Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/BA08.20250198
Published: December 20, 2025

Improving Sigma Level in Wet Blue Leather Processing: Context of Bangladesh Tannery Industry

Tanvirul Islam
M.Sc. in Occupational and Process Safety (Ongoing)
Chemical Engineering Department
Bangladesh University of Science and Technology
B.Sc. in Industrial and Production Engineering
Mechanical and Production Engineering Department
Ahsanullah University of Science & Technology
Dhaka, Bangladesh
ttanvir35@gmail.com

Alfi Shahriar
Senior Executive, Supply Chain Planning (P&G and AstraZeneca Bangladesh)
MGH Group
B.Sc. in Industrial and Production Engineering
Mechanical and Production Engineering Department
Ahsanullah University of Science & Technology
Dhaka, Bangladesh
shahriar.alfi@outlook.com

Md. Shadman Hossain
Executive, Environment, Health and Safety
American and Efird Bd Ltd.
B.Sc. in Industrial and Production Engineering
Mechanical and Production Engineering Department
Ahsanullah University of Science & Technology
Dhaka, Bangladesh
Sadmansifat99@gmail.com

Abstract

The expansion of economic growth in Bangladesh results in making the leather industry an emerging foreign exchange earner. Although the supply of raw skin is high and the availability of labor is cheap, the industry is not showing it's full capacity within which it can perform. It happens due to non-structured and less productivity based production system. This study will observe the problem by focusing on a tannery which is situated in BSCIC in Savar that works with Wet-Blue Leather. The general objective of this study is to develop a continuous quality improvement model and combine Lean and Six Sigma concepts to reduce defects and increase the sigma level. The study is comprised of primary and scondary data by using Snowball sampling. The primary data includes, process mapping, defect types, cause and effects, as well as secondary data includes, firm records, defect prevalence and lead times. It constructs DMAIC structure (Define, Measure, Analyze, Improve, Control) with Lean tools such as, SIPOC, Value Stream

Mapping, Pareto analysis, Ishikawa diagram and Control Charts. The finding shows that the causes of defects are mainly shortage of manpower, equipment, raw material, improper technique and process, lack of organizational practices. Therefore, the implementation of the systematic and continuous improvement framework raised sigma level from 1.82 to 1.98 and also proposed a future Value Stream Mapping. Although the improvement isn't large enough, it will pave the way to create a great practice in the tannery industry.

Keywords
Lean Six Sigma, DMAIC, VSM, Productivity, Bangladesh leather Industry.

1. Introduction
The leather industry in Bangladesh plays a crucial role in the country's economy, significantly contributing to exports and employment. Despite the availability of abundant raw materials and low labor costs, the sector has faced challenges in achieving high-quality standards. These challenges are particularly prominent in the wet blue leather processing stage, where defects can lead to substantial product quality issues and operational inefficiencies. Many tanneries in Bangladesh still lack effective quality control measures, leading to increased waste and subpar product standards. Addressing these issues is essential for improving the industry's competitiveness on the global stage (Swarna & Sayid Mia, 2018)**.** To improve product quality and reduce defects, this study focuses on enhancing the sigma level in the wet blue leather processing stage by integrating Lean and Six Sigma methodologies on a studied company. Lean aims to eliminate waste and inefficiencies, while Six Sigma targets the reduction of process variation. When combined, these methodologies offer a robust framework for improving both process performance and product quality. Several studies, including those by Jadhav et al. (2015), have demonstrated the effectiveness of Six Sigma in reducing process defects and improving overall quality in manufacturing environments. Similarly, the application of Lean tools has been shown to significantly improve productivity and quality in the leather industry in Bangladesh (Swarna & Sayid Mia, 2018). Furthermore, Mollik (2022) discusses the ongoing challenges faced by the Bangladeshi leather industry, particularly the lack of quality management practices and the sector's struggles to meet international quality standards.

This research utilizes the **DMAIC (Define, Measure, Analyze, Improve, Control)** model, a core component of the Lean Six Sigma framework, to identify and address the root causes of defects in the wet blue leather processing stage. By applying this systematic approach, the study aims to reduce defects, increase sigma level, improve process efficiency, and enhance the overall quality of leather products produced in that company which will effect the production of leather in Bangladesh, thereby increasing the sector's global competitiveness.

2. Literature review
The leather industry in Bangladesh faces significant challenges in terms of productivity and quality, particularly in the wet blue leather processing stage, where defects are common. Lean and Six Sigma, when integrated into Lean Six Sigma (LSS), offer a powerful framework to address these inefficiencies and improve product quality. LSS combines Lean's focus on waste reduction and Six Sigma's emphasis on reducing process variation, which has been shown to enhance operational performance across various industries (H,.2021). For the leather industry, integrating these methodologies provides an opportunity to improve the sigma level by systematically eliminating waste and variation. Additionally, Total Quality Management (TQM), which emphasizes long-term quality improvements through employee involvement, supplier collaboration, and process optimization, can complement LSS by fostering a holistic approach to quality management (Permana et al., 2021). In Bangladesh's leather sector, applying Lean tools like Value Stream Mapping (VSM), Kaizen, and 5S can streamline operations, reduce cycle times, and eliminate non-value-adding activities, as demonstrated in the case study by Swarna and Sayid Mia (2018). These Lean tools, when combined with Six Sigma, are effective in addressing quality defects and ensuring consistent product quality. Furthermore, quality control tools such as Pareto analysis, Ishikawa diagrams, and control charts, as discussed by Ezawa et al. (2017), are essential for identifying and resolving defects by pinpointing their root causes. These tools, integrated with Six Sigma's data-driven approach, can be used to tackle issues in the wet blue leather processing stage. Khan et al. (2019) emphasize that continuous improvement techniques, including Lean and Six Sigma, lead to enhanced efficiency, reduced defects, and better customer satisfaction. For the leather industry in Bangladesh, adopting LSS methodologies could significantly improve product quality, reduce defects, and enhance competitiveness in global markets, thus addressing the ongoing challenges identified by Rahman (2022).

Therefore, the literature demonstrates that Lean Six Sigma, Total Quality Management, and quality control tools offer substantial benefits for improving the efficiency and quality of production processes, particularly in the leather industry. Lean tools for waste reduction, Six Sigma tools for variation reduction, and TQM principles for continuous improvement create a comprehensive framework for enhancing operational performance and product quality. Studies by Swarna & Sayid Mia (2018) and H. (2021) show the effectiveness of LSS in manufacturing, while Permana et al. (2021) illustrate how TQM can reinforce this approach. Furthermore, the use of quality control tools, as demonstrated by Ezawa et al. (2017), provides the necessary diagnostic capabilities to identify and address defects, making them integral to improving the wet blue leather processing stage. Together, these methodologies can help Bangladesh's leather industry reduce defects, improve sigma levels, and ultimately strengthen its global competitiveness.

