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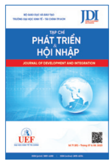

Applying DMAIC Method in Six Sigma to Improve Productivity: A Case Study at a Fabric Manufacturing Company

Nguyen Khac Hieu*, Huynh Thi Mong Ngoc, Nguyen Thi Anh Van
Ho Chi Minh City University of Technology and Education, Vietnam

KEYWORDS

Six Sigma,
DMAIC,
Productivity,
Textile Industry.

ABSTRACT

This study aims to analyse the root causes of fabric creases in a company specialising in Denim production to reduce defect rates and increase productivity. The project team applied Six Sigma and DMAIC method to achieve the research objectives. Based on historical data, crease was the highest defect rate in the define phase. In the measure phase, we use a check sheet and Pareto chart to measure the crease defect rate. Then, we use a fishbone diagram and expert method to analyse the root causes of the crease defect in the analysis phase. In improve phase, we use experts to evaluate the feasibility of the solution and choose the most effective solution. Finally, after applying the solutions, the good product rate increased from 88.44% to 96.26%, surpassing the quality target set by the company of 95%. The solutions also reduced monthly defective fabric products from 6050 to 3046 metres.

1. Introduction

The textile and apparel industry is currently important in the global economy, especially in developing countries, where garment production accounts for many exports. However, along with the rapid development of the market, the requirements for product quality are also becoming more and more stringent (Nguyen et al., 2021). Therefore, quality control has become a significant challenge for textile and apparel enterprises (Islam et al., 2020). In development, the textile and apparel industry faces many challenges in quality control. The complexity of the global supply chain and the rapid technological change require enterprises to adjust and improve their quality control processes continuously. In recent years, the textile and apparel industry has witnessed an increase in applying advanced quality management systems such as Lean Six Sigma to improve production efficiency and minimise product defects (Nguyen & Pham, 2021). This system helps enterprises meet international standards and makes a difference in maintaining consistent quality throughout the production process.

In addition to market challenges, enterprises must compete fiercely, especially in the industrial 4.0 (Nguyen et al., 2024; Van Nguyen et al., 2023). For today's textile industry, maintaining high product quality is critical for businesses to survive and develop. One of the major challenges that fabric manufacturing

*Corresponding author. Email: *hieunk@hcmute.edu.vn*

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companies face is the crease in products. Crease is a defect that affects aesthetics and causes customer dissatisfaction, thereby reducing revenue and competitive advantage of businesses (Nguyen & Tran, 2021). To solve this problem, many companies have applied modern quality management methods, and Six Sigma stands out as a systematic and data-driven approach. Six Sigma focuses on reducing defects in the process and helps improve manufacturing processes through root cause analysis and eliminating variation (Chakraborty & Chuan, 2021). The DMAIC (Define, Measure, Analyse, Improve, Control) process in Six Sigma has effectively reduced wrinkle defects in fabric manufacturing processes (Singh et al., 2020).

Many studies have been related to the theory and development of Six Sigma in different fields (Singh et al., 2020). However, there is a need for more case studies on the development of Six Sigma in emerging countries like Vietnam, especially in the textile industry. For that purpose, this study aims to apply Six Sigma to optimise the production process in a denim manufacturing company in Vietnam. In addition, the study also uses supporting tools such as the Pareto chart, multiplication diagram, and energy analysis to identify, measure, analyse, improve, and control process problems. This study will focus on applying Six Sigma to improve creasing defects in a fabric manufacturing company. The study will analyse the factors affecting crease defects, using statistical analysis tools and proposing improvement measures to enhance product quality. Thereby, the study will help improve production efficiency and contribute to applying Six Sigma in the textile industry. This project will help reduce defects, increase the efficiency of the production process, improve Six Sigma capabilities and reduce production costs. This paper will benefit researchers and practitioners interested in developing Six Sigma in manufacturing.

The rest of this paper is structured as follows: Section 2 presents an overview of the current literature on the development of Six Sigma implementation, mainly focusing on its application in denim fabric manufacturing. Section 3 presents the DMAIC approach and tools used in the study. Section 4 explains the findings of the study and discusses them in depth. Finally, Section 5 provides the paper‘s conclusion, summarising the main issues and highlighting the most basic levels of the research.

