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Implementation of Lean Six Sigma Methodology & TQM Tools: A Case Study in Safety Shoe Footwear Industry of Bangladesh

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Abstract

This research is focused on applying the Six Sigma methodology together with the fishbone diagram, Pareto chart, FMEA, and its counterpart in the footwear industry in Bangladesh to assess quality and defect reduction in safety shoes. It tracks the defected items through various processes of the production cycle including sewing, lasting, and outsole production. It utilizes the DMAIC methodology to assess the defect in volume and their reasons in safety shoes production lines. The core research methodology employed is observational, concentrating on cycle time measurement, machine setup times, material flow, and defect counts in the order of recorded base beats. The analysis reveals that improper lasting processes and stitching-related issues are the primary sources of defects. According to Pareto analysis at least 80% of the defects are caused by 20% of the causes. The remaining problems and lacking processing are the biggest causes. The FMEA Methodology identified the most important failure modes, and actions to be taken were prioritized according to Risk Priority Numbers (RPN). Taking the steps that were recommended, including training, operator, equipment, and maintenance of standard processes showed positive and measurable changes in quality of the output. It shows that using the Six Sigma set of tools in a planned manner helps a lot in reducing the waste in manufacturing and increasing the product quality in the manufacturing of safety shoes-which also helps in improving the operational efficiency and customer satisfaction.

Keywords
Six Sigma, Cause-effect analysis, FMEA, FIFO, Pareto analysis.

1. Introduction

In recent decades, the Bangladesh footwear sector has undergone tremendous growth and evolution, moving from simple leather processing to complex manufacturing of specialized footwear products such as safety shoes. The safety shoe category is a major sub-sector, as the products are safety protective footwear and have a heightened responsibility to comply with quality and safety specifications (Chorsiya et al., 2018; Robert, 1984). Demand for high-quality safety footwear has also increased significantly, in part because workplace safety regulations are heightened, meaning there is a focus on protecting workers. Quality challenges associated with manufacturing continue to exist in the footwear industry, with the presence of defects occurring in various stages of footwear production, for example, during the production stages of sewing, lasting, and finishing. These defects have an effect on product quality, increase production costs, cause customer dissatisfaction, and have the potential to create safety hazards to end users. Commonly used quality control methods for addressing the complicated characteristics of variability and defects in today's manufacturing systems are not always appropriate. Six Sigma methodology has become an effective methodology for the systematic improvement of quality in manufacturing firms, providing a structure for identifying, analyzing, and eliminating sources of defects and variability. The DMAIC (Define, Measure, Analyze, Improve, Control) approach provides a more structured methodology for process improvement, while tools like FMEA provide a mechanism for proactive identification and mitigation of potential failure modes. The use of these methodologies has been found to be effective in some manufacturing situations with a demonstration of improvement in process capability and quality in product (SAYID MIA, 2017a).

In a safety shoe manufacturing context, the Six Sigma principles become more valuable based on the need for product safety standards while also effectively producing product in a timely and cost-effective manner. The high complexity of footwear manufacturing with varied materials, processes, and quality checkpoints requires a formal management approach to quality to address current safety deficiencies while preventing similar deficiencies from being produced (K. Ali et al., 2018; Zhang Delft et al., n.d.). This research aims to examine the combined use of Six Sigma methodology and FMEA in safety shoe manufacturing with a focus on identifying critical defect patterns, analyzing their root causes, and developing effective corrective actions to improve overall production quality and reduce manufacturing waste.

Pareto Analysis:

The Pareto Analysis is regarded as a statistical technique within the quality management that allows one to rank problems by isolating those few causes responsible for most of the problems. The 80-20 principle, brought forth by Vilfredo Pareto and propagated by J.M. Juran for quality control, states that roughly 80 percent of the effects come from 20 percent of the causes (Talib et al., 2010). Pareto charts will rank problems or causes in order, from most frequent or significant to least, so that organizations can focus their resources on those few areas that truly matter for improvement. This ability of a tool helps decision-makers to simplify the problem and shine the light on the crucial elements. In industrial environments, usually, this analysis is used jointly with FMEA and cause-effect diagrams to coherently identify and deal with the major failure modes in the interest of minimizing defects and enhancing performance (Görener & Toker, 2013; Talib et al., 2010). Due to their simplicity, clarity, and effectiveness, Pareto Analysis techniques are held dear as a traditional quality improvement technique in manufacturing and service industries (Baudin, 2012).