3. Model Formulation

The model integrates data collection from both primary and secondary sources, followed by the application of Lean Six Sigma tools such as Value Stream Mapping (VSM), Pareto Analysis, and the DMAIC (Define, Measure, Analyze, Improve, Control) framework(Shown in Figure 1).

3.1 Data Collection

Data collection for this study was carried out through both primary and secondary sources to ensure a comprehensive understanding of the tannery's operational processes and existing quality issues. Primary data was collected through direct observations of the production process and semi-structured interviews with key personnel, including production managers, quality control staff, and workers. These observations focused on understanding the flow of the production process, identifying defect types, and documenting inefficiencies in the wet blue leather processing stages. Semi-structured interviews were conducted to gather qualitative data on the causes of defects and quality issues as perceived by the staff. This primary data collection helped identify specific defect types that significantly affect the wet blue leather quality

Secondary data was gathered from various sources, including company records, production reports, quality control documentation, and related literature. The company's historical data on defects, production volume, and process efficiency was analyzed to identify trends and recurring quality issues. Secondary data helped establish baseline sigma levels and evaluate the overall effectiveness of the current processes in place at the tannery.

3.2 Lean Six Sigma Tools

Several Lean Six Sigma (LSS) tools were employed in this study to analyze and improve the wet blue leather processing stage. These tools, including Data Analysis Methods, Value Stream Mapping (VSM), and Pareto Analysis, were crucial for identifying inefficiencies, eliminating waste, and reducing defects in the production process.

3.2.1 Sigma Level

The Defects Per Million Opportunities (DPMO) metric was used to calculate the current sigma level of the process, which served as a benchmark for improvement. This data also helped in identifying the frequency of various defects and their impact on product quality, guiding the application of targeted improvements. The data analysis provided the foundation for all subsequent analysis and improvement actions

DPMO= $\frac{Total\ Defects}{Number\ of\ Units \times Opportunities\ per\ Unit} \times 1000{,}000$ (Timans et al., 2012).

3.2.2 Value Stream Mapping

Value Stream Mapping (VSM) is a Lean tool used to visually represent the flow of materials and information within the production process. The current state of the wet blue leather processing was mapped to identify value-added and non-value-added activities. This tool helped visualize the entire process, from raw material input to finished product, allowing us to pinpoint inefficiencies such as bottlenecks, delays, and excess inventory. By mapping the production process, we could identify opportunities for waste reduction and process improvement. In addition to the current state map, a Future State Value Stream Map (FVSM) was created to design an optimized process flow. This future state map highlighted areas for improvement, such as reducing cycle times, improving material handling, and eliminating non-value-adding activities. The FVSM aimed to reduce waste, streamline processes, and enhance product quality by improving the flow of materials and information (Swarna & Sayid Mia, 2018).

3.2.3 Pareto Analysis

Pareto Analysis, based on the Pareto principle (80/20 rule), was employed to prioritize defects by their frequency and impact on overall quality. This tool helped identify the most critical defects in the wet blue leather process. By analyzing the occurrence of these defects, we focused on the few critical issues that contributed to the majority of quality problems. A Pareto chart was constructed to visually represent the distribution of defects, allowing us to target the most significant problems. By addressing these primary defects, the research aimed to achieve a substantial reduction in defects and waste, improving both efficiency and product quality. Pareto Analysis thus served as an essential tool for identifying where to focus improvement efforts for maximum impact on the wet blue leather production process (Khan et al., 2019).

3.3 DMAIC Formulation

The DMAIC (Define, Measure, Analyze, Improve, Control) methodology, a cornerstone of Six Sigma, was applied to guide the research process and systematically improve the sigma level of the wet blue leather processing. Each phase of the DMAIC model was implemented as follows(Shown in Figure 1):

- **Define**: The Define phase involved outlining the scope of the research, identifying the problem areas, and setting clear objectives for quality improvement. Key objectives included increasing the sigma level, reducing defect rates, and improving overall product quality. A SIPOC (Supplier, Input, Process, Output, Customer) diagram was used to define the boundaries of the process and identify the key stakeholders involved **(**Rahman, 2022).
-
- **Measure:** The Measure phase focused on collecting data related to the current sigma level, defect rates, and process performance. Using historical production and quality data, the existing VSM was created, the sigma level was calculated, and the current state of the production process was measured against quality standards. The DPMO (Defects Per Million Opportunities) metric was used to quantify defects and assess the process's ability to produce defect-free products.

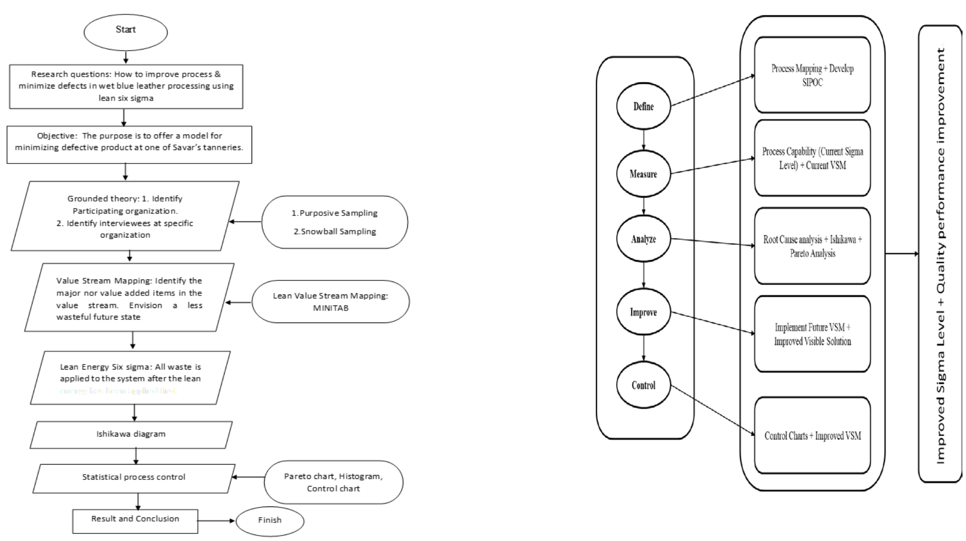

Figure 1. Flowchart of research and formulation of DMAIC.(Source:Authors)

- **Analyze:** The Analyze phase involved identifying the root causes of defects using tools such as Pareto Analysis and Fishbone diagrams. The defects were categorized, and their underlying causes were explored to determine whether they stemmed from man, machine, material, or method factors. This phase helped pinpoint specific areas in the wet blue leather process that required attention.
- **Improve:** During the Improve phase, solutions were developed to address the root causes identified in the Analyze phase. Various process improvements were implemented, such as standardizing procedures,improving training for workers, and optimizing machine settings to reduce defects. A Future State

Value Stream Map (FVSM) was used to design a more efficient process flow with reduced cycle times and waste.