2. Literature Review

Six Sigma is a prominent quality management method developed by Motorola in the mid-1980s. This method was born to reduce defects and manufacturing variation, improving product quality and business efficiency. The name “Six Sigma” comes from the statistical term, indicating an extremely low level of defects - only 3.4 defects per million opportunities, equivalent to 99.99966% efficiency (Pyzdek & Keller, 2014). The goal of Six Sigma is to minimise variation in the production process to the maximum extent, thereby ensuring that the output product meets the highest quality standards.

The Six Sigma methodology improves process quality by identifying and eliminating the root causes of errors and minimising variation in production and business processes (Jones & Smith, 2018; Brown et al., 2021). Over time, Six Sigma has become a statistical and project-focused analysis method that promotes higher product and process quality. Today, Six Sigma is widely applied in many fields as a breakthrough strategy to help improve processes and production, allowing companies to apply simple but effective statistical principles and tools to optimise production. Optimise operations (Williams et al., 2020).

For example, according to the study of Smith et al. (2017), Six Sigma was implemented at a small furniture manufacturing company. The DMAIC methodology is applied to identify improvement opportunities and demonstrate potential benefits. Results showed that Six Sigma helped reduce errors by 25%, reduce waste by 13%, and increase sales productivity by 14% in the first year. The study also highlighted challenges in implementing Six Sigma, including poor quality management systems and a need for standard processes (Smith et al., 2017).

Research by Nandakumar et al. (2020) recently successfully applied the DMAIC method to improve production processes at an animal feed manufacturing company in Southern India. The team identified and eliminated process bottlenecks using DMAIC and other tools, such as SIPOC and VSM, thereby improving overall plant performance. Through analysis, research shows that 60% of process activities do not create added value, especially in packaging, leading to an increase in defective products. Results after implementing DMAIC showed significant improvements in productivity and product quality while minimising machine downtime and material waste (Nandakumar et al., 2020). This evidence proves that DMAIC is a powerful and flexible tool

Table 1. DMAIC process tools

Define (D)	Measure (M)	Analyse (A)	Improve (I)	Control (C)
- Project selection - SIPOC (Supplier, Input, Process, Output, Customer) - Value stream mapping (VSM - Voice of customer (VOC)	- Pareto chart - Histogram - Statistical sampling - Control charts - Process performance	- Fishbone diagrams - Pareto charts - Hypothesis testing - Brainstorming	- Benchmarking - Hypothesis testing - Kaizen - Expert method - Line balancing	- Standard operating procedures (SOPs) - Training plan - Process control plans - Project commissioning

that can effectively be applied to process optimisation in many fields.

3. Methodology

In this study, we use the DMAIC (Define, Measure, Analyse, Improve, Control) process in Six Sigma to reduce crease defects in fabric manufacturing. Table 1 shows the tools used in the DMAIC process.

3.1. Define

According to Kumar et al. (2023), the defined phase identifies the objectives of the development actions. These goals are strategic at the macro level in businesses, such as boosting return on investment (ROI) or market share. These objectives can be productivity or operational efficiency at the functional level. In more detail, the objective can be as simple as lowering the defect rate or increasing the number of high-quality output items. SIPOC and VSM are tools often used in the Define phase.

3.2. Measure

The second phase focuses on the measurement of the process using statistical tools. The objective of the measure phase is to determine the requirements that must be met in terms of the essential quality features, create process diagrams for defined inputs and outputs, showing the connection of input elements that might affect output factors at each step of the process, create a list of possible metering systems, identifies places where measuring system errors may occur (Chakraborty & Chuan, 2021). Supporting tools in this phase are flowcharts, cheek Sheets, fishbone diagrams, data collection, etc.

3.3. Analyse

The third phase analyses the process to determine the root causes of the defect. Systems analysis aims to determine how to bridge the gap between the system‘s or process‘s current performance and the desired goal (Kumar et al., 2023). Using statistical tools to analyse the steps of the analytical method: Consider the various sources of fluctuations and the necessary inputs. The analysis objectives are to identify a few key drivers and inputs that have the most impact and test these hypotheses with multivariate analysis. Supporting tools in this phase are cause and effect diagrams and root cause analysis.