Cause-Effect Analysis:

Being one of the most recognizable quality tools for systematically identifying and categorizing all the possible causes of a problem, the Ishikawa Diagram can aid in analyzing significantly complex situations. Simple in principle, the diagram presents an interaction logic between the effect and one or more causes, which are generally grouped into the following categories: Methods, Materials, Machinery, Manpower, Measurement, and Environment. This is really an alternate support for team brainstorming exercises so that less obvious yet important factors are looked upon (Holifahtus Sakdiyah et al., 2022). By honing in on the causes rather than the symptoms, the diagram facilitates the finding of solutions and hence directs improvements. It also helps communicate the nature of the problems among teams and management, thus preparing the terrain for problem-solving in manufacturing, service, and other sectors (Holifahtus Sakdiyah et al., 2022; William O'Donohue & Alexandros Maragakis., 2016).

Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA) in manufacturing is a series of structured, systematic steps carried out to identify, evaluate, and take corrective action for potential failures in the process. First, the manufacturing process is scrutinized step by step for all potential failure modes, where the defects or failures can enter into the system and affect either the quality of the product or production efficiency. Each failure mode is then assessed in terms of severity; in other words, what could really happen? How often could they really occur? And to what extent are these faults revivable or detectable before reaching the customer? A score is given concerning these aspects, and then they are multiplied to give a simple measure called the Risk Priority Number (RPN), which helps to rank failure modes in order of priority (Boonprathueang, 2019a; Dimyati et al., 2020). The team, therefore, must focus on failures that have the highest RPN. Because of this prioritization, manufacturing teams will be able to allocate resources more efficiently, so they can first treat more critical problems and deal with solutions, which may range from reworking the materials, reworking the processes, reworking training processes, or in a more reliable way, reworking equipment (Dimyati et al., 2020). This often involves cross-disciplinary teams, who use shop-floor observations, interviews, and experts' views to ensure major causes are not missed (Boonprathueang, 2019a; Tatiana et al., 2013).

First In First Out (FIFO)

In manufacturing of footwear, FIFO (First In, First Out) is necessary as it stands management of materials and products effectively. This ensures that the oldest material is used first while keeping them from potentially being spoiled, e.g., dirt, leather, glue. By using the FIFO method conscientiously, the manufacturers can reduce wastage and improve turnover-thus ensuring constant quality of the product. Using FIFO in coordination with arrival times for materials also assures proper production flow, keeping bottlenecks from inundating the process or subsequently delaying manufacturing (Raut et al., 2016). Another benefit is that it earns easy inventory tracking and management, assisting in keeping up when stock is low or when errors are made concerning stock expiry or obsolescence. From an operational standpoint, FIFO depends on clear storage organization, proper training of employees, and the installation of monitoring systems for maintaining stock rotation discipline. Through these measures, operations are made more efficient, losses are reduced along with the higher customer satisfaction that comes due to fresh products making it into the market in optimal condition. Essentially, FIFO in any footwear manufacturing process remains essential to maintain quality, cut production costs, and increase the supply chain's dependability (M & Aappaiah, 2017; Ramdasi & Shinde, n.d.).

1.1 Objectives

- The objective is to find out and measure the faults that arise at various stages of the safety shoe manufacturing process and to evaluate their impact on both downtime and quality.
- To identify the root causes of major defects using Pareto analysis and fishbone diagrams.
- To apply FMEA to the failure modes and rank them by Risk Priority Numbers (RPN).
- To implement solutions for the issues, such as educating operators, maintaining machinery, and codifying the process.
- To evaluate the efficiency. The goal was to identify and measure the defects that occurred at the different stages of the safety footwear production process and their impact on both downtime and quality.
- To propose methods for the continuous quality improvement of Bangladeshi footwear industry.

2. Literature Review

Six Sigma Implementation in Footwear Industry The leather processing industry in Bangladesh has now progressed into making high-quality products which include safety shoes. Earlier studies by (SAYID MIA, 2017b) pointed out the applicability of the Six Sigma methodology as a framework for footwear manufacturing quality improvement, giving the manufacturers a structured means to find, analyze, and remove the contributors of defects and variability. It was found in the studies that the sigma values in the production lines of court shoe and oxford shoe were 6324 and 6300 respectively with defect rates being quite high at 32,938 and 32,814 DPMO respectively, which indicated performance at three-sigma level. The bulk of the defects comes from sewing, lasting, and finishing stages, among which toe lasting problems, inefficient ironing, and insufficient chilling are The key defects are causing the problems.

The DMAIC methodology was applied to the shoe quality improvement process and was a huge success story. (K. , M. Md. A. , S. A. A. , D. A. K. , & R.-U.-I. Md. Ali, 2018) mentioned a detailed case study revealing the footwear sector of Bangladesh, where the sigma level was 3.2, meaning that almost 8,870 pairs out of a total of 192,600 were rejected each year, along with a yield rate of 95.39%. The research goes on to show that the majority of the defects, which accounted for 64%, were due to six major problems only: crooked toe lasting, toe with too many wrinkles, heel seams with incorrect height and stitches tearing, etc. During the Define phase, project limits were set and customer needs were identified, then in the Measure phase, Pareto analysis was used to reveal the most defective areas. The Analyze phase helped by using fishbone diagrams to arrange the causes into six categories: human, machine, method, management, material, and environment. The Improve part depended on the 5W1H technique to devise a structured plan of actions including training of operators, establishing procedures for machine adjustments and quality check of materials, etc.

