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I. Introduction

Bangladesh is the second vast garments exporter of western fashion brands. Among them, 60% of contracts are with European buyer, and 40% is with American buyer. The textile and clothing industry of Bangladesh has been the foremost driver of the national exports and the GDP for the last 40 years. In 2016-2017 the RMG industry raised US$28.14 billion, which was 80.7% of the total export earnings in exports and 12.36% of the GDP. Because of some weaknesses in textile processes and systems, the textile industry of Bangladesh has been unable to sustain in some sectors. Denim is one of the most prominent and rising parts in Bangladesh RMG. As of now, Bangladesh is the largest exporter of denim products to Europe topping China with a 27% market share, with a 14.20% market share the largest exporters of clothing products to both Europe and the US. Bangladesh is also considered the third largest exporter of denim products in the US after Mexico and China. To improve the performance of its manufacturing processes, the industries are turning towards effective management techniques and quality improvement methodologies such as Six Sigma.

To keep up with the increasing competition various quality management tools such as Six Sigma methodologies are used in different industries. The impact of six sigma has been proved for analyzing and improving the manufacturing problems. Six Sigma methodology aims at developing production processes resulting in less than 3.4 defects per million opportunities[1], [2]. The method requires companies to measure and analyze their business processes and build their business around an understanding of their customers' requirements[3].In Thailand, they applied Six Sigma to reduce defects in denim weaving mill which specializes in rope dyeing process[4]. The focal point of this paper is the application of Six Sigma methodology in reducing faults in Denim weaving industry of Bangladesh. The work consists of a case study of a Denim weaving mill (Shasha Denims Ltd.) facing the problem of fabric production due to defects in the fabric.

II. Objectives

"Six Sigma is a quality program that, when all is said and done, improves your customer's experience, lowers your costs, and builds better leaders." — Jack Welch. Six Sigma at countless firms denotes a measure of quality that strives to achieve near perfection. Six Sigma is a disciplined, data-driven outlook and method whose main objectives are to gain operational excellence as well as customer satisfaction. Its main aim is to eliminating defects in any process – from manufacturing to transactional and from product to service. It also focuses on process improvement and variation reduction. The clear understanding is that Six Sigma's methodologies aim to attain a success rate of 99.9997% or less than 3.4 defects per million opportunities.

III. Methodology

Six Sigma requires process improvement through identifying the problem, primary causes, process redesign and reengineering, and process management by using a five-phase approach known as the DMAIC process.

The define phase focuses on defining the problem and scope, identifying customers and the high impact characteristics and pointing out the work effort of the project team. In the measured phase, the data represent and gather the performance of the current process. The analysis phase focuses on determining the key variables and relating them to the improvement goals. It is the phase where statistical analysis tools and qualitative analysis tools are employed to identify significant causes of variation. At the improve phase, the quality improvement team brainstorms potential

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solutions, prioritize them based on customer requirements, make a selection, and test to see if the result settles the problem. In the control phase, it develops and manages a process considering incorporated sustainable improvements.

a) Define phase

The define phase of the six-sigma method consists of defining the problem, project launch, outcomes, determine project approach and project plan[5]. It finds many complications, we must build the case for why this problem is paramount to address now, does the trouble relate to the product or is it strategically important for the organization. We should find the gap and if a difficulty that is not much important then should not be much enthusiastic about the trouble. In denim production at first yarn selection is done. Then the yarn is checked for faults & imperfection. After that dyeing and it goes for sizing. The mill where we conducted our case study specializes in slasher dyeing system. The sized yarn has to send to the weaving section for fabric weaving. At last finishing, inspection, and grading is done in accordance with the grading method given by the buyer. The process flow of denim production show below