3.4. Improve

This phase identifies ways to improve the process. System enhancement entails inventing a way to do the work better, cheaper, and faster. In this phase, the project team can manage and implement new improvement ideas, use project management and other planning and management tools, and use statistical approaches to assess the efficacy of improvements (Nandakumar et al., 2020). The objectives of the improvement phase are to determine how to eliminate the source of the oscillation, explore elemental correlations, optimise major input agents or re-establish critical process parameters. The supporting tool is the design of the experiment (DOE).

3.5. Control

In this final phase, we must evaluate whether the performance objective identified in the previous phase is achieved. The first step is to validate the measurement system to be used. The second step is to establish process capability. The third step is to implement the process. The objective of the control phase is to measure the entire system, check the process‘s long-term viability, and implement process control in conjunction with a control strategy to ensure that problems do not reoccur by regularly monitoring the processes involved (Brown et al., 2021). Check sheets, control plans, potential failure mode, and effects analysis (PFMEA) are supporting tools.

4. Results and Discussion

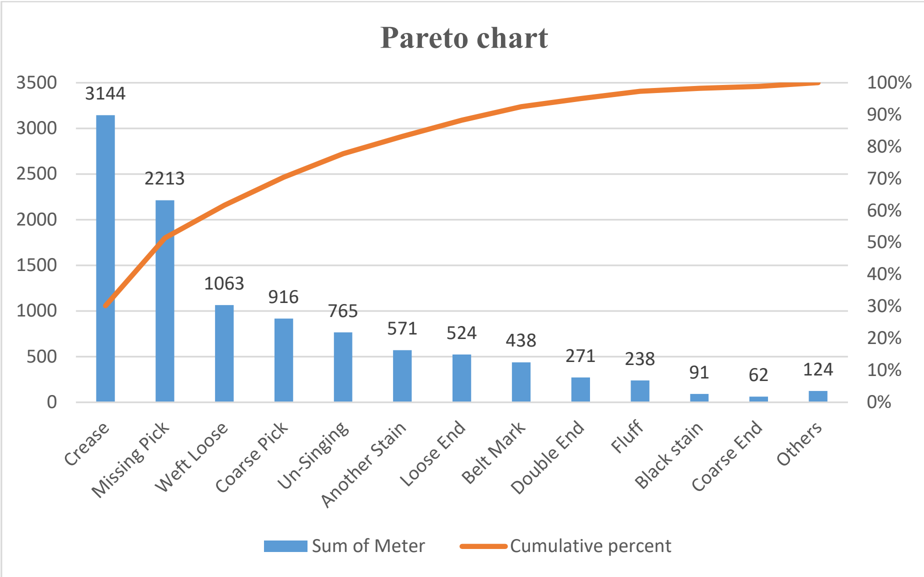

Figure 1. Pareto chart of defects

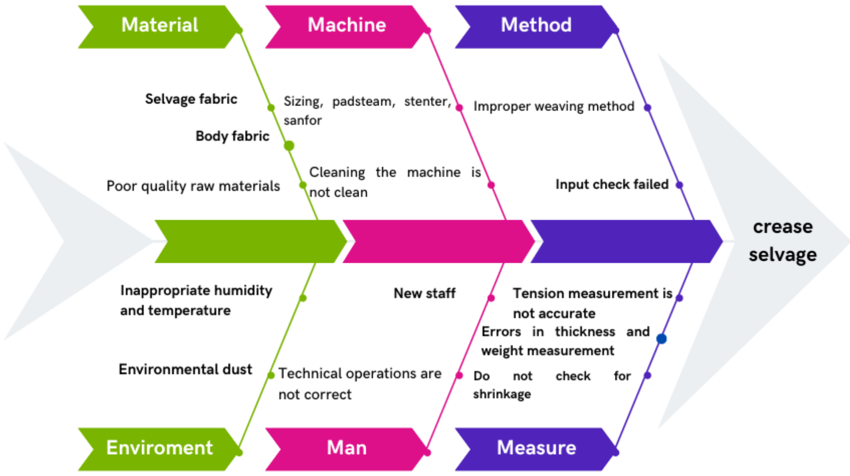

Figure 2. Fishbone diagram analysing the causes of crease defect

4.1. Define

Denim production has four production stages: spinning, warp preparation, weaving, and finishing. According to statistical data from the Quality Management Department, crease defects accounted for 10% during the weaving stage and 34% during the finishing stage, making the finishing stage the most error-prone in the production process. This crease defect causes the production rate of first-class products to be below 90%. Therefore, the company established a project team implementing the DMAIC process to analyse the defect‘s root causes and improve the product‘s productivity. The project‘s objective is to achieve a good product rate of over 95% in Denim production.

