Journal of Engineering and Technology for Industrial Applications

ISSN ONLINE: 2447-0228

ITEGAM-JETIA

Manaus, v.11 n.52, p. 173-178. March./April., 2025.
DOI: https://doi.org/10.5935/jetia. v11i52.1575

RESEARCH ARTICLE OPEN ACCESS

SOLDER LEAD WASTE REDUCTION OF A SELECTED MOBILE PHONE FACTORY: A SIX SIGMA DMAIC APPROACH

Md. Mehedi Hassan Munna[1], Jonayed Abdullah[2], Tarequl Islam[3], Most. Anika Tabassum Little[4]

[1,2]Department of Industrial and Production Engineering Shahjalal University of Science and Technology, Sylhet, Bangladesh
[3]Department of Logistics Systems Engineering Bowling Green State University, Ohio, USA.
[4]Department of Electrical and Electronic Engineering. Khulna University of Engineering & Technology, Khulna, Bangladesh.

[1]http://orcid.org/0009-0000-6480-0048, [2]http://orcid.org/0009-0006-7130-7597, [3]http://orcid.org/0009-0002-8313-3150, [4]http://orcid.org/0009-0002-1330-7784

Email: mehedi.ipe.sust@gmail.com, jonayedabdullah.ipe@gmail.com, tareq.ipe.sust@gmail.com, anika.kuet.eee@gmail.com

ARTICLE INFO

Article History
Received: January 21, 2025
Revised: February 20, 2025
Accepted: March 15, 2025
Published: April 30, 2025

Keywords:
Quality,
Six Sigma,
DMAIC,
VOC,
Wastage.

ABSTRACT

Six Sigma is an explicit statistical method of reducing variability and improving processes. Our research works with internal customers within the assembly lines. This study aims to identify and analyze the VOC of internal customers and show improvement based on the VOC. The Six Sigma DMAIC method was followed to conduct this research. Six mobile phone assembly lines were selected to collect wastage data for two months after identifying the problem. Collected data were analyzed in MS Excel and this analysis showed that the wastage rates were 91.38% in July 2024 and 80.67% in August 2024. The average waste rate was 0.44 g/unit and 0.41 g/unit in July 2024 and August 2024. The root cause analysis, and cause and effect diagram illustrated that most of the reasons behind wastages were related to soldering operators. An awareness and training session was conducted. We collected data for the next month and found the wastage was reduced to 69.27% in September 2024 which is a 24.5% reduction considering August 2024 as the base. The average waste rate was reduced to 0.28 g/unit. The effectiveness of following the Six Sigma method to solve quality or wastage issues is evident hereafter accomplishing this research.

I. INTRODUCTION

Manufacturing firms are concerned with reducing wastage from the production process. Some wastages can be identified and eliminated, and some cannot. This wastage has a great impact on the pricing of any product. Increased wastage also increases the cost of making products [1]. Customers always want good products at a reasonable price [2].

Companies invest significant amounts of money to provide the best product to the customer at a minimum price. Thus, the market has become price and quality-competitive [3]. If any organization fails to give the products with higher products and lower prices, that organization is said to be out of the competition [4].Process improvements play a vital role here that reducing the waste in the process by eliminating process variability. This reduction leads to a decrease in the cost of product making.

Six Sigma is one of the most effective approaches that deals with process variability. The integration of Six Sigma and Lean can reduce process variability and process waste. The purpose of this research is,

- to observe the process and define the problem
- to measure the extent of the problem and find root causes
- to take required actions for improvement
-

This study explored a real problem and observed the difference between before and after improvement scenarios. A mobile phone company was selected for this study. The scenario was observed and then a problem statement was generated. Following this, five steps of Six Sigma were deployed to get effective outcomes.

II. THEORETICAL REFERENCE

II.1 SIX SIGMA

Six Sigma is not a reactive or detection-based approach; rather, it is proactive and prevention-based. A top-quality process gives fewer than 3.4 defective parts per million and is considered as Sigma level six. Sigma (σ) is a Greek letter that stands for standard deviation, a measurement of variance [5].

Six Sigma is a methodical approach that lets businesses analyze their current state of operations and enhance their procedures to cut down on variances [6]. Both the industrial and service sectors use Six Sigma [7]. Manufacturing companies deploy hundreds of Six Sigma projects annually, which need a significant financial commitment and careful research to guarantee that the benefits outweigh the initial expenditure [8]. Six Sigma offers academics and practitioners new challenges even though it has more benefits than traditional quality management techniques [9]. The total quality management (TQM) procedures include Six Sigma practices [10].