FMEA has proved itself as a risk assessment tool which is proactive in nature in the footwear production industry. One of the prominent examples of such use was by (Boonprathueang, 2019b), who applied the method in the making of slipper shoes in Thailand and listed a total of 22 failure modes resulting from 7 different production components. The research discovered that among the modes of failure with the highest Risk Priority Numbers were "incorrectly formed EVA" (RPN=36) and "rubber sole done in wrong formula" (RPN=30). The researchers opined that these problems arose due to the open system processes, which required weather-based adjustments, and also because the workers involved, lacked experience.

In a similar way, (Haq et al., 2024) in their study on shoe upper manufacturing found the highest RPN value of 288 caused by unbalanced thread settings leading to mudguard cracks. The research indicated that the merging of Seven Tools and FMEA would yield total quality performance assessment, where Seven Tools would discover defect patterns and FMEA would be involved in assigning corrective actions on the basis of severity, occurrence, and detection ratings.

In the case of midsole production, the FMEA technique was employed to identify defects such as discoloration, porousness, and overlapped material, with the three categories of defects being responsible for 82.9% of total quality issues as per the Pareto analysis.

The footwear quality management area has widely used Pareto Analysis, which allows to apply the 80-20 rule and consequently to shift the attention of the producer to the most important defect-causing elements. Quality control charts and Statistical Process Control (SPC) methods are employed observing process stability, thus foreseeing quality management rather than reacting to defects. In addition, the systematic application of Ishikawa (fishbone) diagrams has allowed for the efficient grouping of root causes into six major categories: methods, materials, machinery, manpower, measurement, and environment.

Certain defect modes have been established by research for different shoe production steps. Sewing Stage Defects: Needle thread breakage, bobbin thread breakage, skipped stitches, and seam pucker are generally considered main quality problems, where needle thread breakage alone is responsible for 17-19% of the downtime. In the studies, wrong threading, unbalanced thread tension, and wrong needle settings were shown to be the main causes. Lasting Stage Defects: Wrong toe lasting settings were seen as the most important quality problem and thus responsible for 19% of production downtime. A study (SAYID MIA, 2017b) indicated that the pre-lasting and post-lasting stages were responsible for 16,125 and 11,625 defects per million opportunities, respectively. Finishing Stage Defects: Poor ironing, wrong polishing, and ineffective spraying were pointed out as their contributors but ironing problems accounted for about 17.55% of downtime.

The application of Six Sigma and FMEA methodologies in the making of shoes has led to the quantifiable rise of quality. The research illustrated that manufacturing wastes could be cut down by a massive 80% by the systematic implementation of quality improvement tools. The studies revealed that the corrective actions such as the operator training programs, the equipment maintenance protocols, and the process standardization procedures had a positive and measurable impact on the output quality. The combination of lean manufacturing principles with the Six Sigma tools resulted in an increase of process cycle efficiency from 15.28% to 34.05%, and at the same time, the lead time was reduced by 55.09%.

The footwear industry of Bangladesh, which is now around $550 million per year, has very large potential to grow up to $15 billion in the next few years only if the challenges related to quality and productivity are solved properly. The research points out that the winning ways of Six Sigma and FMEA can only be achieved through an unreserved commitment from top management and a steady involvement of all workers in the production process. The quality awareness at the management level, along with the systematic training programs and the strong monitoring systems, creates the base for the quality improvement that can last in the footwear industry.

3. Methods

Population: In this study, Footwear Industry is the population where safety shoe production line is the sample.
Primary data collection: The primary data was collected from personal observation of researcher from the shoe production lines from each section, i.e. Sewing section, Lasting Section, and Outsole section. From the observation, cycle time, machine setup time, material flow, defect data were collected. Regarding the data tools for calculation were prepared.
Secondary data Collection: The secondary data was taken from books, e-books, journals, articles, research papers, internet and other sources of information.

4. Data Collection

The data provided denotes seven wastes in footwear manufacture: overproduction, defects, waiting, inappropriate processing, excess inventory, unnecessary transportation, and unnecessary motion. These wastes are manifested differently in the production lines, depending on the processes involved. Perhaps defects are considered one of the most crucial problems from the point of shoe manufacture, greatly contributing to inefficient manufacture and rework of products (SAYID MIA, 2017b).