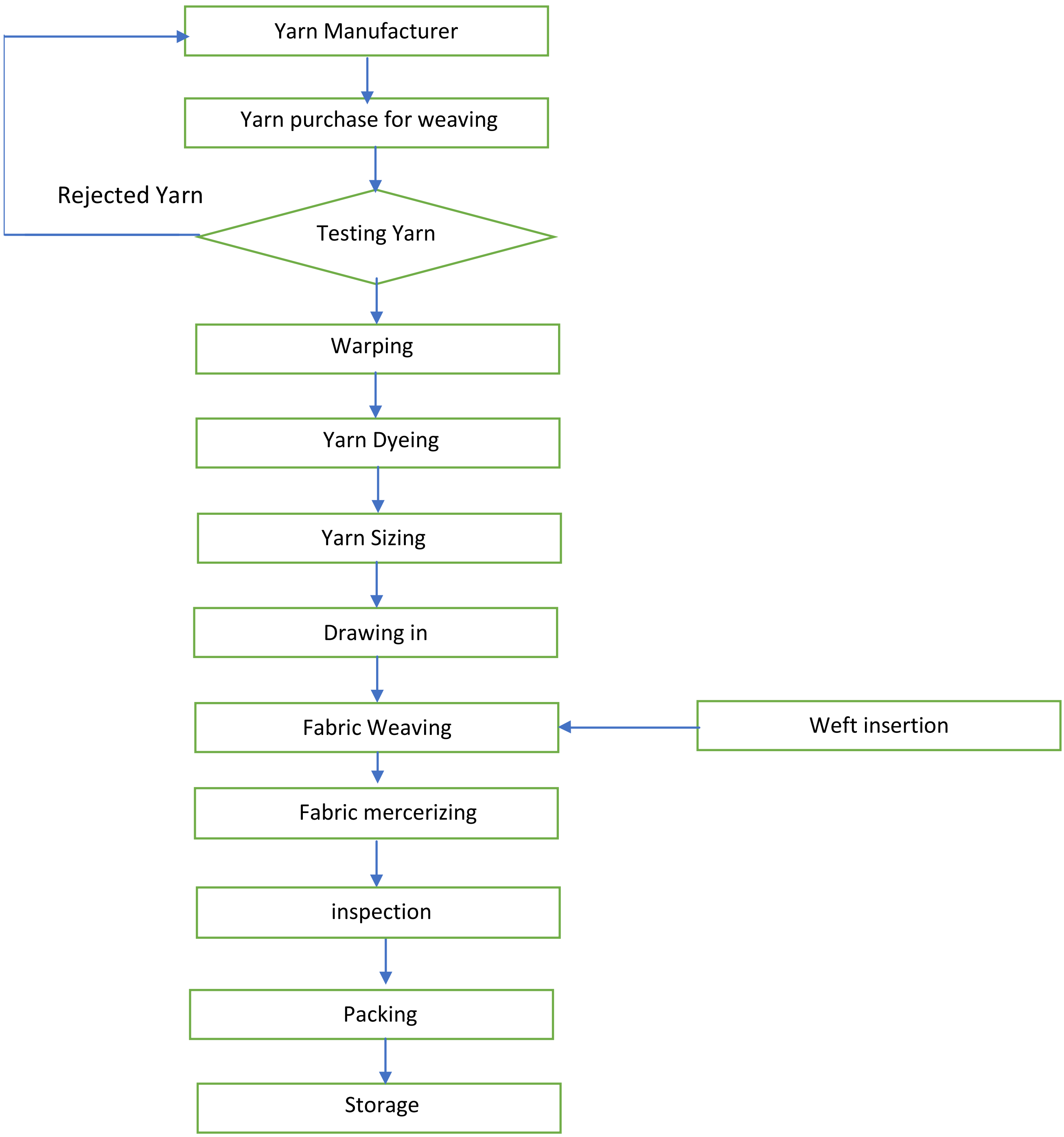

Figure 1: Process flow diagram

b) Measure phase

In the measured phase, it develops theories, confirm the theories with collected data and then identify the root cause of the problem. Then select the severity of the problems by identifying the major and minor problems. Major defects are the defects with the maximum penalty points and are not likely to be accepted by the buyer. Minor defects are the defects that are less severe and have a fair chance of acceptance by the buyer[6].

On the basis of the collected fabric defect data, the sigma level existing in the weaving process was calculated as follows:

Total fabric length inspected = 5,520 m
Total major defects = 196
Total minor defects = 118
Total defects = 314
Defects per unit (DPU) = Total defects/ total length inspected = 314/5520 = 0.057

Hence,

Yield = $e^{-DPU} = e^{-0.057} = 0.9445$
PPM = –ln (yield) × 10,00,000
= –ln (0.9445) × 10,00,000
= 57100

Consulting with the table for sigma level, the calculated existing sigma level now is 3.1.

c) Analyze phase

In the analyze phase, this step includes analyzing preliminary data to evaluate current process performance and capability to identify the main causes of defects or failure. Figure 2 contain the cause and effect diagram. It is easier to separate potential problems and target areas for improvement when a clear and organized way of listing all the causes. After inspecting fabric lots faults were noted down, the reasons and intensity of faults were also noted. The data obtained are presented in Table 1. Total inspected fabric length was 5520 m, total major faults noted were 196 and minor faults were 118.The Pareto analysis of the identified faults show in Figure 3.The Pareto analysis helps to differentiate between the 'vital few' and the 'trivial many': It is clear from Figure 3 that ~81% of the defects in the woven fabrics were being caused by improper weaving machine settings.