Six Sigma is a process, system, or product improvement methodology emphasizing scientific and statistical techniques to lower the rejection or waste [11],[12]. This approach can lower the quantity of faulty goods the business produces. DMAIC stands for Define, Measure, Analyze, Improve, and Control, and it is one approach to the Six Sigma methodology. The Plan-Do-Check-Act and Juran and Gryna's Seven-Step Method are two popular manufacturing techniques that are comparable to the DMAIC methodology in that they both seek to enhance [13]. It has been successfully applied to many procedures and needs in the healthcare industry. Certain articles in the literature discuss the use of SS, frequently in conjunction with the Lean methodology, to enhance surgical procedures by decreasing hospital stays and wait times or increasing the effectiveness of operating rooms[14],[15]. Another approach is named DMADV, which stands for Define, Measure, Analyze, Design, and Verify. This approach is very well-liked for creating new processes or products [16].

II.2 DMAIC

DMAIC is a six-sigma method that is based on the PDCA or plan, do, act, and check developed by Deming. Define, measure, analyze, improve, and control are the five specified stages.

Define: During the Define phase, the team is formed, the project's goals are defined, the process is mapped, customers are identified, and the high impact qualities, or CTQs (Critical to Quality), are identified.

Measure: The Measure phase entails creating and carrying out a methodical plan for gathering data for the targeted process's critical metrics (CTQs).

Analysis: By identifying the primary types of wastes embedded in the production processes and their underlying causes, the Analyze phase analyzes the data gathered in the Measure phase to determine the underlying causes of the discrepancy between the current performance and the goals established in the first phase.

Improve: Identifying expected solutions, proposing a range of alternative solutions to improve performance, and putting some of these solutions into practice under the available budget and the anticipated cost of each alternative are the main goals of the improvement phase.

Control: The control phase focuses on developing and monitoring response strategies to maintain improvements, disseminate the results and methods throughout the organization, and ensure the development of a new organizational culture. Additionally, the Control phase documents and publishes operating standards and procedures [9],[12].

II.3 LEAN MANUFACTURING

Delivering the best quality product to customers at the lowest cost while reducing waste from the value-adding process is known as lean manufacturing. Here, customer needs are given priority. To properly implement lean services, key principles must be followed, such as ensuring that all services operate and, in particular, collaborate to solve customers' problems; preventing time waste; and giving customers exactly what they want, exactly where they want it, and at the exact moment they want it [17], [18].

II.4 SEVEN QC TOOLS

Quality control management uses some tools within any organization to monitor the ongoing processes and check the process parameters whether they match the defined standards.

Check Sheet: Since data collection and measurement serve as the foundation for any analysis, this activity must be organized to ensure that the information gathered is thorough and pertinent. Check sheets are instruments for collecting information. They are made especially for the kind of data that would be collected. Check sheets facilitate the methodical collection of data. Daily maintenance check sheets, attendance logs, production logbooks, and so forth are a few examples of check sheets. The collected data must be appropriately categorized. To plan for more analysis and provide a relevant result, this classification aids in obtaining a preliminary knowledge of the data's relevance and dispersion. Stratification is the process of meaningfully classifying data. Group, location, kind, origin, symptom, etc. are some examples of stratification [19]. Researchers used check sheets in pharmaceutical quality control to monitor input variabilities [20].

Histogram: A histogram is an effective tool to identify the distribution of any dataset. This bar chart helps users illustrate the distribution of recorded data and the degree of deviation in a process by visualizing both variable data and attributes of a product or process. It shows the mean, mode, and average of the three different measurements of central tendency. It should be appropriately constructed so that those working on the operational process may use and comprehend it without any problem. Additionally, a histogram can examine and determine the variable’s distribution [21].

