International Journal of
Advanced Science Computing and Engineering

Journal Homepage www.ijasce.org/index.php/ijasce

Enhance Operational Efficiency of Manufacturing Process Using Six Sigma in Small Scale Manufacturing Industry: DMAIC Approach

Narender Kumar [a,*], Raj Kumar [a]

[a] *Amity University University Guragaon, Amity Education Valley Gurgaon, Manesar, Panchgaon, Haryana, India*
Corresponding author: [*]nkumar@ggn.amity.edu

***Abstract*— An effective framework for driving process enhancement and boosting operational efficiency in the manufacturing sector has developed as the Six Sigma DMAIC approach. Focusing on its capacity to methodically detect and resolve process inefficiencies, minimise defects, and optimise performance, this article investigates the implementation for Six Sigma DMAIC concepts in manufacturing. According to the research, it's crucial to set precise objectives for each project and measure success based on those goals in order to implement focused improvement efforts at the manufacturing plant The importance of data-driven decision-making, stakeholder participation, and a culture of continuous improvement in generating sustainable outcomes is highlighted in the article via a thorough analysis of the four DMAIC phases—Define, Measure, Analyse, Improve, and Control. In order to successfully apply DMAIC, the results highlight the need of leadership buy-in, employee agency, and cross-functional cooperation. In today's fast-paced manufacturing industry, staying ahead of the competition is crucial. To achieve continuous improvement, customer satisfaction, & long-term success, manufacturing organisations must embrace the Six Sigma DMAIC concepts.**

***Keywords*— Six sigma; DMAIC; operational performance; quality enhancement; data-driven decision-making.**

Manuscript received 17 Apr. 2024; revised 19 Jul. 2024; accepted 21 Nov. 2024. Date of publication 31 Dec. 2024.

I. INTRODUCTION

Manufacturing businesses under ongoing pressure to increase productivity, lower prices, and improve product quality in today's competitive market. Organisations often use strong methods that provide organised frameworks on process improvement in order to satisfy these needs. Six Sigma is one such approach that has been widely used in many different sectors [1]. The DMAIC technique is a fundamental component of the Six Sigma architecture, providing an organised approach to problem-solving and process improvement[2], [3].

Define, Measure, Analyse, Improve, and Control, or DMAIC for short, is a methodical, data-driven methodology to finding and fixing flaws or inefficiencies in manufacturing processes [4], [5]. Six Sigma began at Motorola within the 1980s and was later popularised by organisations such as General Electric. Over time, it developed into a complete approach that is now used by global industrial behemoths like Toyota, Ford, & Boeing. The DMAIC approach's emphasis on improving process efficiency & product quality makes it especially relevant to the manufacturing sector [6]–[8]. Manufacturing organisations may systematically identify areas in improvement, analyse the underlying causes of defects, inefficiencies, apply focused interventions, and set up controls to maintain improvements over time by adhering to the DMAIC framework.

Define, the first stage of DMAIC, lays the groundwork for improvement initiatives by precisely outlining the objectives, parameters, and needs of the client [9], [10]. This phase in the manufacturing process entails determining key operations, comprehending client expectations, and setting quantifiable goals like cutting down on errors, speeding up cycle times, or increasing product dependability [11]. After the Describe phase, the Measure phase uses pertinent metrics and data collecting techniques to measure the defined processes' current performance [12], [13]. This often means collecting data regarding key performance indicators (KPIs) in the manufacturing sector, such as defect rates, cycle durations, yield percentages, and overall throughput. With the help of this data-driven approach, organisations can make well-informed decisions and prioritise areas for development by

having a comprehensive picture of the present condition of their processes.

The Analyse step concentrates on finding the core causes of flaws or inefficiencies with the manufacturing processes once the existing condition has been determined. By using methods like statistical analysis, process mapping, and root cause analysis, businesses are able to identify the variables that lead to differences or flaws in their processes or products [14],[16]. This stage is essential for identifying underlying problems that may not be obvious right away, enabling organisations to deal with them successfully and stop them from happening again.

Organisations go on into the Improve phase, when focused actions are put in place to address identified fundamental causes and optimise the production processes, armed using insights from the Analyse phase [14]. This might include standardizing operational processes, introducing new technology, revamping workflows, or providing staff with ongoing training to improve their skills and expertise [17]. Implementing lasting solutions that result in quantifiable gains in process efficiency and product quality is the main goal of the Improve phase. The Control phase, which concludes, focuses on developing systems to track and maintain the advancements made all through the DMAIC process. By putting control measures in place, like standard operating procedures (SOPs), statistical process control (SPC) charts, and continuous performance monitoring, organisations can make sure that performance targets are met on time and that improvements are sustained over time.