Table 1: Defects identified after fabric inspection

Lot no	Fabric length inspected (m)	Major defects	Reason	Minor defects	reason
1	804	21	Weaving m/c faults, Yarn Thickness, Uneven tension, Finishing	11	Faulty weaving, Yarn thickness, Uneven tension, Sizing, Slub, Oil, Drawing in
2	530	23		17	
3	522	25		11	
4	804	19		13	
5	474	21		9	
6	522	25		11	
7	410	16		14	
8	804	23		15	
9	530	23		17	

Figure 2: Cause and effect (Fishbone) diagram

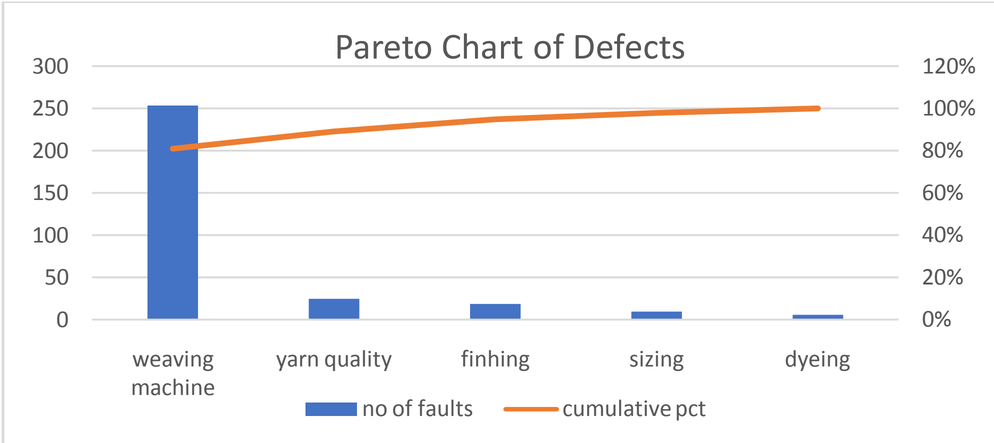

Figure 3: Pareto chart of defects

Source of faults	No. of faults	Percentage	Cumulative %
Weaving machine	254	81%	81%
Yarn quality	25	8%	89%
Finishing	19	6%	95%
Sizing	10	3%	98%
Dyeing	6	2%	100%

d) Improve phase

In the improve phase we target to eliminate the fault of the root cause for which the defect occurs. After that, we implement these improved processes. A risk matrix table where the risk, likelihood of occurrence of problem and impact of the possible problems show in table 2.These problems marked, and possible corrective actions for all the faults were defined. From the Pareto chart, we found the major fault was faulty weaving leading to starting mark, thick and thin place, warp and weft rupture. All the possible rectifications of the faulty weaving explored. All the new-found better results implemented with the consultation of the experts.

Table 2: Risk matrix table

Activity	Risk	Likelihood	Impact	level of risk
Yarn quality	Thick-thin lines	Possible	Major	Extreme
	Slub	Possible	Major	Extreme
Dyeing	Shade variation	Likely	Minor	Low
	Dyeing Patta	Likely	Minor	Low
Sizing	Hard size	Possible	Major	Extreme
	Sizing spot	Likely	Major	Moderate
Weaving machine	Wrong denting	Rare	Major	Extreme
	Starting mark	Likely	Major	Extreme
	Missing and double pick / end	Likely	Moderate	Moderate
	Knot	Likely	Major	Extreme
	Faulty weaving	Likely	Major	Extreme
Finishing	Hole	Likely	Major	Extreme
	Crease mark	Possible	Moderate	Moderate

The expert suggestion was to use easing motion on all the machines. Due to using the easing motion the additional tension on the wrap sheet compensated.The faulty weaving was improved by using better quality yarn and maintaining proper process parameter at the machines. It resulted in eliminating most of the faulty weaving. After that, the starting marks were settled down by upgrading machine settings. Through which we eliminated 90% of starting marks. The problems of double pick drastically reduced by making sure the cutters are working properly. The miss pick problems removed by making sure the filling detector is working properly because they are responsible for the detection of weft yarn. The absence of weft yarns is the reason for missing ends.

For other faults that mentioned in the risk matrix table taken corrective actions show below:

- For all the problems related to yarn quality, better quality yarns used.
- For dyeing faults, soft water is used and rechecked for dirt in the water. Also, better quality dyes and chemicals used.
- For sizing faults, a proper mixture of size ingredients, maintaining right temperature, cleaning size box is done.
- For removing the faults of finishing, proper mercerizing agent used and temperature maintained.
- At last skilled manpower is recruited. Moreover, we arranged a training session for employees.