Pareto Analysis: A Pareto diagram is a tool that shows which elements have the most influence by ranking them according to the size of their contributions. In SPC and quality improvement, this tool is used to prioritize projects for improvement, prioritize the formation of corrective action teams to address issues, identify the products that receive the most complaints, determine the type of complaints that occur most frequently, determine the most common reasons for rejections, and for other related purposes. An Italian economist, Vilfredo Pareto, noticed that a significant amount of wealth was owned by a small number of individuals. He saw that most fields shared this distribution trend. The 80/20 rule, sometimes referred to as the Pareto principle, is applied in materials management for ABC analysis. 80% of the value is accounted for by 20% of the things that a corporation purchases. These are the things that receive the most attention. To separate the "vital few" issues from the "trivial many," or what is now known as the "useful many," Dr. Juran proposed using this theory for quality control [21]. Pareto charts were used in grinding unit research [22] to determine the major reasons for downtime, which improved maintenance plans.

Fishbone Diagram: Kaoru Ishikawa is credited for creating and popularizing the ‘Fishbone’ diagram, also known as the Cause-and-Effect Diagram. In 1943, Dr. Kaoru Ishikawa introduced the cause-and-effect diagram. The diagram is also known as the Ishikawa diagram or fishbone because of its design, which resembles a fish's skeleton and is used to rank quality issues according to their significance. One method for solving problems is the cause-and-effect diagram, which methodically examines and evaluates every possible or actual cause that contributes to a certain outcome. However, it is a useful tool that gives the ability to investigate potential problem reasons [23]. By “gathering and organizing the possible causes, reaching a common understanding of the problem, exposing gaps in existing knowledge, ranking the most probable causes, and studying each cause” this diagram may aid in finding solutions. Six elements or causes typically comprise categories: environment, materials, machine, measurement, man, and method [19].

Scatter Diagram: This diagram identifies and analyzes a pattern relationship between two variables, as well as determines whether a relationship exists at all and what type of relationship it is such as weak, strong, positive, or negative. A scatter diagram is a useful tool for drawing the distribution of information in two dimensions. The correlation may indicate the root causes of an issue, and the scatter diagram's form frequently illustrates the strength and direction of a connection between two variables. When it comes to regression modeling, scatter diagrams are quite helpful. [24],[25]. The following correlations between two variables can be shown by the scatter diagram: a) positive, b) negative, or c) no correlation.

Flowchart: A flowchart is a diagrammatic representation of a sequence of steps in an activity or process that shows several symbols. In contrast, a flowchart shows the inputs, actions, control points, and outputs in an image that is easy to use and comprehend concerning the process's overall goal [19]. This chart is an invaluable tool for finding and improving process quality. It is used methodically to identify and analyze parts or points of the process that may have had potential difficulties by documenting and interpreting an operation. Flowcharts were used [26] to document production workflows in a quality management system for mining operations, streamlining processes and reducing delays.

Control Chart: Walter A. Shewhart created the control chart, also known as the Shewhart control chart, at Bell Telephone Laboratories in the 1920s. It is arguably the most technically sophisticated tool for quality control [24]. A specific type of run chart that illustrates the amount and nature of variation in the process over time is a control chart. Additionally, it illustrates and explains the process. Applying a control chart is crucial because it allows for the observation and monitoring of methods that are in statistical control following sampling that fall between the upper control limit (UCL) and the lower control limit (LCL). Since there is no statistical control between UCL and LCL, the process is out of control; therefore, a control chart can be used to identify the root causes of any quality issues. The primary goal is to stop process flaws. Because poor products or services are more expensive than preventing them with tools like control charts, it is crucial for a variety of enterprises and industries [27]. A food sector case study [28] illustrated how control charts can minimize deviations and guarantee consistent meat quality.

III. CASE STUDY

This case study was conducted in a renowned mobile phone and accessories manufacturer in Bangladesh. This organization manufactures mobile phones: Feature phones, Smartphones, mobile accessories: battery, charger, USB cable. The capacity of production is around 17,300 phones/day and 28,000 accessories/day. Around 500 employees work in a single shift to produce the targeted products. The management found a huge amount of waste from solder lead in the soldering of mobile phones in different parts. After that, this study was initiated. The study was focused on mobile assembly lines. This study is divided into five stages based on DMAIC and discussed in the following subsections.

III.1 DEFINE

Before defining our problems, we have selected our team as an internal customer so that we can represent our problem as VOC and identify CTQs. After observing the total processes of 6 assembly lines, we noticed a significant amount of solder lead wastage in the assembly lines. Some of the photographs have been given.

Figure 1: Solder Lead Wastages.
Source: Authors, (2025).