- **Control:** The Control phase focused on maintaining the improvements by establishing a proposed model which includes monitoring key performance indicators (KPIs) and implementing ongoing quality checks. Control charts were used to track the performance of the wet blue leather process, ensuring that improvements were sustained over time. The final sigma level was recalculated after the improvements were implemented to measure the success of the interventions.

4. Model Implementation

4.1 Define

The "Define" phase of the DMAIC methodology focused on understanding the problem and outlining the improvement goals. This phase involved identifying the Wet Leather process, its issues, and defining the Process objectives.

4.1.1 SIPOC Diagram

The SIPOC diagram (Supplier, Input, Process, Output, Customer) helped identify the key elements of the process. For the wet blue leather process, raw materials such as hides from suppliers were processed through steps like soaking, liming, and chroming. The SIPOC diagram identified how variability in suppliers, inputs, processes, outputs, or customers affected quality. The process was affected by the quality of raw materials and the efficiency of the steps.The SIPOC diagram is shown in Table 1 below.

Table 1. SIPOC diagram

Supplier	**Input**	**Process**	**Output**	**Customer**
Raw Material Supplier	Raw skin	Soaking	Salt free sized hide	Local Crust Leather Manufacturer, Outside Dhaka
Salt Supplier	Salt			
Chemical Supplier	Chemical	Liming	Dehaired hide	
		Chrome Tanning	Wet blue	

4.1.2 Process Mapping

Process mapping (shown in Figure 2) was used to visually represent the flow of activities in Wet Blue Leather Processing. It identified the stages where defects and waste occurred. In this case, the process was broken down into different stages in Wet Blue Leather Processing. Mapping the process highlighted inefficiencies like excessive inventory, waiting times, and unnecessary steps, which contributed to defects such as flay cuts and gauge marks.

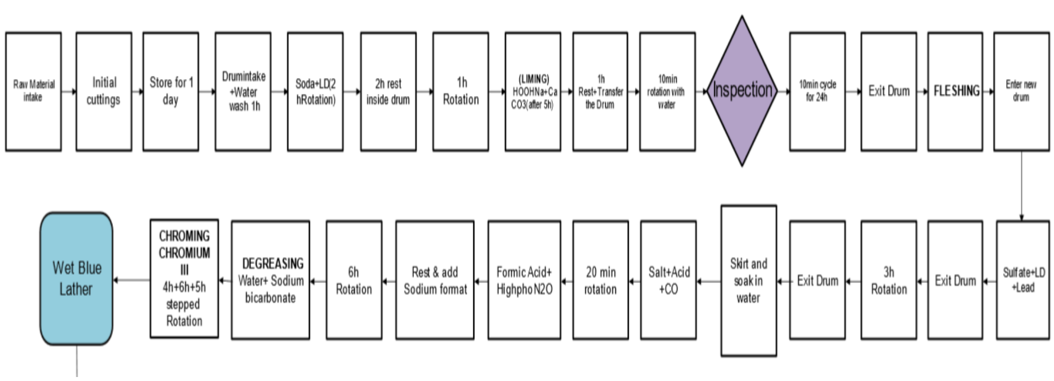

Figure 2. Wet Blue Leather Processing flow chart. (Source: Company data)

4.2 Measure

At this stage, the percentage of defects, existing Defects per Million Opportunities (DPMO), and Sigma Level of the chosen product were calculated in order to comprehend the current system situation. Using the lean tool VSM, the current state (baseline) of the process is determined. In order to identify critical defects using a Pareto chart, information regarding defects on the finishing stage and their frequency of occurrence is compiled. As part of the measure phase of the Lean Six Sigma methodology, data was collected to determine the size and nature of the existing problems. The defect records for the previous six months, from January 2022 to June 2022, at the completion stage were collected as shown in Table 2.

Table 2. Number of non-conformities

month	Production Unit	No of Defects
january,2022	23302	8062
February,2022	30102	10415
March,2022	24423	8450
April,2022	26678	9231
May,2022	23777	8227
June,2022	24132	8350
	152415	52735

4.2.1 sigma Level Calculation

To estimate the capability of a process to produce defect-free products, one must define and quantify the defects per million opportunities (DPMO). The existing sigma level is computed using the above information.

$$DPMO=\frac{52,735}{1,52,415\times 5}\times 1000,000$$

DPMO= 69,200

For this DPMO, the Sigma Level= 1.82

Sigma level, also known as process sigma, is a measure of process capability, the higher the level, the more capable the process.

4.2.2 Current Value Stream Mapping

In the value stream mapping shown below in Figure 3, the primary processes are listed, and the process flowchart identifies the activities that add value to the product and those that do not. The process flowchart reveals that sizing, trimming, soaking, liming, fleshing, de-liming, bating, degreasing, chroming, pilling, summing, wet shaving and thickness adjustment, wet trimming, and re-chroming are value-adding steps. The process map identifies the non-value-adding activities as receiving and storing raw materials, selecting raw materials, receiving for re-tanning, inspection, thickness check, area measurement, packing, and moving to the supply station. The model depicts a total cycle time of 79.5 hours and a total lead time of (108+4) =112 days. Significant non-value-adding activities observed in the current VSM include high raw material inventory, waiting between each process stage or work in process inventory, and unnecessary process.

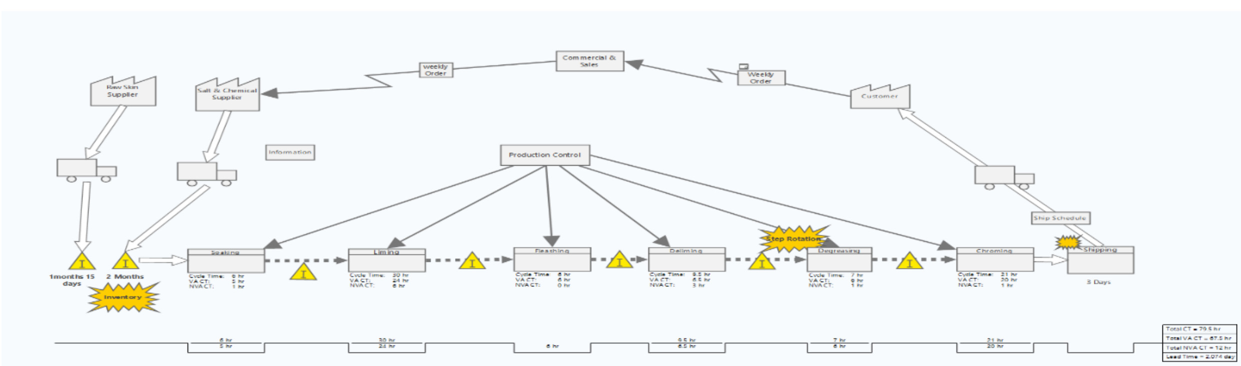

Figure 3. Current value stream mapping. (Source: company data)

4.3 Analyze

The principal categories of flaws were detected during the measure phase, and the objective of this phase is to identify all of their probable causes. Lean problem solving at the analysis phase, six sigma techniques were utilized, including the cause-effect diagram and Pareto diagram. To identify the primary sources of the flaws and their corresponding solutions. The type of defect observed is shown in Table 3 and it's corresponding pareto chart is shown in Figure 4.