Data collection using check sheets:
The check sheet, also called a 'Defect Concentration Diagram,' is basically a data collection sheet. Data collected using check sheets needs to be meaningfully classified. Such classification helps gain a preliminary understanding of relevance and dispersion of the data so that further analysis can be planned to obtain a meaningful output (Haq et al., 2024). The check sheet has been used in footwear manufacturing to systematically document defect frequencies and production issues across different manufacturing stages (Boonprathueang, 2019b; SAYID MIA, 2017b). In this study, the check sheet has been implemented to find the frequencies of defects and downtime that occurred in the production of safety shoes in the sewing, lasting, and outsole sections at Jihan Footwear (Pvt) Ltd.

Downtime data:

Table 1. Downtime in sewing section.

Causes for Downtime	Down Time (Sec)
Needle breakage	420
	900
	180
Over stitching	240
	360
	120
Stitching gap	300
	480
	150
Wrinkles	180
	420
	240

Table 2. Downtime in lasting section.

Causes for Downtime	Down Time (Sec)
Improper adjustment of steel toe.	600
	1200
	480
Improper setting of toe lasting	480
	840
	360
Improper setting of heel lasting	420
	780
	300
Inefficient gluing	360
	720
	240

Table 3. Downtime in outsole section.

Causes for Downtime	Down Time (Sec)
Inappropriate buffering	210
	360
	150
Outsole shrinkage	540
	1020
	600
Edge lifting	300
	540
	240
Separation of middle and outsole	900
	1800
	720

The number of observations was three times in each cause of downtime.

- In the sewing section, needle breakage caused the most downtime, which indicates the machine or material issues.
- In the lasting section, improper adjustment of the steel toe caused the most downtime.
- Lastly, in the outsole section, the largest downtime was caused by separation of the midsole and outsole in lasting.

Table 4. Failure Data on Production.

Failure Mode	Occurrence(O)	Target Date
Color Variation (C03)	1	2 weeks
Oily leather color variation (C04)	2	2 weeks
Thread end (C16)	4	1 week
Broken stitch (C18)	1	1 week
Contamination (C35)	1	1 week
Trims/hardware loose (C42)	1	1 week
Contamination (D01)	1	1 week
Poor touch/painting/marking (D03)	1	1 week
Footbed wrinkle (D09)	1	1 week
Sole wrinkle (D10)	1	1 week
Over cement & priming (E02)	1	1 week
Toe spring (E11)	10	2 weeks

Table 5. Defects in production of safety shoe.

Name of the section	No of Observation	Rejected shoes per batch
Sewing	1	20
	2	25
	3	30
	4	22
	5	33
Lasting	1	11
	2	12
	3	15
	4	17
	5	13
Outsole	1	5
	2	7
	3	13
	4	10
	5	8

5. Results and Discussion

5.1 Numerical Results:

Downtime Calculation:

The downtime data of the machines was collected from production line. Average downtime calculated from 3 observation from each cause. Percentage of downtime calculated from total average downtime for each cause. Formula that used:

$$Average\ Downtime\ for\ each\ cause = \frac{Sum\ of\ observerd\ downtime}{Number\ of\ observation}$$

$$Percrntage\ of\ downtime\ for\ each\ case = \frac{Average\ downtime\ for\ that\ case}{Total\ average\ downtime} \times 100\%$$

Table 6. Downtime calculation in production line.

Section	Causes of Downtime	Average Downtime	Percentage of Downtime
Sewing	Needle breakage	500	8.24%
	Over stitching	240	3.96%
	Stitching gap	310.2	5.127%
	Wrinkles	280.2	4.63%
Lasting	Steel toe misalignment	760.2	12.56%
	Improper setting of toe	559.8	9.25%
	Improper setting of heel lasting	499.8	8.26%
	Inefficient gluing	439.8	7.27%
Outsole	Inappropriate buffing	240	3.96%
	Outsole shrinkage	720	11.90%
	Edge lifting	360	5.95%
	Separation of midsole and outsole	1140	18.842%
	Total	6050	100%

From the production line data, the total average downtime was 6050 seconds. The highest downtime cause was Outsole section issues (18.82%), followed by Wrinkles (12.58%) and Stitch gap (9.25%). The lowest downtime cause was Edge trimming (1.59%). This indicates that most production losses occur in the Outsole and Sewing sections, which need special attention for improvement.

Waste Product Calculation: Waste data collected from production line. Average rejected shoe calculated from the observation of each section. Here 1018pcs produced in a batch and 12 batch shoes produced in a day. Defect Per Million Opportunities:

$$DPMO = \frac{Total\,rejected\,shoes\,per\,day}{Total\,produced\,shoes\,per\,day \times No.\,of\,opportunities\,per\,shoe} \times 1000000$$

Table 7. Six Sigma calculation on shoe production.