Some points we raised as VOC are,

- Solder lead wastage is higher
- Unnecessary rework
- Violation of SOP

Some points for CTQs are,

- Wastage results in lower productivity
- Recycling or reusing this waste solder lead might lower the joint quality

Therefore, the major focus of this study is to reduce the waste of solder lead by taking necessary actions.

III.2 MEASURE

After identifying the problem, we collected necessary data from the floor for two months. The data have been presented in the following Tables 1, 2 and 3.

Table 1: Wastage Data for July 2024.

Line	S. Lead Provided (Kg)	Actual Wastage (Kg)	Actual Wastage (%)	Output Qty	Avg. Wastage (g/pc)
A-1	22	15.36	69.82%	63,052	0.24
A-2	57	52.679	92.42%	115,221	0.46
A-3	46	44.89	97.59%	95,586	0.47
A-4	42	39.527	94.11%	81,474	0.49
A-5	37	40.51	109.49%	88,667	0.46
A-6	66	53.766	81.46%	112,889	0.48
July	**270**	**246.732**	**91.38%**	**556,889**	**0.44**

Source: Authors, (2025).

Table 2: Wastage Data for August 2024.

Line	S. Lead Provided (Kg)	Actual Wastage (Kg)	Actual Wastage (%)	Output Qty	Avg. Wastage (g/pc)
A-1	52	44.501	85.58%	98,747	0.45
A-2	42	33.391	79.50%	102,478	0.33
A-3	57	46.367	81.35%	115,836	0.40
A-4	54	42.327	78.38%	78,324	0.54
A-5	19	13.8	72.63%	41,964	0.33
A-6	49	39.84	81.31%	102,436	0.39
August	**273**	**220.226**	**80.67%**	**539,785**	**0.41**

Source: Authors, (2025).

Table 3: Summarized Wastage Data for Two Months.

Month	S. Lead Provided (Kg)	Actual Wastage (Kg)	Used (%)	Actual Wastage (%)	Output Qty	Avg. Wastage (g/unit)
July	270.00	246.73	8.62%	91.38	556,889	0.44
August	273.00	220.23	19.33 %	80.67	539,785	0.41

Source: Authors, (2025).

III.3 ANALYZE

In this phase, we worked to identify the underlying reasons for the wastage of solder lead. We performed root cause analysis and illustrated a cause-and-effect diagram to analyze the reasons.

After analyzing the scenario on the production floor, we found the following root causes,

- The direct reason is that the solder withdrawal is too late. Another reason is inserting extra lead while soldering.
- Operators are maintaining proper SOP while soldering. Operators often don't use jigs while soldering which results in mismatches and misalignment and increases soldering wastages because those need to be re-soldered.
- Soldering iron excessive heat. According to SOP, the soldering iron temperature is 350±10 °C.
- The excessive heat of soldering iron results in wastage and reduces the soldering bit life cycle.
- Operators do not maintain proper working method soldering. They didn't clean the soldering bit when it was needed. That results in longer soldering time and excess Lead for soldering.

A cause-and-effect diagram is illustrated in Figure 2 to find the sources of the causes.

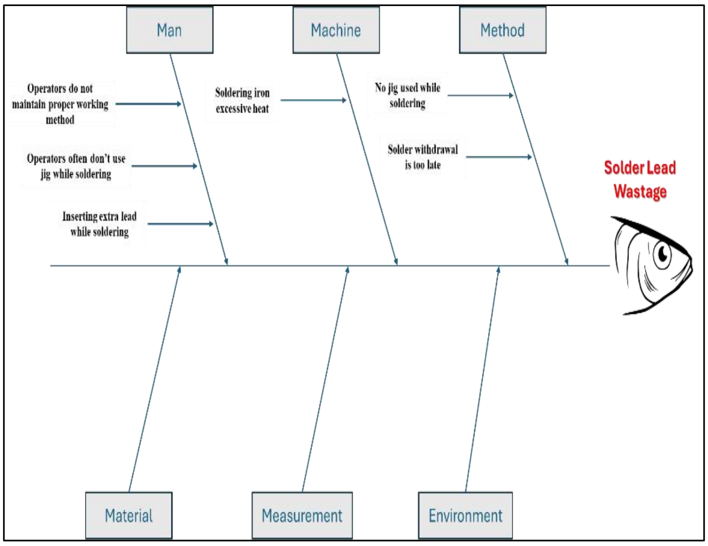

Figure 2: Cause and Effect Diagram of Reasons for Wastages.
Source: Authors, (2025)

This figure shows that the most responsible reasons are from the sources man and method. We have identified the sources for improvements.