Table 3. Types of defects in observed wet Blue Leather Process. (Source: company data)

Defects	Frequency	Percent Defect	Cumulative defects
Flay cut	218	22.9%	22.95%
Gouge Mark	174	18.3%	41.26%
Scratch	155	16.3%	57.58%
Corduroying	120	12.6%	70.21%
Scar	88	9.3%	79.47%
Putrefication	52	5.5%	84.95%
Cockle	49	5.2%	90.11%
Poor Pattern	36	3.8%	93.89%
Machine Defects	26	2.7%	96.63%
veniness	21	2.2%	98.84%
Tick Hole	8	0.8%	99.68%
Wound	3	0.3%	100.00%

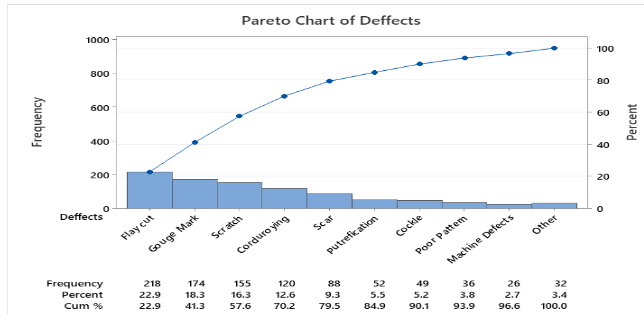

Figure 4. Pareto chart

The Figure 5 below illustrates which leather product flaws are most serious. And using the Pareto Chart, several flaws were uncovered. This consists of a Flay Cut, a Gauge Mark, and a Scratch. The above-mentioned three problems account for 57.6% of the overall proportion of defects. According to the Pareto Analysis, Flay Cut is the most prevalent defect kind, occurring 22.9% of the time. Among other sorts of defects, Gauge Mark accounts for 18.3% and Looseness for 16.4%. Therefore, these three categories of flaws account for 57.6% of the total number of flaws found in finished leather. In this phase, a Cause-and-Effect diagram is utilized to evaluate the fundamental causes of the three basic categories of defects. Also, the Ishikawa Diagram below shows the root and contributing causes for two of the most significant defects such as, Flay Cut and Gauge Mark with respect to the 4M perspective.

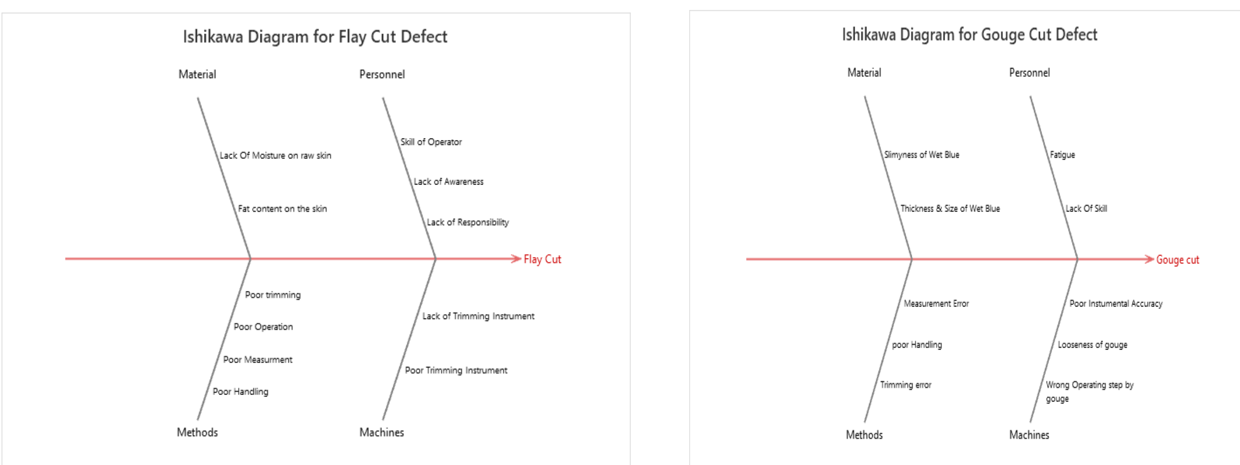

Figure 5. Cause and effect diagram for Flay cut and Gauge mark defect.

4.4 Improve

The goal is to come up with a workable solution to the issue that the work is intended to solve on the Improve phase of the DMAIC model. Improvement was attained using future state VSM and the proposed model solution, and critical root causes were discovered using the Cause-and-Effect Diagram to help focus on the most impactful solutions. Here, The improvement plan addresses key areas impacting leather quality, focusing on four main categories**: Man, Machine, Method, and Material**. For **Man**, the plan included ongoing training, changing work sections, and scheduled breaks to combat lack of skill and fatigue. In the **Machine** area, solutions to poor instrumental accuracy include ensuring sharp edges and automating the slitting machine. For **Method**, the plan involved training workers, restructuring the area layout, conducting numerous inspections, and ensuring proper lighting to address poor handling and measurement. Lastly, in **Material**, actions like proper initial shaving, maintaining correct chemical and moisture content, and accurate degreasing would address issues related to thickness, fat content, and sliminess.

4.4.1 Future Value Stream Mapping

The desired outcomes were a decrease in cycle time and lead time, a decrease in the number of stages, and an improvement in quality performance. For the chemical and salt inventory that was purchased from local suppliers, the company maintained a two-month supply. However, the company was only able to hold a 15-day supply, as the suppliers could deliver the products in 10 days. Additionally, the work in process between different stages of the process is one to three days, which is non-value-adding because it was caused by waiting for the next process to be completed on time. Another modification was made to the degreasing process, which no longer required 6 hours of rotation. If both 2h and 2h step rotations are conducted, outcomes were nearly identical. Where the cycle time was decreased from 7 hours to 5 hours. By implementing the enhancement, the whole production process lead time was decreased to 63 days and total cycle time decreased to 77.5 hours. Shown in Figure 6.