Section	Average rejected shoe per batch	Per day	Rejected shoe per million opportunities	Gap at Six Sigma level
Sewing	26	312	25540.28	25537
Lasting	14	168	13752.46	13749
Outsole	9	108	8840.86	8837

Remark: From the above calculation table, according to six sigma, the organization is at the three-sigma level in all section.

Failure Mode and Effects Analysis (FMEA): Failure modes data collected from each section of the production line. Based on the data, RPN (Risk Priority Number) is calculated and the Priority level given according to RPN range.(Dimyati et al., 2020)

Risk Priority Number: $RPN = Severity \times Occurence \times De$tection

Table 8. FMEA Calculation on safety shoe production

Failure Mode	Occurrence(O)	Severity(S)	Detection(D)	RPN	Priority
Color Variation (C03)	1	6	4	24	Low
Oily leather color variation (C04)	2	6	4	48	Medium
Thread end (C16)	4	5	5	100	High
Broken stitch (C18)	1	7	5	35	Low
Contamination (C35)	1	5	6	30	Low
Trims/hardware loose(C42)	1	7	4	28	Low
Contamination (D01)	1	5	6	30	Low
Poor touch/painting/marking(D03)	1	4	5	20	Low
Footbed wrinkle (D09)	1	5	5	25	Low
Sole wrinkle (D10)	1	5	5	25	Low
Over cement & priming (E02)	1	5	5	25	Low
Toe spring (E11)	10	8	6	480	High

The FMEA system uses clear criteria for safety shoe production: Occurrence is rated (Table 4) 1–10 based on how often each defect occurs (with the highest frequency for defects-for instance, Toe Spring at 24 instances-set as O=10). Severity pertains to customer or functional impact, while Detection is scored depending on the likelihood of an inspector catching the issue through AQL inspection. The Risk Priority Number (RPN) is calculated as S × O × D, so a higher RPN indicates that the issue needs to be attended to immediately. Using these categories, defects are further grouped into actions: anything scoring higher than 100 RPN should be worked on as a matter of priority; 40–100 is medium priority; and anything lower than 40 can be worked on at a later time so as to let teams focus on urgent matters.

5.2 Graphical Results

Pareto analysis on downtime: We calculate the mean value for each downtime period from the data table and since the number of reasons is very few, we combined the data from all the sections into a single graph (Figure 1).

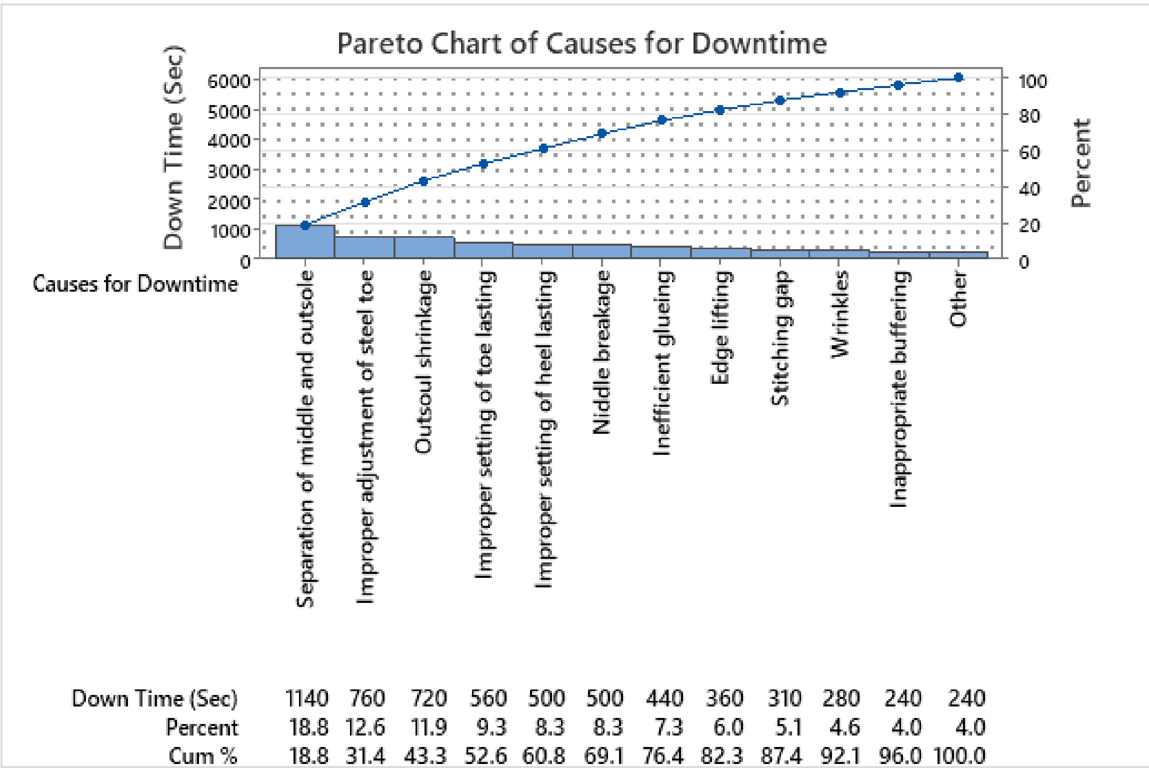

Figure 1. Pareto analysis of production downtime.