II. Materials and Method

Six Sigma was originally developed as a quality control method with the intention of improving industrial performance, with a focus on large-scale manufacturing companies. Improving and decreasing the number of manufacturing process defects is the major objective of this quality control system. Afterwards, the Six Sigma methodology was adopted by a wide range of industries throughout the world [18], [19]. What does “Six Sigma manufacturing” mean? Let's find out by looking at the Six Sigma definition.

As a statistical symbol & measure of process variance, the Greek letter sigma has recently entered common use [20]. Six Sigma may be written in a variety of ways, but the most common is this 6F. “The Six-Sigma quality aims to reduce process output variance so that on a long term, this will res ult in no >3.4 defects per million opportunities (statistical definition). Hence, Six-Sigma represents a statistical notion that stands for the degree of variability in any given process in relation to quality and client demands[16], [21]. After losing ground in the marketplace to foreign corporations on a regular basis, Motorola came up with the Six Sigma methodology in the 1980s. Products and services produced by a Six-Sigma process have a defect-free rate of 99.9997% because the amount if variation is so tiny or minimum (Kwak & Anbari, 2006). Because of its emphasis on input variables, Six-Sigma's methodology is distinct from more traditional quality improvement programmes. Traditional approaches to process improvement rely on output measurement and control plan creation to shield customer needs from organisational flaws (Leathers, 2006). A data-driven, methodical, and customer-centered approach to improvement is the foundation of Six Sigma. From production to transactions to the end user's service, it is a data-driven, disciplined method for removing flaws from any process (Kumar et al., 2021). Six-Sigma is a lean and precise method for reaching, maintaining, and optimising company success [25]. Neither a management philosophy nor a specific business technique can be characterised as Six-Sigma. Delivering a service or product to clients without any flaws is the goal of the Six Sigma methodology. Six-Sigma provides a variety of resources for methodically enhancing the company as a whole.

Motorola created the Six Sigma idea in 1986 as a collection of methods and instruments to enhance their production operations. Jack Welch utilised this idea as the cornerstone of General Electric's corporate strategy in 1995; it is being used by several industrial sectors. By the end all the twentieth century, this method had been implemented by over half all the Fortune 500 businesses.

To increase the quality of the outputs from a manufacturing process, Six Sigma finds and eliminates components that cause defects as well as lowers the degree of changeability in the business and manufacturing processes. Using this technique, an organisation measures the project's intended value by following a predetermined series of stages. An organisation may increase revenues and customer satisfaction by using Six Sigma in manufacturing. This approach can help minimise pollution, shorten the cycle time of one or more processes, & lower production costs. Upon registering its service mark, Motorola revealed some startling information regarding the advantages Six Sigma had for its company: by the end of 2006, they had saved over $17 billion thanks to the quality improvement procedures provided by this special method.

A. Six Sigma Features and Goals

Six Sigma's steadfast focus on measuring and tracking the project's financial outcomes is a key component for industrial sector progress. With these features, a business may increase its production process by clearly outlining the roles and responsibilities of each team member.

Using Six Sigma production methods aims to reduce manufacturing process defects to a minimum. The system's end goal is to have 3.4 errors for every million possible outcomes. It may seem implausible, yet this is really the method most manufacturing companies use to consistently provide high-quality products.

Numerous training and certification options are another strength of Six Sigma. Certificate holders are organised into various “belt” levels, similar to the amount of martial arts systems do the same; for example, Six Sigma's first certification is called the Six Sigma Green Belt. Masters achieve the status of Six Sigma Black Belt.

Experts in the field who can show they can find projects, quantify them, assess them, make improvements, and oversee them are in great demand. Anyone holding a Six Sigma certification, such as a Green Belt, falls into this category. Certified experts, who may apply their expertise in institutions all over the world, profit from Six Sigma's adoption by other industries, even if it started as a manufacturing technique.

1) The two Six-Sigma process statistical viewpoints are as follows: The statistical viewpoint defines Six-Sigma as having a success rate of 99.9997% or less than 3.4 errors per million possibilities. Therefore, sigma is utilised to express a system's average process variation.