III.4 IMPROVE

Based on the analysis phase, some measures had been taken as follows. A session has been taken with all the soldering people and educated about the SOP and proper handling method while soldering to solve the problems associated with operators.

A check sheet has been maintained to ensure that every soldering operator has appropriate jigs to maintain the optimum temperature of a soldering iron.

Strongly follow up on all the issues related to lead wastage by all the assembly lines concerned.

There is a problem with the machine because of the excessive soldering iron heating issue.

A temperature controller must be mounted on the soldering iron to eliminate this problem. After implementing the improvement techniques, we collected data for another month. The collected data are represented in the following Tables 4 and 5.

Table 4: Summarized Wastage Data for September 2024.

Line	S. Lead Provided (Kg)	Actual Wastage (Kg)	Actual Wastage (%)	Output Qty	Avg. Wastage (g/pc)
A-1	43	35.091	81.61%	130,528	0.27
A-2	44	30.984	70.42%	124,175	0.25
A-3	50	38.067	76.13%	131,261	0.29
A-4	43	29.967	69.69%	95,193	0.31
A-5	17	0	0.00%	-	-
A-6	43	32.143	74.75%	119,245	0.27
September	**240**	**166.252**	**69.27%**	**600,402**	**0.28**

Source: Authors, (2025).

Table 5: Summarized Wastage Data for Three Months.

Month	S. Lead Provided (Kg)	Actual Wastage (Kg)	Used (%)	Actual Wastage (%)	Output Qty	Avg. Wastage (g/unit)	Wastage Reduced (%)
July	270.00	246.73	8.62 %	91.38 %	556,889	0.44	-
August	273.00	220.23	19.33%	80.67 %	539,785	0.41	10.74 %
September	240.00	166.25	30.73%	69.27 %	600,402	0.28	24.51 %

Source: Authors, (2025).

III.5 CONTROL

We observed remarkable improvements in reducing waste. To keep an eye on the sustainability of this improvement some controlling instructions must be followed,

- Follow the standard operating procedure or SOP strictly
- Training of the operators regularly
- New operators should not be engaged in soldering operations
- Proper documentation of daily wastage must be ensured

IV. RESULTS AND DISCUSSIONS

The improvement phase showed that there is a significant change in the wastage of solder lead. Figure 4 and Figure 5 show the gradual decrease in the wastage of solder lead in soldering. The waste rate was 91.38% in July 2024 and was reduced to 80.67% in August 2024 by consulting the operators. After focusing on wastage and implementing improvement strategies, the waste rate was reduced to 69.27% in September 2024 as shown in Figure 3. In addition, solder waste per unit was 0.44 g/unit in July 2024 and was reduced to 0.28 g/unit in September 2024 as shown in Figure 4.

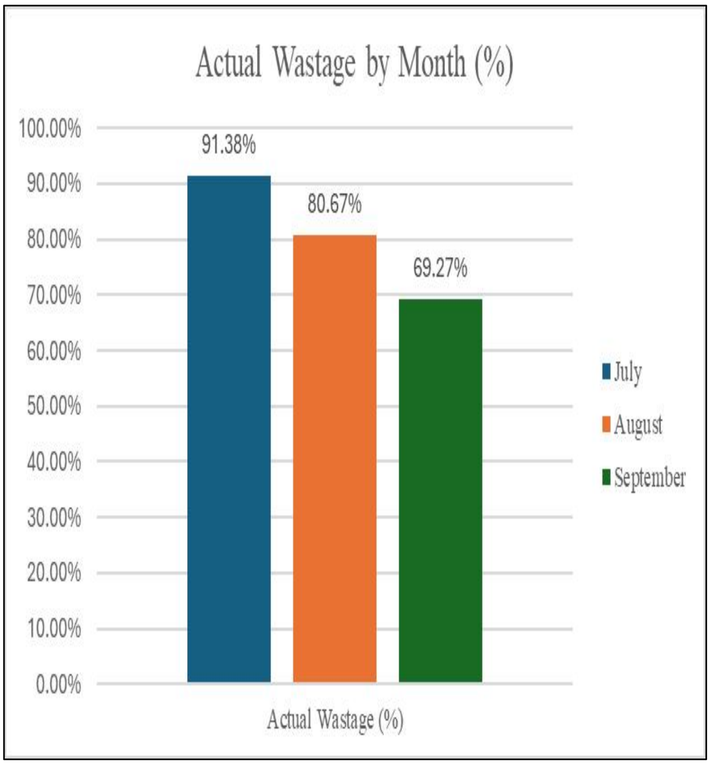

Figure 3: Monthly Comparison by Waste (%).
Source: Authors, (2025).