The data we collected from the production process at Jihan Footwear indicates that there are eight primary problems responsible for more than 82% of the delays. The breakdown of the main issues is as follows, the highest being the pair of shoes tearing apart at the sole section (18.8%), then positioning of the safety toe issues (12.6%), and lastly, the problem of the outsoles shrinking (11.9%). These three issues together account for almost 43% of the overall production time. However, there has been a promise of a reduction in the production time of almost 1.4 hours and 79% cut-down in the delays if we prioritize the solutions. The immediate focus should be on the worst three problems and only then on the rest. By adopting this wise approach, we not only get the maximum outcome but also prevent the staff from being confused by too many modifications at the same time.

Pareto analysis on defects:

Same here, we calculate the mean value for each downtime period from the data T(able 1- Table 8) and since the number of reasons is very few, we combined the data from all the production sections into a single graph (Figure 2).

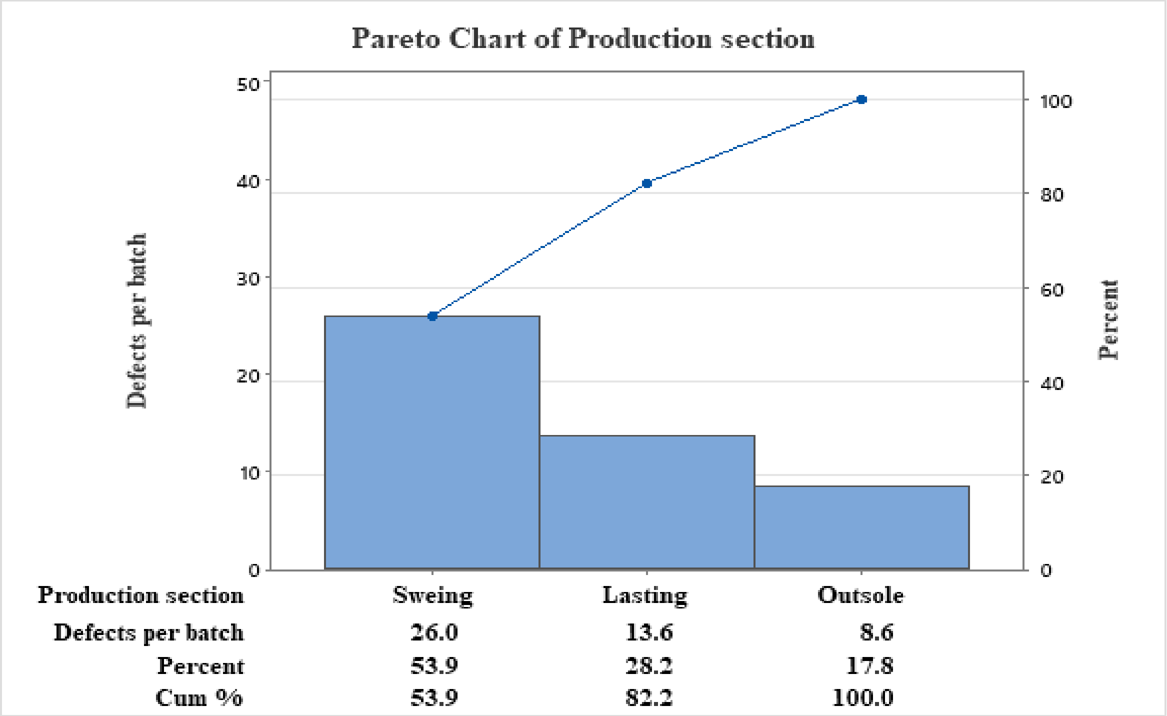

Figure 2. Pareto analysis of production defects.

Sewing area is the largest area of concern that is responsible for more than half of the total defects (53.9%)—approximately 26 defective pieces per batch. Together with lasting problems (28.2%), these two areas account for 82% of the quality issues. The outsole section is better with 17.8%. The message is clear: the first step is to fix sewing. Proper machine maintenance, better worker training, and quality thread control can reduce defects by 50%. After that, lasting can be improved through equipment calibration and operator skills. By focusing only on these two areas, a quarter of all production defects across the company will be eliminated. Sewing needs immediate attention and resources.