2) From a business standpoint: Six-Sigma is a business approach that aims to improve all operations' efficiency and effectiveness in order to meet or surpass the demands and expectations of customers while also increasing firm profitability. It began with applications in industrial operations and swiftly spread to other functional domains such as engineering, buying, manufacturing and marketing, and service.

Six-Sigma performance is primarily achieved by training, cultural transformation, leadership commitment, data-driven decision-making, and training. High profitability, value addition, and reduced variance are all benefits of six-sigma performance (Figure. 1).

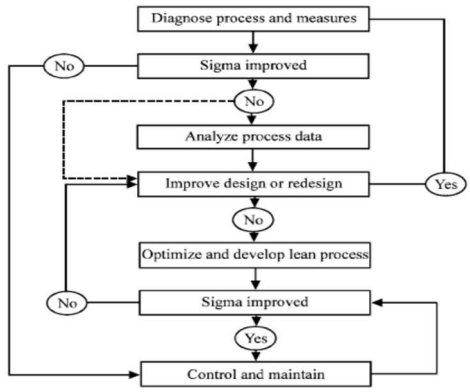

Fig. 1 Essentials of lean Six-Sigma by Taghizadegan

3) Benefits, applications, and techniques of Six-Sigma: For process improvement, Six-Sigma offers two methodologies: "DMAIC" (Define, Measure, Analyse, Improve & Control) and "DMADV" (Define, Measure, Analyse, Design, Verify).

The DMAIC technique is used when a process or product that is already in use at organisation does not function well enough or does not match client specifications whereas the DMADV technique is used when a process or product is needed to be created or to generate a new product.

III. Results and Discussion

A. Impact of Six-Sigma DMAIC Approach on Manufacturing Industries

Statistics are the backbone of the Six-Sigma methodology; sigma denotes the number of standard deviations off the mean of a dataset, or variance, and six-Sigma is an abbreviation for that. At the Six-Sigma level, a process is almost flawless, with an error rate of just 3.4 per million. Statistical & analytical tools allow businesses to eliminate process-related sources of variation, which in turn improves the process's output quality by reducing process variation. Applying Six-Sigma best practices like DMAIC and DMADV is key to the Six-Sigma approach, which aims to optimise processes and sub-processes via measurement-based strategies. It is possible to enhance current processes and seek out incremental improvements by using the Six-Sigma DMAIC (Define, Measure, Analyse, Improve, and Control) method. If you want to build new processes or products to Six-Sigma quality standards, you should use the DMADV (Define, Measure, Analyse, Design, and Verify) method. Fundamental culture change is the only possible outcome of this methodology's successful implementation in an organisation.

The goals of this study are as follows: (1) to evaluate the present state of the Six-Sigma DMAIC method by counting the number of times each tool is used and how difficult it is to use; (2) to identify the obstacles to and advantages of using the DMAIC method.

B. Case Study

Since its inception almost a century ago, the tyre has undergone several transformations. Back in the day, bicycles and carts pulled by horses mostly used solid rubber tyres. John Dunlop first created a tyre with a tube attached to a wheel with spokes. Pneumatic tyres were later used in the 20th century alongside the advent of motor vehicles. The first step in making tyres involves choosing the rubber and other raw ingredients, such as carbon black, specific lubricants, etc. Gum is used to mould these different raw materials with a uniform, one-of-a-kind black combination. In order to guarantee that the raw ingredients are homogeneous, the process of mixing is regulated by computerised systems. Additionally, this combination is transformed into other tyre components, such as the sidewall, treads, and more. Inside the tire's polymer composition, the tyre bead wire serves as a reinforcement.

The primary use of high-carbon steel bead wire is to secure the tyre to the wheel rim. The bead wires of a working tyre may operate at pressures ranging from 30 to 35 psi. Through the rim, bead wires assist in transferring the vehicle's weight to the tyre. Tyre quality and dependable performance are of utmost importance in light of the rising demand for tyres. Furthermore, in this age of technical developments in pneumatic tyre design, it is necessary to preserve quality.

In order to be competitive in the market, businesses must assess, track, and enhance their current production processes. When it comes to developing programmes for continuous quality improvement, various firms utilise different strategies, tactics, and technologies. Beyond this, it is essential that throughout implementation, each organisation makes the right choice and uses the right mix of methods, tools, and processes. The production of any product always involves some degree of variation. Process capability analysis and process management both aim to assist organisations monitor and quantify the process's potential by investigating variability in product manufacture.