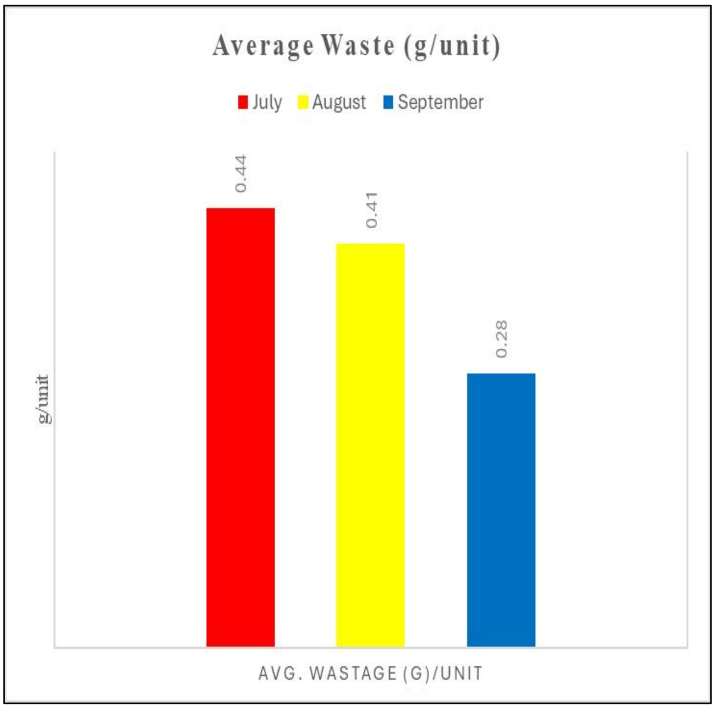

Figure 4: Monthly Comparison by Average Waste (g/unit).
Source: Authors, (2025).

V. CONCLUSIONS

This study has reflected the effectiveness of Six Sigma in solving practical problems on the production floor. This study aimed to identify the variability within the processes and take necessary actions to eliminate or reduce the variability. After recognizing the problem, we found that the total solder lead wastage was 91.38% and 80.67% in July and August respectively and the average solder waste per unit was 0.44 g/unit and 0.41 g/unit. The waste rate was way higher than our expectations. We reduced the waste rate by 10.74% after this finding in August 2024. As a part of continuous improvement, we continued analyzing the root causes for this unusual finding, we found that the workers' skills and some methodological problems aroused this wastage rate. We arranged a training session for the soldering operators and instructed them on the proper use of solder iron and adjusted the solder iron temperature issue.

Then we collected data for another month and found that in September 2024 the wastage rate was dramatically reduced to 69.27%. It is still a bit high, but the change is noticeable. The waste rate was reduced by 24.51% as compared to the waste rate in August 2024. Per unit, average solder waste was also reduced to 0.28 g/unit. To sustain the improvement, we developed some controlling strategies to keep the operators and lower management alert.

We have some limitations to this study,

- We could not find the sigma level of the process as the unit of solder lead wastages is not pieces.
- We could not show the exact value of recycling the solder lead waste.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Md. Mehedi Hassan Munna, and Jonayed Abdullah.
Methodology: Jonayed Abdullah, and Tarequl Islam.

Investigation: Md. Mehedi Hassan Munna, and Most. Anika Tabassum Little.
Discussion of results: Jonayed Abdullah, Md. Mehedi Hassan Munna, and Tarequl Islam.
Writing – Original Draft: Jonayed Abdullah.
Writing – Review and Editing: Jonayed Abdullah, Tarequl Islam, and Md. Mehedi Hassan Munna.
Resources: Md. Mehedi Hassan Munna, and Most. Anika Tabassum Little.
Supervision: Jonayed Abdullah, and Md. Mehedi Hassan Munna.
Approval of the final text: Md. Mehedi Hassan Munna, Jonayed Abdullah, Tarequl Islam, and Most. Anika Tabassum Little

VII. ACKNOWLEDGMENTS

The author would like to express his gratitude to all parties, starting from data collection and data processing so that this article can be compiled. Hopefully this article is useful and useful as learning material.