By eliminating the major defects caused by faulty weaving and other taken improvement measures the sigma level dramatically improved from 3.1 to 3.5 and the company's profit increased.

e) Control phase

In the control phase, a new process is developed and controlled to ensure that all steps taken for the improvements sustained. Statistical process control (SPC) and Failure mode and effect analysis (FMEA) are tools that used in the control phase. Here the FMEA tool was used to identify the potential failure modes, their effects and severity, causes, risk priority number (RPN) and possible preventive actions. In FMEA analysis all the data of the defects that happened in the entire weaving process were gathered and analyzed. The FMEA analysis shows in table 3.

Table 3: FMEA for woven denim fabrics

Issues	Potential Failure	Potential Effect of Failure Mode	S	Potential Cause of Failure Mode	0	D	Rpn	Preventive Action
Yarn	Thick-thin lines	Thread differing in diameter from the surrounding thread	3	irregular let-off, gear wheel teeth worn out or broken	5	5	75	Proper yarn selection
	Slub	Poor appearance	2	Improper yarn selection	1	1	2	Proper yarn selection
	Coarser warp	barre and dense stripes running along the fabric	2	physical properties of fibers, yarm parameters and machine parameter	1	1	2	Better quality yarn selection
Warping	Lot variation	Varying appearance of fabric	1	Several lot yarns co-me from spinng mill	0	0	0	Yarn cone must be tested before Production
Dyeing	Dyeing patta	Stain on fabric	1	Yarn count & tension variation	2	2	4	Proper yarn count & tension
	Shade variation	Difference in depth of color	3	Variation in process	1	1	3	Follow same process parameter
Sizing	Ball formation	Small globularfibrous substanceappearing on fabric surface	2	Entanglement of fibrous substance on the yarn	1	1	2	Less hairy yarn should be used
	Hard size	Yarn breakage	5	Excessive size material & drying temp.	0	0	0	Maintenance of size material & drying temp

Weaving m/c	Wrong denting	Inappropriate weave design	4	Incorrect order of denting	2	2	16	Denting should be done carefully
	Starting mark	Streak on fabric	5	Sudden machine stoppage	14	14	980	Proper machine setting
	Double pick&end	Repping mark	4	Incorrect drawing & cutter malfunction	17	17	1156	Proper drawing & cutter grinding
	knot	small, tightly tangled knotlike masses on fabric	2	Poor skilled worker	3	3	18	Training of worker
	Miss warp&weft	Streak on fabric	5	Malfunction of warp stop motion and FD	11	11	605	Proper functioning of machine
Finishing	Hole	Holes in fabric surface	5	one or more yarns are sufficiently damaged	3	3	45	Better quality yarn
	Crease mark	Curling on fabric surface	2	Improper tension on fabric edge	2	2	8	Maintaining proper tension

After taking the preventive measure, we can notice the reduction of faults in the same amount of fabric. The new-found data shows in table 4

Table 4: Defects identified after fabric re-inspection

Lot no.	Fabric length inspected (m)	Major defects	Reason	Minor defects	Reason
1	804	11	Weaving m/c faults, Yarn Thickness, Uneven tension, Finishing	5	Faulty weaving, Yarn thickness, Uneven tension, Sizing, Slub, Oil, Drawing in
2	530	9		8	
3	522	10		4	
4	804	7		6	
5	474	12		3	
6	522	5		5	
7	410	9		6	
8	804	10		9	
9	530	8		5	

Total fabric length inspected = 5,520 m
Total major defects = 81
Total minor defects = 51
Total defects = 132
Defects per unit (DPU) = Total defects/ total length inspected = 132/5520 = 0.024
Hence, Yield $= e^{-DPU} = e^{-0.024} = 0.9763$
PPM = $-\ln(\text{yield}) \times 10{,}00{,}000$
$= -\ln(0.9763) \times 10{,}00{,}000$
$= 23985$

Consulting with the table for sigma level, the existing sigma level calculated as 3.5

IV. Conclusion

Six-sigma can be used to improve product quality. Using the experimental data, we reduced the defects of denim weaving industry. The main aim was to identify the possible defects and improve an effective solution to these defects. The key recommendation for these problems is

- Weaving machines regularly monitored if there is any problem or not.
- Denting should be done properly.
- Better quality yarn need to be purchased.
- In dyeing and sizing, proper process parameter should be maintained.

- Grinding or polishing of all the cutter blades need to be done on regular basis.

From the study, we can say that, by finding the exact remedies the production of better-quality fabric increased. At the initial stage, the sigma level was 3.1, and after the implementation of the preventive measures, it improved to 3.5 resulting in a higher profit of the company.

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