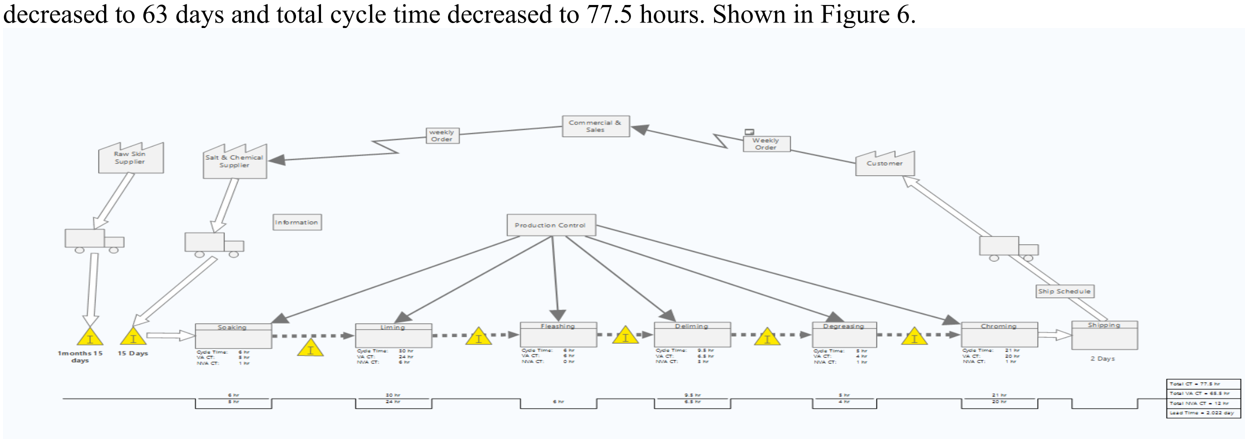

Figure 6. Future value stream mapping. (source: Author)

4.5 Control

In this control stage, the current sigma level was remeasured using one month's worth of production data, as the industry was only able to pilot our proposed solution for one month to validate the improved results. So, data from July 2022 was used to measure the current sigma level. And after implementing a portion of our proposed solution, the industry provided the new data used to measure the improved sigma level. Also, Moisture content, grease content, chrome content, pH, and shrinkage temperature were the five opportunities taken. Due to the fact that the industry was unable to provide the defects for each combination, the research could only be compared using the most recent data based on the implemented solution. Shown in Table 4.

Table 4. Previous production defects and five factors data.

July		
Day	Production	Defects
1	741	224
2	622	188
3	523	158
4	685	242
5	806	308
6	825	316
7	550	188
8	585	165
9	600	212
10	460	162
11	498	176
12	286	115
13	366	129
14	486	147
15	221	107
16	287	130
17	559	197
18	672	203
19	731	258
20	744	262
21	769	271
22	621	219
23	600	182
24	808	285
25	975	382
26	937	368
27	902	273
28	870	263
29	840	296
30	812	246
31	786	277

Current Data													
Moisture Content	Moisture Marking		Grease Content	Marking		Chrome Content	Marking		pH	Marking		Shrinkage Temp	marking
47.55	10.00		28.58	10.00		25.35	5.00		5.63	9.00		90.57	6.00
61.68	2.00		16.95	6.00		18.12	9.00		5.81	9.00		87.76	8.00
49.57	9.00		21.43	9.00		28.38	3.00		4.35	0.00		96.69	2.00
46.43	0.00		23.69	10.00		26.54	4.00		4.87	9.00		102.18	10.00
58.28	5.00		14.58	4.00		19.28	9.00		5.22	9.00		98.54	1.00
50.85	9.00		18.42	7.00		35.87	10.00		5.36	9.00		100.41	1.00
64.56	12.00		15.33	4.00		16.76	10.00		5.18	9.00		95.57	3.00
62.53	2.00		20.78	8.00		20.28	9.00		5.32	9.00		80.87	10.00
54.51	7.00		21.75	9.00		14.23	10.00		4.64	0.00		82.59	10.00
53.15	8.00		30.65	10.00		38.54	10.00		4.72	0.00		93.81	4.00
68.78	12.00		34.48	10.00		33.78	10.00		3.45	6.00		105.88	10.00
56.21	6.00		29.21	10.00		17.65	10.00		3.67	7.00		104.58	10.00
54.29	8.00		19.78	7.00		25.35	5.00		3.35	6.00		97.21	2.00
44.68	0.00		27.54	10.00		34.65	10.00		3.38	6.00		90.28	7.00
52.17	9.00		22.63	9.00		32.28	10.00		3.12	5.00		84.74	9.00
50.52	9.00		26.42	0.00		28.51	3.00		4.24	10.00		80.38	10.00
47.58	10.00		20.25	8.00		25.23	5.00		4.79	9.00		81.21	10.00
47.49	10.00		12.56	3.00		19.77	9.00		4.35	0.00		89.57	7.00
48.37	10.00		17.87	6.00		25.81	5.00		4.83	9.00		93.35	5.00
50.45	9.00		23.51	10.00		30.85	1.00		5.12	9.00		101.27	10.00
54.55	7.00		38.12	11.00		30.48	2.00		3.21	5.00		110.68	10.00
52.81	9.00		34.65	10.00		32.56	10.00		4.52	0.00		105.91	10.00
44.25	0.00		29.81	10.00		24.65	6.00		4.63	0.00		103.25	10.00
51.34	9.00		24.67	0.00		29.71	2.00		5.08	9.00		99.35	1.00
55.28	7.00		25.98	0.00		37.58	10.00		4.11	9.00		92.76	5.00
67.52	12.00		22.34	9.00		23.67	6.00		3.61	7.00		91.49	6.00
63.59	1.00		15.32	4.00		27.74	4.00		3.21	5.00		102.55	10.00
68.95	12.00		16.34	5.00		16.85	10.00		3.32	5.00		90.54	6.00
50.18	9.00		18.29	6.00		13.39	10.00		3.69	7.00		101.44	10.00
52.45	9.00		28.91	10.00		29.84	2.00		4.27	10.00		100.77	10.00
56.81	6.00		26.21	0.00		32.61	10.00		4.48	0.00		98.24	1.00
55.23	7.00		28.59	10.00		28.54	3.00		5.17	9.00		95.59	3.00

The current and improved five factor data was compared with the standard data found in our literature review. Which is Moisture = 52.5, P^H = 4, Chrome = 25.35, Shrinkage = 92.5, Grease = 23 (leather international 2007, M. Gutterres 2011, leather dictionary.com)

Following incorporation of our suggested updated VSM and consideration of some of our proposed solutions from our improvement plan and action model, the following additional information is provided in Table 5:

Table 5. Improved production defects and five factors data.