4.2. Measure

In this phase, the project team measured the defect rate by collecting data on the number of defects in the production process of denim products during four months from February to April 2024. Then, the project team drew a Pareto chart to identify the most significant defects. As shown in Figure 1, the highest frequency of defects is crease, which has the highest number of metres. The number of meters of crease defects is 3144, accounting for 30% of the total defects.

Table 2. Evaluate the causes of crease defect

5M+1E	Causes	Evaluate							Average score
		Ex1	Ex2	Ex3	Ex4	Ex5	Ex6	Ex7	
Material	Selvage Fabric	2	1	2	1	3	2	2	1.9
	Body fabric	3	2	1	3	1	1	2	1.8
	Poor quality raw material	3	3	4	3	3	4	4	3.4
Environment	Inappropriate humidity and temperature	3	3	3	3	3	3	3	3.0
	Environmental dust	3	3	2	3	2	3	3	2.7
Machine	Sizing machine, Padsteam machine, Sanford machine	4	4	5	4	5	4	4	4.3
	Cleaning the machine is not clean	3	4	3	3	3	4	4	3.4
Man	New staff	2	2	3	2	2	1	2	2.0
	Technical operations are not correct	4	3	5	3	3	4	3	3.6
Method	Improper weaving method	5	5	5	5	5	5	5	5.0
	Input check fails	2	2	3	2	3	2	2	2.3
Measure	Tension measurement is not accurate	3	3	3	3	2	2	3	2.7
	Errors in thickness and weight measurement	2	2	2	2	2	2	2	2.0
	Do not check for shrinkage	3	3	2	4	2	3	4	3.0

Table 3. Summary of solutions for the crease defect

No.	Root causes of crease defect	Solutions	Solution symbol
1	The machine is faulty or damaged	Change the pressing roller on the Sanfor machine.	M1
		Change another sizing shaft on the weaving machine, and change the production line on another weaving machine.	M2
2	The weaving method fails	Change the selvedge structure from 2/2 to 3/3 or 4/3.	P1
		Increase yarn density and reduce yarn count.	P2
3	Improper technical operation	Change the operator	C1
		Conduct training for machine operators and supervisors.	C2

Therefore, the project team will focus on analysing the causes of this defect.

4.3. Analyse

The research team recorded these data after participating in meetings and hearing the opinions and assessments from QC staff and production engineers. Then, we investigated and predicted the causes of crease defects in both the weaving and finishing processes. The result of the analysis is presented in Figure 2.

After identifying the defect and receiving potential cause predictions from QC staff and production engineers, the research team began analysing and identifying the root cause of the defect. We identified the root causes by surveying seven experts (Ex1 to Ex7), including the General Director, Spinning factory director, Warp production factory director, Weaving factory director, Finishing factory director, R&D director and Technical director. We designed a questionnaire and interviewed the experts face to face. The questions are about the causes of the defects. The experts will choose from 1 to 5 (1: Least likely to cause crease defect, 5: Very high probability of causing crease defect). The evaluation results of the seven experts on root causes are presented in Table 2.

Through the total evaluation score in Table 2 of the expert's assessment of the cause of the defect, the authors found the three most likely underlying causes, including The machine being faulty or damaged, The weaving method failing, and Improper technical operation.

4.4. Improve

To propose solutions, the project team had a group discussion to consider potential solutions. Table 3 summarises proposed solutions.

