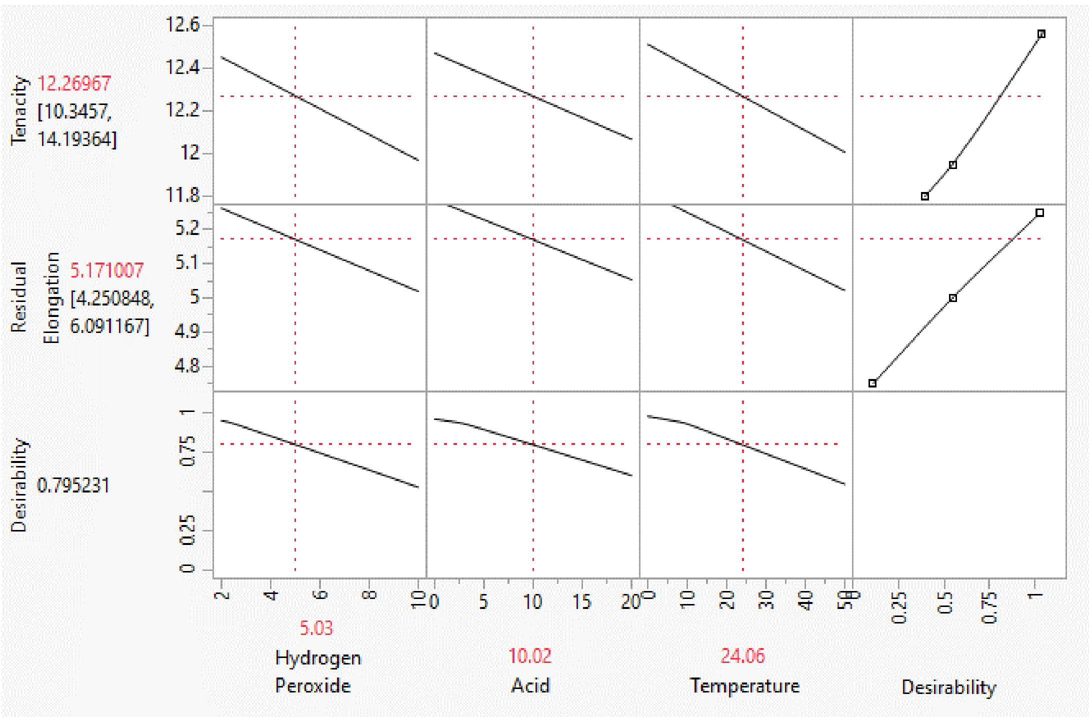


Figure 5. Prediction profiler for cause of defective product

Control Phase

The last step of the Six Sigma method is the control phase, performed in the form of various process control activities, followed by the improvements. İn order to determine the success level of the improvement's implementation, the pareto chart, baseline performance level (Six Sigma) and the four-block diagram needs to be calculated/redrawn again. The control stage, in this study, was carried out by considering the production and the defective products data in the months of December and January, 2020, as shown in Table 6.

Table 6. Defective products in December And January, 2020

Month	Production (metres)	BE	DPU	DPMO	Yield	Zst
December	74218	388	0.002088	2088.44	99.79	4.06
January	89975	470	0.001878	1878.29	99.79	4.06
Average	82096	429	0.001973	1973.29	99.79	4.06

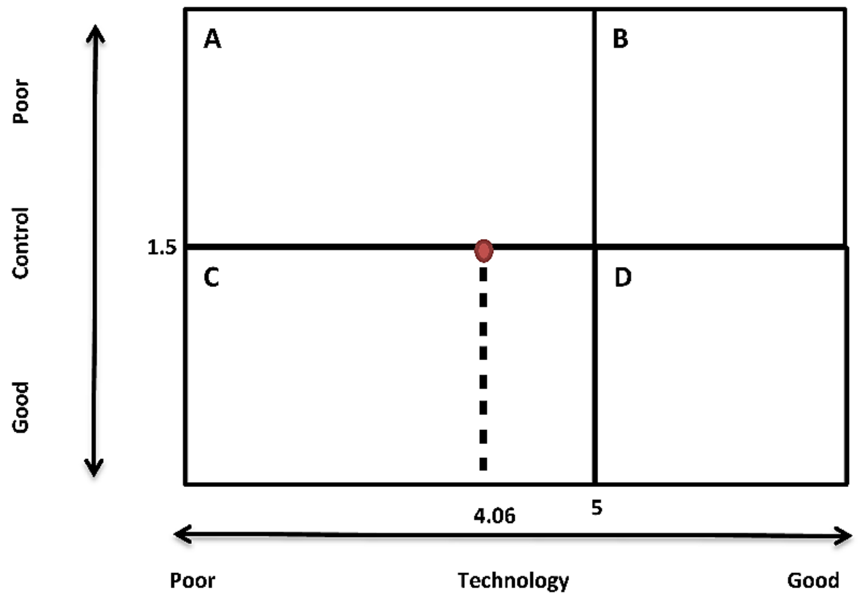
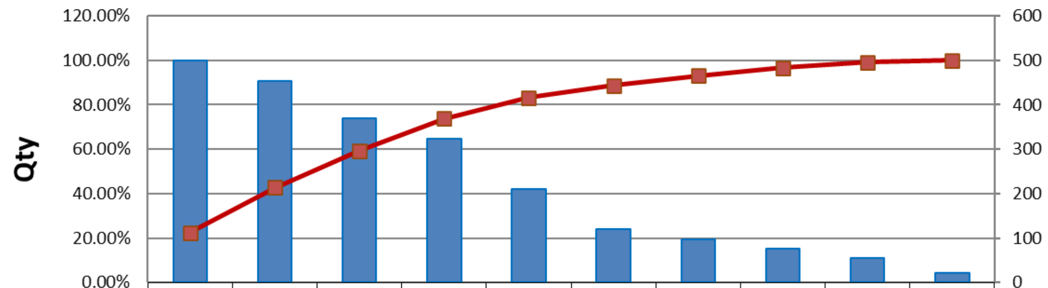


Figure 6. Defective product four block diagram after improvement

RESULTS AND DISCUSSION

DMAIC (define, measure, analyse, improve and control) refers to a data-driven life-cycle approach to Six Sigma projects for the improvement of process; it is a requisite of a company's Six Sigma program. In this study, the main problem of Broken End is rectified in the measure phase. After implementation of DMAIC methodology, the defect magnitude of Broken End is reduced, as shown in Figure 7.



	Broken End	Tight End	Loose End	Short End	Knots	Double End	Finishing Spot	Finishing Crease	Fibre Ball	Color Spot
Rejection %	22.43%	20.32%	16.60%	14.49%	9.47%	5.43%	4.40%	3.45%	2.47%	0.94%
Qty	500	453	370	323	211	121	98	77	55	21
Cummulative %	22.43%	42.75%	59.35%	73.84%	83.31%	88.74%	93.14%	96.59%	99.06%	100.00%

Figure 7. Pareto chart of defect, Dec-Jan 2020

CONCLUSION

Six Sigma can be cast off to improve product quality. Using experimental design to set the optimal condition of the dyeing recipe reduces warp yarn rupture defects, which were found to be a main imperfection. By defining the problem, measuring the process data, analysing the root cause, improving the process and eventually controlling the improved process parameter, it could be concluded that the DMAIC philosophy helped reduced the Broken End (BE) defective products and eventually improved the Sigma level from 3.75 to 4.06. Furthermore, the four-block diagram demonstrated well the situation before and after improvement. In a nutshell, this research has successfully reduced the cost incurred due to defective product.

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