VIII. REFERENCES

[1] A. H. Ibrahim, X. Lyu, H. E. Sharafeldin, and A. B. ElDeeb, "Eco-Friendly and Complex Processing of Vanadium-Bearing Waste for Effective Extraction of Valuable Metals and Other By-Products: A Critical Review," *Recycling*, vol. 10, no. 1, p. 6, Jan. 2025, doi: 10.3390/recycling10010006.

[2] A. Palange and P. Dhatrak, "Lean manufacturing a vital tool to enhance productivity in manufacturing," *Materials Today: Proceedings*, vol. 46, pp. 729–736, 2021, doi: 10.1016/j.matpr.2020.12.193.

[3] C. Bai, A. Satir, and J. Sarkis, "Investing in lean manufacturing practices: an environmental and operational perspective," *International Journal of Production Research*, vol. 57, no. 4, pp. 1037–1051, Feb. 2019, doi: 10.1080/00207543.2018.1498986.

[4] T. M. Khalil, *Management of technology: the key to competitiveness and wealth creation*. Boston, Mass.: McGraw-Hill, 2000.

[5] Arunesh Patel, Chintan Chudgar, and ITM Universe, Vadodara, "Understanding basics of Six Sigma," *IJERT*, vol. V9, no. 05, p. IJERTV9IS050866, Jun. 2020, doi: 10.17577/IJERTV9IS050866.

[6] H. Erbiyik and M. Saru, "Six Sigma Implementations in Supply Chain: An Application for an Automotive Subsidiary Industry in Bursa in Turkey.," *Procedia - Social and Behavioral Sciences*, vol. 195, pp. 2556–2565, Jul. 2015, doi: 10.1016/j.sbspro.2015.06.447.

[7] A. C.R. and J. J. Thakkar, "Application of Six Sigma DMAIC methodology to reduce the defects in a telecommunication cabinet door manufacturing process: A case study," *IJQRM*, vol. 36, no. 9, pp. 1540–1555, Oct. 2019, doi: 10.1108/IJQRM-12-2018-0344.

[8] J. Singh, H. Singh, A. Singh, and J. Singh, "Managing industrial operations by lean thinking using value stream mapping and six sigma in manufacturing unit: Case studies," *MD*, vol. 58, no. 6, pp. 1118–1148, May 2019, doi: 10.1108/MD-04-2017-0332.

[9] A. Mittal, P. Gupta, V. Kumar, A. Al Owad, S. Mahlawat, and S. Singh, "The performance improvement analysis using Six Sigma DMAIC methodology: A case study on Indian manufacturing company," *Heliyon*, vol. 9, no. 3, Mar. 2023, doi: 10.1016/j.heliyon.2023.e14625.

[10] S. Salah and A. Rahim, "Integrated Company-Wide Management System (ICWMS)," in *An Integrated Company-Wide Management System*, Cham: Springer International Publishing, 2019, pp. 127–163. doi: 10.1007/978-3-319-99034-7_8.

[11] A. Baptista, F. J. G. Silva, R. D. S. G. Campilho, S. Ferreira, and G. Pinto, "Applying DMADV on the industrialization of updated components in the automotive sector: a case study," *Procedia Manufacturing*, vol. 51, pp. 1332–1339, 2020, doi: 10.1016/j.promfg.2020.10.186.

[12] S. Hakimi, S. M. Zahraee, and J. Mohd Rohani, "Application of Six Sigma DMAIC methodology in plain yogurt production process," *International Journal of Lean Six Sigma*, vol. 9, no. 4, pp. 562–578, Jan. 2018, doi: 10.1108/IJLSS-11-2016-0069.

[13] Y.-T. Jou, R. M. Silitonga, M.-C. Lin, R. Sukwadi, and J. Rivaldo, "Application of Six Sigma Methodology in an Automotive Manufacturing Company: A Case Study," *Sustainability*, vol. 14, no. 21, p. 14497, Nov. 2022, doi: 10.3390/su142114497.