When a process is statistically controlled—that is, when the sample mean on the X-bar and R-chart is within three-sigma limits but varies randomly—its capability can be ascertained. Even when a process is under statistical control, it doesn't always mean the results are within specs. The existence of a common cause or the process mean not being properly centred (i.e., there being a considerable difference between the mean value and the stipulated nominal value) might be the reasons for this difficulty. By using control charts, process capability procedures may identify common sources of variance and

work towards achieving statistical control over the process. Numerous applications make use of process capacity indices, such as continuous improvement measurement, defect avoidance in processes or products, improvement direction determination, and so on. How well a process can produce a product that lives up to expectations is quantified by process capability indices. Traditional methods for evaluating a process's viability and efficiency relied on three primary metrics: process capability indices, process anticipated loss, and process yield. Among other processes, the manufacturing sector might benefit from the uncomplicated use of capacity indexes C p and C pk.

IV. Conclusion

Finally, the Six Sigma DMAIC methodology provides a systematic and organised way for manufacturing companies to drive constant enhancement, increase operational efficiency, and provide high-quality products. Meeting customer expectations and achieving corporate goals may be achieved by manufacturing organisations using the Define, Measure, Analyse, Improve, and Control framework. This methodology helps to discover and remove process inefficiencies, minimise defects, and optimise performance.

Given the breadth of this project, it is clear that pinpointing certain processes or locations inside the factory is the way to go for making significant changes. The DMAIC framework allows organisations to set attainable project objectives, track progress towards those goals, identify and address problem areas, and finally, put controls in place to ensure that improvements continue over time.

Additionally, Six Sigma DMAIC projects need buy-in from upper management, participation from key stakeholders, and an attitude of constant improvement to succeed. In order to make a real difference, organizations need to provide their workers with the tools they need to work together across departments, encourage participation in process improvement initiatives, and give them the support they need.

Organizations in the industrial sector that want to survive and thrive in today's fast-paced, highly competitive market must use the Six Sigma DMAIC framework. Organisations may position themselves towards long-term success by adopting a data-driven strategy, using best practices, and developing a culture of excellence. These strategies can help companies create sustainable competitive advantage.

Excellence, quality, and happy customers are the end goals of implementing Six Sigma DMAIC. The concepts and practices of Six Sigma DMAIC will always be useful for industrial organisations as they adapt to new market demands and strive for operational excellence via continuous improvement.

A. Case Study: Discussion

This study examined the tyre industry's use of the DMAIC methodology for process improvement. The present process's capability index, C pk, was first determined to be smaller than 1. Consequently, a diagram with causes and effects was used to ascertain the problem's origins in order to enhance the process performance's worth. Further investigation into the current system was carried out in order to resolve the discovered root cause. Statistical analysis was used in the enhance phase to determine the procedure's capability index value that was improved after the corrective measures were taken. The study's results suggest that a tyre manufacturing plant's process performance may be greatly enhanced by using the six-sigma DMAIC technique.

A study was conducted to identify the factors that helped a radial tyre manufacturing business in India successfully use lean methods. However, this study did not include any manufacturing-related topics either. In order to enhance the process performance, the six-sigma DMAIC approach is used in this research.

Improving the beads splice's process capacity index was the main goal of this study. The index was raised to 2.66, achieving this purpose. Statistically controlled, stable processes are required to provide data for this study. This follows the six-sigma DMAIC excellence methodology, which describes the ability to make decisions for a particular issue type and the best tool for improving the issue kind.

In addition to serving as a benchmark for quality, six sigma may also lead to more efficient and effective processes. The primary goal of implementing the six-sigma methodology is to eliminate all possible sources of error, both internal and external, in order to achieve product and service quality standards that are world-class. For a six-sigma project to be executed properly and effectively, an organization needs the appropriate resources, clear instructions from upper management, and capable leadership. The case company adheres to a variety of quality criteria. To handle problems that emerge in the manufacturing process, they have an R&D division and a strong system of cooperation. As a result, the corrective actions were successful.

B. Limitations

Only the production of 12.7×108 mm Training form Ammo (aircraft & anti-aircraft ammunition) floor was chosen for this case study, which was one of the constraints of the research. They did their best to collect as much data as possible, however. Businesses discourage employees from collecting thorough and reliable data. Thus, similar constraints were encountered in this data collection as well. There had access to skilled personnel from the relevant department, but they knew very little regarding the quality tools. To the best of their abilities, the researchers worked to keep the data and sequence in sync.