October		
Day	Production	Defects
1	899	206
2	584	157
3	490	117
4	488	126
5	412	107
6	827	198
7	917	219
8	594	124
9	474	111
10	604	114
11	666	126
12	485	111
13	754	188
14	805	208
15	296	105
16	364	112
17	906	217
18	298	107
19	947	179
20	671	127
21	283	104
22	750	142
23	540	102
24	815	195
25	453	140
26	397	103
27	406	101
28	868	207
29	747	141
30	850	203
31	396	103

Future Data													
Moisture Content	marking		Grease Content	Marking		Chrome Content	Marking		pH	Marking		Shrinkage Temp	Marking
51.16	9.00		23.34	10.00		20.77	8.00		4.25	10.00		88.93	8.00
66.37	12.00		18.28	6.00		17.79	9.00		4.33	0.00		86.17	9.00
53.34	8.00		23.12	10.00		22.19	7.00		3.37	6.00		94.94	3.00
49.96	9.00		25.55	0.00		20.75	8.00		3.92	8.00		100.33	1.00
62.71	2.00		17.06	6.00		19.03	9.00		4.31	10.00		98.73	1.00
54.71	7.00		21.55	9.00		27.46	4.00		4.21	10.00		100.60	1.00
58.18	5.00		17.94	6.00		18.08	9.00		4.07	9.00		95.75	3.00
56.35	6.00		24.31	0.00		21.88	8.00		4.45	0.00		81.02	10.00
52.20	9.00		25.45	0.00		16.44	10.00		3.97	9.00		82.75	10.00
50.90	9.00		28.16	10.00		29.28	3.00		4.04	9.00		93.99	4.00
65.86	12.00		28.27	10.00		25.67	5.00		3.02	4.00		101.85	10.00
54.45	7.00		23.95	10.00		17.81	9.00		3.21	5.00		101.64	10.00
52.59	9.00		17.80	6.00		22.96	7.00		3.00	4.00		94.48	4.00
48.18	10.00		24.78	0.00		27.22	4.00		3.33	6.00		87.74	8.00
56.25	6.00		20.36	8.00		26.86	4.00		3.08	4.00		82.36	10.00
54.48	7.00		23.77	10.00		25.43	5.00		4.18	10.00		84.55	10.00
48.58	10.00		18.22	6.00		23.63	6.00		4.48	0.00		85.42	9.00
48.49	10.00		14.70	4.00		18.51	9.00		4.07	9.00		94.22	4.00
49.39	9.00		20.91	8.00		24.17	6.00		4.52	0.00		98.19	1.00
51.51	9.00		27.51	10.00		26.11	5.00		4.23	10.00		99.44	1.00
55.70	7.00		32.49	10.00		25.80	5.00		3.32	5.00		104.25	10.00
53.92	8.00		31.61	10.00		27.56	4.00		4.45	0.00		100.82	10.00
45.18	0.00		27.20	10.00		23.85	6.00		4.19	10.00		100.35	1.00
54.41	7.00		22.51	9.00		26.93	4.00		4.60	0.00		96.56	2.00
53.00	8.00		23.70	10.00		32.98	10.00		3.72	7.00		90.15	7.00
64.73	12.00		20.38	8.00		23.61	6.00		3.27	5.00		88.92	8.00
57.64	5.00		17.58	6.00		27.67	4.00		3.04	4.00		99.67	1.00
62.50	2.00		18.75	7.00		16.81	10.00		3.31	5.00		82.56	10.00
54.02	8.00		20.99	8.00		15.22	10.00		3.67	7.00		99.60	1.00
47.55	10.00		26.85	0.00		31.53	1.00		4.25	10.00		98.95	1.00
51.50	9.00		24.34	0.00		32.17	1.00		4.46	0.00		97.44	2.00
55.04	7.00		26.55	0.00		28.15	3.00		4.58	0.00		98.64	1.00

$$\text{DPMO}=\frac{4501}{18986\times 5}\times 1000{,}000$$

DPMO= 47413.884

For this DPMO, Sigma level= 1.98

4.5.1 Proposed Integrated Model

Customer demand for high-quality, low-cost products challenges companies to lower production costs without sacrificing quality. To do so, minimizing defects via process improvement is the first step to decreasing manufacturing costs and enhancing quality. It will also improve the lead time and ultimately increase the Sigma Level. The fact is that there are several management techniques that may be used to raise the Sigma level, however integrated models are preferred since they provide solutions to multiple problems at once. This model shown in Figure 7 will help to control the gained improvements and streamline the overall process efficiently.

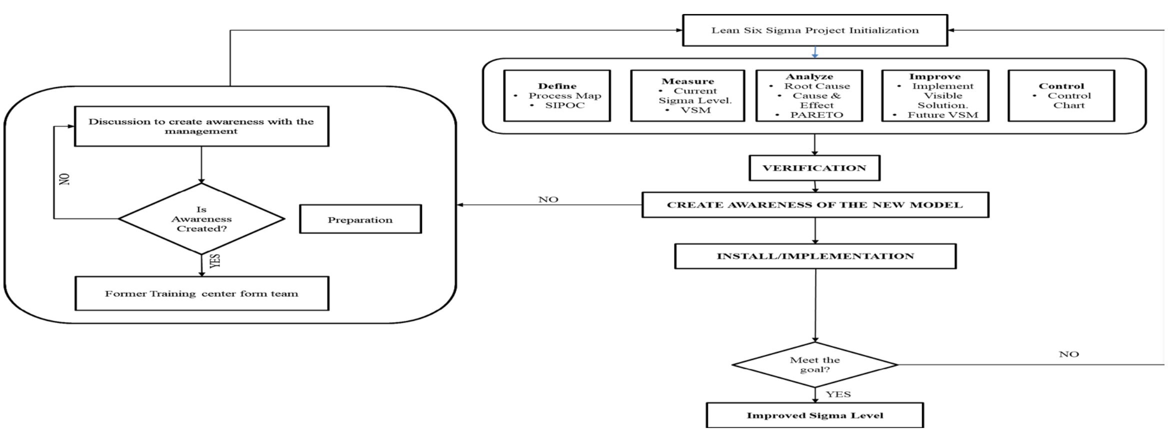

Figure 7. Proposed integrated model.