Then, the project team evaluates and chooses the most optimal solution based on the cost and benefit analysis of the solutions. To evaluate the feasibility,

Table 4. Solution Feasibility

Root causes	Solutions	Time	Estimated cost	Feasibility
The machine is faulty or damaged	M1	One month	10.000 USD	Low
	M2	One month	5.000 USD	Low
The weaving method fails	P1	Two weeks	1.600 USD	High
	P2	Two weeks	1.600 USD	High
Improper technical operation	C1	Two weeks	400 USD	High
	C2	Two months	700 USD	Medium

Table 5. Data before and after improvement

Before improvement					After improvement				
Month	Output (m)	Defective output (m)	Defective rate	Good Quality rate	Month	Output (m)	Defective output (m)	Defective rate	Good Quality rate
2	7,880	448	5.69%	94.31%	6	102,000	4080	4.00%	96.00%
3	19,280	2,816	14.61%	85.39%					
4	90,540	13,829	15.27%	84.73%	7	60,800	2011	3.31%	96.69%
5	91,590	7,105	7.76%	92.24%					
Total	209,290	24,198	11.56%	88.44%	Total	162,800	6091	3.74%	96.26%

the project team used criteria to evaluate three levels, including high, medium and low. The high level is that the solution is highly feasible; it meets the requirement to have low investment costs within the company's spending capacity; and the time to improve defects is short. The medium level is that the solution has high investment costs, but it is necessary to improve the quality of products; Implementation time is in the allowable range; The solution does not interrupt the production process during implementation. The low level is that investment costs are too high; Waiting and execution time is long, exceeding the company's production allowance, causing interruptions in the production process while waiting and execution. Details of the feasibility results are presented in Table 4.

We choose the solution that has high or medium feasibility, including changing the selvedge structure from 2/2 to 3/3 or 4/3 (P1), increasing yarn density and reducing yarn count (solution P2), changing to another operator (C1), conducting training for machine operators and supervisors (solution C2). We deployed four solutions simultaneously to compare improvement results and make the most optimal choice for mass production lines.

To test the effectiveness of the solutions, we applied the above four solutions and produced a trial production of 100 meters of fabric to test the solution's effectiveness. The following are the results of each solution. Solution 1 (P1) eliminated the initial crease problem, but this was only a tiny amount, so we could not be 100% sure about the solution's capabilities. Solution 2 (P2) effectively reduces the crease defect rate but causes a yarn tension defect, creating another problem for production. The project team realised this solution was not feasible in mass production. Solution 3 (C1) has progressed in reducing the number of error points per 100m of fabric, but it is not optimal. Implementing this solution depends too much on people, so it will increase costs if put into mass production. So, the author does not prioritise this solution. Solution 4 (C2) reduces the number of error points per 100m of fabric, but it is not optimal. Implementing this solution depends too much on people, so it will increase costs if put into mass production. So, the author does not prioritise this solution.

4.5. Control

After testing four solutions on 100 meters of fabric, we found that the defect rate decreased significantly, so we applied the four solutions to mass production. We monitored and recorded the defect rate from June 2024 to July 2024. The results before and after the improvement are shown in Table 5.

The data in Table 5 shows that the results of the project have achieved the initial set goals of the project; 2 months of project implementation have made the rate of quality of first-class products reach over 95%. The number of defective products has decreased significantly. The defective rate decreased from 11.56% (before improvement) to 3.74% (after improvement). The change can satisfy customer quality requirements. Based on these results, we applied the above solutions to the entire factory, standardised the process and trained workers to perform standard operations after the change.

5. Conclusion

This case study is a successful example of a Six Sigma project in a fabric manufacturing enterprise that significantly improved efficiency. The fabric crease improvement project was carried out according to the DMAIC process. In the definition phase, we defined the project goal to decrease the defect rate below 5%. We used the Pareto chart to display the defect frequency in the measurement phase. In the analysis phase, we applied the expert method and the fishbone diagram to identify the root causes of the defect. In the improvement phase, we proposed improvements in the fabric weaving change work to avoid the root causes of the defect. Finally, in the control phase, we summarised the results before and after the project. The project results showed that the percentage of good products increased from 88.44% to 96.26%, and the monthly defective products decreased from 6050 to 3046 metres. These results helped the company produce quality fabrics with a higher percentage of good products than the quality target of 95%, thereby helping the company have the trust of customers.

Although the project reduced the defect rate in the production process and saved production costs, the project only focused on one defect. Other defects have not been mentioned, and the research period is still short. Therefore, in the future, the company can continue to carry out new projects, apply the DMAIC method to identify new problems and propose solutions to solve these problems to help the production process reduce the company's defect rate and bring significant benefits to the company.

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