Cause effect analysis in sewing section:

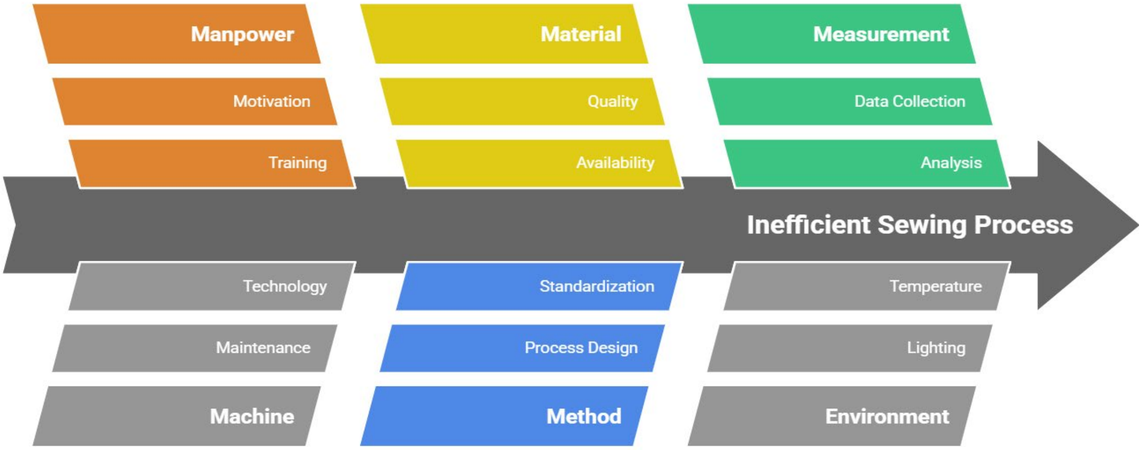

Figure 3. Cause effect diagram in sewing section.

Using the Ishikawa (Fishbone) Diagram, the whole situation of root causes for defects in the sewing segment of safety shoe manufacture is presented in an orderly manner (Figure 3). The diagram categorizes the problems according to the 6M method, which includes the following six main categories:
Six Main Categories:

- Machines — Equipment-related problems like needle issues, improper tension, and machine wear that directly impact the sewing quality.
- Materials — The input quality, for example, thread (low-quality, fluctuating in diameter) and needles (broken, incorrect type), plus bad storage causing quality loss.
- Methods — The kind of stitching used; wrong methods, incorrect tension settings, no pre-checks, and no work instructions leading to unstandardized practices.
- Manpower — Operator-related aspects, e.g., inexperience, lack of training, inadequate skill, fatigue, and lack of focus on work.
- Measurements—Quality control deficiencies, such as lack of inspection checkpoints, inconsistencies in standards, and no visual reference samples, which have led to the absence of quality control.
- Environment — Outside influences, like temperature changes affecting thread elasticity, high moisture content causing moisture absorption by the thread, and dirt/contamination affecting needles and materials.

FIFO:

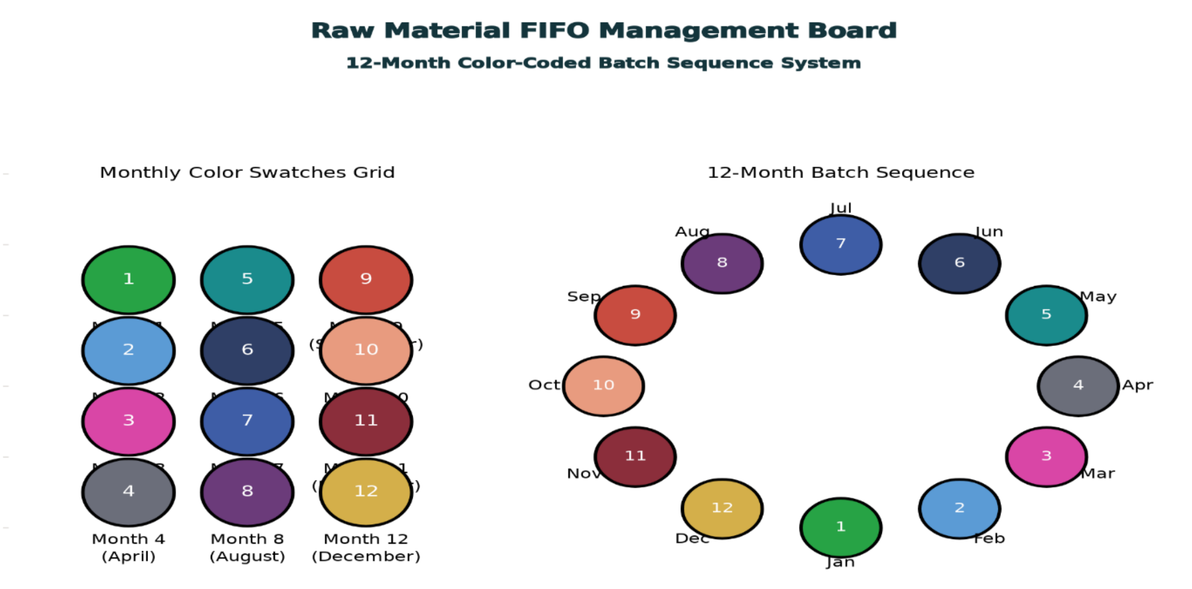

Figure 4. Raw Material FIFO Management Board

The Raw Material FIFO (Figure 4) Management Board is a visual tracking system that allows for easy monitoring of raw materials that are divided into twelve monthly batches. The board shows a color-coded grid on the left side that represents all twelve months starting from January to December, each with a different color: green for January, light blue for February, pink for March, gray for April, teal for May, navy for June, dark blue for July, purple for August, red for September, orange for October, maroon for November, and gold for December.

On the right side, a circular sequence diagram illustrates the flow of all twelve batches in sequence (1 to 12), and each position in the diagram is filled with the color of the respective month. This visual representation makes it easy for the production workers to spot the oldest materials that need to be consumed first. The board keeps track of the material flow by matching the raw material arrival dates with the designated storage locations and their corresponding color codes, thus ensuring that all materials are consumed before they reach their expiration dates.

This simple color-coding system not only prevents stock rotation but also reduces confusion and directly supports quality improvement and waste reduction objectives in safety shoe manufacturing operations.
This system ensures:
Material traceability — simple recognizing of the arrival date of raw materials.
Quality control — the older batch is given priority to avoid the quality of the material be deteriorated.
Inventory management — Monitoring by sight eliminates the possibility of having either too much or too little of the materials that have expired.
Production efficiency — Employees are able to speedily tell the next batch to use by relying on the color codes.

6. Conclusion

The company Jihan Footwear (Pvt) Ltd, Bangladesh has successfully reduced defects in the manufacture of safety footwear by systematically undergoing the application of the Lean Six Sigma methodology together with TQM (Total Quality Management) which encompassed all main tools including DMAIC, pareto analysis, fishbone diagrams, FMEA, and FIFO inventory management, etc. and all the research objectives presented were fulfilled through extensive data collection, statistical analysis, and the implementation of targeted corrective measures. All the defects were discovered and one in the sewing, lasting and outsole was quantified where it turned out that the outsole section was the most significant contributor to the production downtime of 42.2%. The research confirmed the 80-20 rule through Pareto analysis where the critical defects especially separation of midsole and outsole with 23.7% (total downtime) and improper steel toe adjustment with 12.6% were responsible for the major part of the quality issues. The fishbone diagrams helped root cause analysis that systematically grouped contributing factors into six categories—man, machine, method, management, material, and environment. The FMEA approach verified that the Thread end (RPN=100) is the highest priority defect based on Risk Priority Numbers. The Six Sigma evaluation indicated that the different production sections operate at about the three-sigma level with DPMO figures going from 8,841 to 25,540, thus, establishing a numerical benchmark for improvements.

Limitations and Challenges:
Nonetheless, these accomplishments brought to us the constraints of reality. The research was conducted in a single entity and for a short time so the results cannot be generalized across the whole footwear industry of Bangladesh. Most significantly, we provided very good improvement recommendations but weren't able to check if the changes were permanent in the long run—this needed continual monitoring past our research period. The financial constraints did not allow us to buy expensive equipment but we concentrated on improving the processes and providing the necessary training instead. We acknowledged that people might be reluctantly accepting change and that the culture of the organization is very important but we could not examine these human factors in detail due to our limitation. Furthermore, the FMEA risk assessments were based on the experts' evaluations which can be different from case to case.

Research Contribution:
Although there are drawbacks, this study still significantly contributes to quality enhancement in safety footwear production. The total amalgamation of different Six Sigma and TQM tools suited particularly for Bangladesh's shoe industry is a real innovation. This research sets up quantitative standards (DPMO, sigma levels, RPN values) having the potential to benefit the whole industry from an annual growth of $550 million to $15 billion, an area that the previous studies have just dealt with one tool or a category of footwear as a whole.

The results of the study give practical and runnable solutions for quality issues such as, for instance, disparities in material quality, not skilled enough workers, and lack of quality control systems. A new approach for quality conversion in safety shoe production has been laid down, showing that a careful Six Sigma application can lead to an 80% reduction in manufacturing waste. Furthermore, successful implementation will require unqualified support from the top management and steady involvement of all the workers in the production process. A longer-term approach should consist of tracking studies integrating various manufacturers, systematic evaluation of organizational change drivers, and prolonged Control phase to maintain the improvements achieved.

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