5. Results and Discussion

It was estimated that the proposed improved value stream will reduce the Kanban lead time for salt and chemical supply from 2 months to 15 days. Since the supplier's lead time was 10 days, the corporation could store 15 days of inventory.

- The overall cycle time was reduced by 2 hours.
- Which helped to overcome the surplus of chemical and salt storage. Excess chemical inventory led to deteriorating chemical quality, an increase in moisture levels, and an unbalanced pH level.
- An increase in pH (>4.2) induces chromium iii to undergo a chemical transformation into chromium vi. Which is extremely damaging to human skin and a wet blue rejection criterion. By lowering the time required to get salt and chemicals, there would be no need for surplus stock (Figure 8 shows effect on P^H)

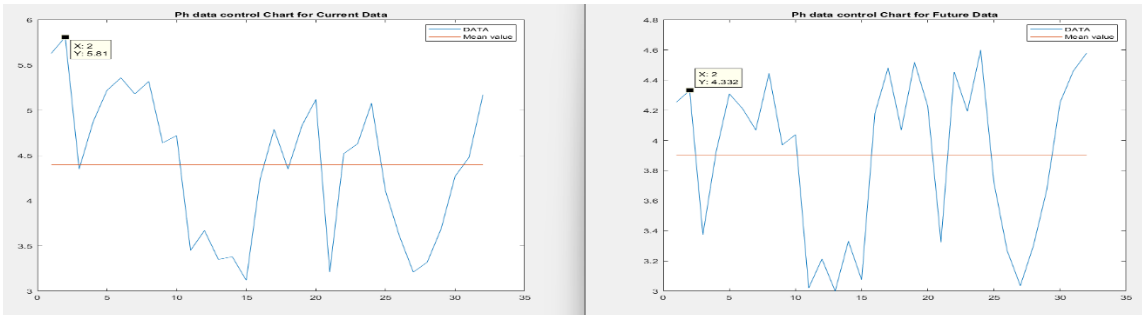

Figure 8. Control chart to determine P^H control level (before vs improved).

- Pareto analysis gave three major defects for the rejection of wet blue leather, where flay cut at most significant following gauge mark and scratch. Where Ishikawa was used for better understanding on factors leading to these defects. The company used some of our proposed solution under Man, Machine, Method, Material to implement for a pilot run.

- The five opportunities following Moisture content, Grease content, Chrome content, pH and shrinkage temperate was analyzed based on standard data for both the current data and improved data. Some marking was provided to both of the data based on the deviation from standard data and the deviation was validated from the company. Shown in Figure 9.

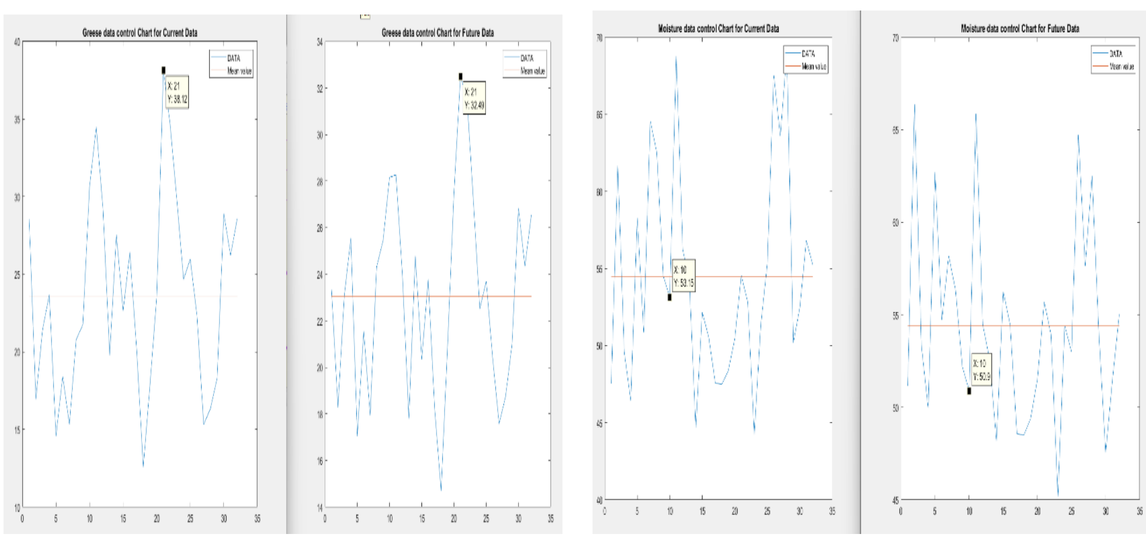

Figure 9. Control charts showing the control level of Grease content and Moisture content respectively (before vs improved)

According to the significance level for these five factors pH and Chrome content is critical then the rest (source: company). Following graph shows the difference after integrating our proposed solution. In figure 10.

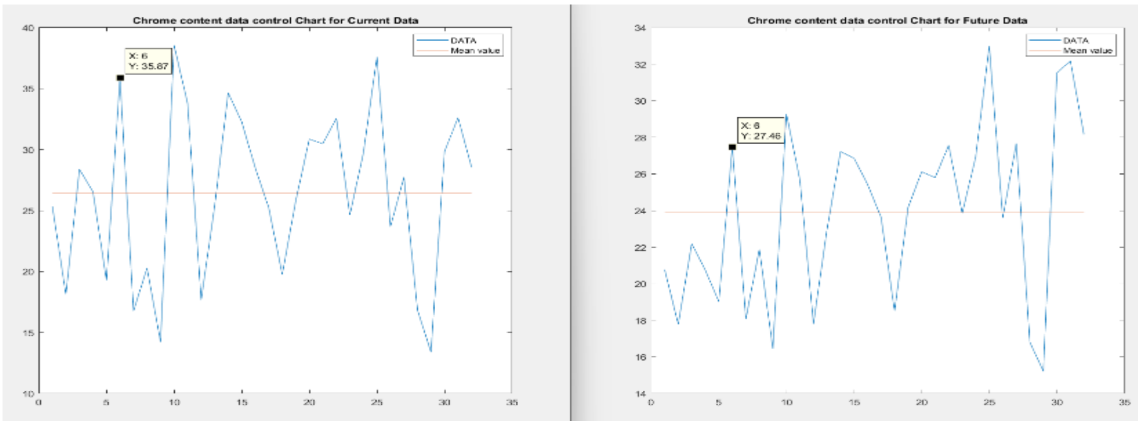

Figure 10. Control chart of critical factor chrome content. (before vs improved)

Some of the solutions were implemented as part of the company's consideration of our recommended solution, as seen by the changes in the control charts above. And based on Figure 10 data acquired by the company following a one-month experimental run. An improvement in sigma level from **1.82 to 1.98** can be seen.