[14] G. Improta *et al.*, "Agile Six Sigma in Healthcare: Case Study at Santobono Pediatric Hospital," *IJERPH*, vol. 17, no. 3, p. 1052, Feb. 2020, doi: 10.3390/ijerph17031052.

[15] A. M. Ponsiglione *et al.*, "A Six Sigma DMAIC methodology as a support tool for Health Technology Assessment of two antibiotics," *MBE*, vol. 18, no. 4, pp. 3469–3490, 2021, doi: 10.3934/mbe.2021174.

[16] M. T. Pereira, M. I. Bento, L. P. Ferreira, J. C. Sá, F. J. G. Silva, and A. Baptista, "Using Six Sigma to analyse Customer Satisfaction at the product design and development stage," *Procedia Manufacturing*, vol. 38, pp. 1608–1614, 2019, doi: 10.1016/j.promfg.2020.01.124.

[17] N. Kumar, S. Shahzeb Hasan, K. Srivastava, R. Akhtar, R. Kumar Yadav, and V. K. Choubey, "Lean manufacturing techniques and its implementation: A review," *Materials Today: Proceedings*, vol. 64, pp. 1188–1192, 2022, doi: 10.1016/j.matpr.2022.03.481.

[18] M. A. Samad, J. Abdullah, and Md. A. H. Rifat, "Reduction of Manufacturing Lead Time by Value Stream Mapping of a Selected RMG Factory in Bangladesh," *AJEAT*, vol. 12, no. 1, pp. 10–17, May 2023, doi: 10.51983/ajeat-2023.12.1.3578.

[19] N. A. Parmar and S. Awasthi, "Review on Quality Management using 7 QC Tools," *International Journal of Trend in Research and Development*, vol. 5, no. 2, pp. 355–358, 2018.

[20] A. Silva, P. Miranda, D. D'Aiuto, and G. Conceição, "Implementation of the Lead Time methodology for managing the analysis of pharmaceutical inputs in Quality Control," in *Annals of the Symposium: building pathways to accelerate the development of the national technological innovation ecosystem*, Instituto de Tecnologia em Imunobiológicos, 2024, pp. 112–112. doi: 10.35259/isi.biomang.2024_63725.

[21] J. George, A. Singh, and A. K. Bhaisare, "A Study of Basic 7 Quality Control Tools and Techniques for Continuous Improvement," in *A Study of Basic 7 Quality Control Tools and Techniques for Continuous Improvement*, Bhopal: Journal of Engineering & Technology, Mar. 2018.

[22] Y. Sadraoui, M. Er-Ratby, M. S. Kadiri, and A. Kobi, "Quality Process Control and Preventive Maintenance Optimization of a Grinding Unit: A Case Study," in *2024 10th International Conference on Optimization and Applications (ICOA)*, Almeria, Spain: IEEE, Oct. 2024, pp. 1–6. doi: 10.1109/ICOA62581.2024.10753891.

[23] J. M. Juran and A. B. Godfrey, *Juran's quality handbook*, 5th ed. New York San Francisco Washington [etc.]: McGraw Hill, 1999.

[24] D. C. Montgomery and W. H. Woodall, "An Overview of Six Sigma," *Int Statistical Rev*, vol. 76, no. 3, pp. 329–346, Dec. 2008, doi: 10.1111/j.1751-5823.2008.00061.x.

[25] J. S. Oakland, *Total quality management: text with cases*, 3. ed., Reprint. Oxford: Butterworth Heinemann, 2007.

[26] A. A. S. Elmahdi, "SYSTEMATIC REVIEW: THE IMPACT OF TOTAL QUALITY MANAGEMENT ON GOLDMINING INDUSTRY PERFORMANCEIN SUDAN," *Geostrategy*, 2023, doi: 10.30546/3006-0346.2023.6.78.109.

[27] D. C. Montgomery, *Introduction to statistical quality control*, 8th ed. Hoboken, NJ: J. Wiley & Sons, 2019.

[28] N. Trisno, B. Arnawisuda Ningsi, and I. Arofah, "ANALISIS PENGENDALIAN KUALITAS DAGING DENGAN MENGGUNAKAN SEVEN TOOLS DI THE FOODHALL PLAZA INDONESIA," *SCI TECH ED MATH*, vol. 5, no. 3, pp. 2109–2130, Dec. 2024, doi: 10.46306/lb.v5i3.785.