6. Conclusion

To sustain in today's dynamic business environment, organizations must supply high conformance products in a timely and cost-effective manner. In the leather industry, the leather undergoes three steps of processing before becoming perishable leather, namely Wet Blue Leather, Crust Leather, and Finished Leather. It is essential to maintain quality throughout all processes of leather processing. Specifically, the quality will be largely determined by the wet blue stage. Therefore, reducing defects at this stage is crucial for ensuring the quality of leathers in the next two phases. In this study, the case company processes wet blue leather after receiving orders from local clients, sister firms, and overseas customers. As was said in previous chapters, the firm faced a significant obstacle in satisfying the needs of its clients and maintaining a good sigma level. Return of items owing to defective outputs and failure to maintain quality specifications were the primary issues observed. According to Pareto analysis, the two most significant defects found on leather were Flay Cuts and Gauge Marks, which account for 22.9% and 18.3% of defects, respectively. The current value stream mapping demonstrated the presence of a high chemical inventory with unnecessary lead time, unwanted steps in the drum operation of the degreasing stage, and reduceable lead time during the distribution of wet blue leather to customers. After implementing corrective measures on those Kanban Bursts, the lead time decreased from 112 days to 63 days in the improved value stream mapping. The Lean Six Sigma based DMAIC model was applied as Lean concentrates on increasing the flow of information and materials between processes, whereas Six Sigma focusses on enhancing the value-adding transformations that occur within processes. On the control chart, the progress in leather quality was depicted in relation to the leather's five most important elements, with marking criteria assigned to each. Using statistical tools, prior and present data on the improved state of these five variables was analyzed to generate the charts. In conclusion, it is demonstrated that the Sigma level was increased from 1.82 to 1.98. The created integrated model was used to enhance both internal and external customer satisfaction by reducing the defect rate and ultimately sustaining the improved Sigma level.

References

Rahman , An Analysis on The Leather Industry of Bangladesh: An Analysis On The Leather Industry Of Bangladesh : Identification of Barriers , Challenges , And Way Outs. March. 2022. Https://Doi.Org/10.51594/Ijmer.V4i3.310

Mollik, B. A, " Bangladesh's Leather Industry " "Bangladesh's Leather Industry" Ssrn J Abstract Id = 4044704 B.Sc. Agricultural Economics (Hons.) Sher-E-Bangla Agricultural University, Dhaka-1207. March, 0–10. 2022.

Rahman , An Analysis on The Leather Industry Of Bangladesh : An Analysis On The Leather Industry Of Bangladesh : Identification of Barriers , Challenges , And Way Outs. March. 2022. Https://Doi.Org/10.51594/Ijmer.V4i3.310

H, H. , Lean Six Sigma Implementation, A Systematic Literature Review. 9, 125–139.2021.

Khan Et Al. , Application of Continuous Improvement Techniques To Improve Organization Performance A Case Study, 2019. Https://Doi.Org/10.1108/Ijlss-05-2017-0048

Swarna, N. A., & Sayid Mia, M. A. S, Productivity Improvement of Leather Products Industry In Bangladesh Using Lean Tools: A Case Study. Leather And Footwear Journal, 18(3), 219–230, 2018. Https://Doi.Org/10.24264/Lfj.18.3.7

Ezawa, H., Jilcha, K., Hailu, H., & Tabuchi, H. , Reduction Of Excessive Trimming And Reject Leather By Integration Of 7 Qc Tools And Qc Story Formula: The Case Report of Sheba Leather Plc. Industrial Engineering & Management, 06(03), 2017. Https://Doi.Org/10.4172/2169-0316.1000223

Jadhav, G. P., Jadhav, S. B., & Bhagat, A. , Six Sigma Dmaic Literature Review. 6(12), 117–122, 2015.

Timans, W., Antony, J., Ahaus, K., & Van Solingen, R., Implementation of Lean Six Sigma In Small- And Medium-Sized Manufacturing Enterprises In The Netherlands. Journal Of The Operational Research Society, 63(3), 339–353, 2012. Https://Doi.Org/10.1057/Jors.2011.47

Acknowledgements

The authors would like to express gratitude to the Department of Mechanical and Production Engineering, Aust for the continuous support, would like to thank **Prof. Dr. A N Mustafizul Karim** (MPE, AUST) and also would like to thank **Mr. Sohanur Rahman Sohan** (Group Deputy COO- Akij Resource) for their wise guidance, rapid assistance and kind contrinution.

Biographies

Tanvirul Islam, a graduate of Industrial and Production Engineering from Ahsanullah University of Science and Technology (AUST), is deeply interested in Occupational and Process Safety, Risk and Reliability Engineering, and productivity improvement in manufacturing. He is currently pursuing an MSc in Occupational and Process Safety at Bangladesh university of Engineering and Technology (BUET). He has developed strong analytical abilities in process safety assessment, quantitative risk analysis, and productivity enhancement using Lean and Six Sigma tools. Tanvir strives to bridge academic research with industrial practice, combining his technical insight and problem-solving mindset to promote safer, more efficient, and high-performing industrial operations.

Alfi Shahriar is an Industrial and Production Engineering graduate from Ahsanullah University of Science and Technology with nearly three years of experience in supply chain optimization across FMCG and pharmaceutical sectors. His professional focus includes Lean Six Sigma, process automation, and operational excellence. Alfi has successfully implemented data-driven strategies to enhance efficiency and reduce waste, aligning with the principles of continuous improvement. He has led major initiatives such as deploying SAP MM across 27 distribution points, integrating SAP WMS for 10+ categories, and designing optimized logistics networks with multiple hubs and linehaul routes. His contributions include improving demand forecast accuracy by 7.33%, reducing NPI inventory by BDT 4.8 million, and automating reverse logistics for pharmaceutical channels. By combining theoretical knowledge with practical application, Alfi aims to advance Lean Six Sigma practices in Bangladesh's supply chain landscape, fostering sustainable and world-class operational standards.

Md. Shadman Hossain is currently working as an Executive in Environment, Health and Safety dept in American and Efird Bd Ltd. He completed his undergraduate degree in Industrial and Production Engineering department in Ahsanullah University of Science & Technology. With distinguished achievements such as NEBOSH IGC Certification, Fire Safety Training Certification from BRAC, Social Labor Convergence Program from INTERTEK Bangladesh, "CSCA"™ Certification from ISCEA Bangladesh, Shadman has proven his critical thinking, a sound knowledge in the sector of Health and Safety and improving the productivity and efficiency in the relevant industry. Shadman continues implementing his learning, creative skills and academic knowledge to tackle diverse challenges in the industrial sectors and strive for optimized and better outcome.