1) Extending the scope: As a result of the study's exclusive focus on the manufacturing industry, its results may not apply to other sectors. The findings may not be generalizable to various industrial settings due to differences in organizational culture, industry, and location.

2) Access to Data: The availability of comprehensive data and case studies may limit the study's ability to illustrate real-world examples and empirical evidence. It may be difficult to conduct in-depth analyses and get valuable insights if industrial organizations' private information or sensitive data is not readily available.

3) Limitations on Time: There may be constraints on the depth of the research due to the study's length and scope. The research may miss certain subtleties or complexity in the deployment using Six

4) Sigma DMAIC in the manufacturing business due to time limitations.

5) Implicit bias: The results and conclusions of the study might be impacted by researcher bias and subjective interpretation, even if every attempt was made to remain objective and neutral. A person's biases might be rooted in their own experiences, assumptions, or ties to Six Sigma or other industrial groups.

6) Limited Resources: The scope and depth of the investigation might be affected by limitations in terms of funding, manpower, and logistical assistance. Comprehensive analysis or addressing areas or Six Sigma DMAIC implementation may be hindered due to a lack of specialized experience, training, or technological resources.

REFERENCES

[1] "A comprehensive study of barriers to implementation of green supply chain management in SMEs," *J. Xidian Univ.*, vol. 14, no. 6, pp. XX-XX, Jun. 2020. [Online]. Available: [DOI link]. doi:10.37896/jxu14.6/090.

[2] S. M. M. I. B. M. E. Kabir, "Productivity improvement by using Six-Sigma," *Int. J. Eng. Technol.*, vol. 3, no. 12, pp. 1056-1085, 2013.

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

[4] H. Tannady and F. Jiddan, "The application of Six Sigma framework (Define-Measure-Analyse-Improve-Control) to improve product quality in water dispenser manufacturing company," *J. Sistim Inf. Teknol.*, pp. 7-12, Feb. 2024, doi: 10.60083/jsisfotek.v6i1.339.

[5] N. Mohamad et al., "The application of DMAIC to improve production: Case study for single-sided flexible printed circuit board," *IOP Conf. Ser.: Mater. Sci. Eng.*, vol. 530, no. 1, p. 012041, Jun. 2019, doi: 10.1088/1757-899X/530/1/012041.

[6] I. Daniyan et al., "Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry," *Heliyon*, vol. 8, no. 3, p. e09043, Mar. 2022, doi:10.1016/j.heliyon.2022.e09043.

[7] A. Mittal et al., "The performance improvement analysis using Six Sigma DMAIC methodology: A case study on Indian manufacturing company," *Heliyon*, vol. 9, no. 3, p. e14625, Mar. 2023, doi: 10.1016/j.heliyon.2023.e14625.

[8] M. H. Sajjad et al., "Waste reduction of polypropylene bag manufacturing process using Six Sigma DMAIC approach: A case study," *Cogent Eng.*, vol. 8, no. 1, Jan. 2021, doi:10.1080/23311916.2021.1896419.

[9] R. S. Peruchi et al., "Integrating multivariate statistical analysis into Six Sigma DMAIC projects: A case study on AISI 52100 hardened steel turning," *IEEE Access*, vol. 8, pp. 34246-34255, 2020, doi:10.1109/access.2020.2973172.

[10] A. Boon Sin et al., "Structural equation modelling on knowledge creation in Six Sigma DMAIC project and its impact on organizational performance," *Int. J. Prod. Econ.*, vol. 168, pp. 105-117, Oct. 2015, doi: 10.1016/j.ijpe.2015.06.007.

[11] P. Tsarouhas and N. Sidiropoulou, "Application of Six Sigma methodology using DMAIC approach for a packaging olives production system: a case study," *Int. J. Lean Six Sigma*, vol. 15, no. 2, pp. 247-273, May 2023, doi: 10.1108/IJLSS-06-2022-0140.

[12] N. Kumar, G. Kumar, and R. K. Singh, "Big data analytics application for sustainable manufacturing operations: analysis of strategic factors," *Clean Technol. Environ. Policy*, vol. 23, no. 3, pp. 965-989, Jan. 2021, doi: 10.1007/s10098-020-02008-5.

[13] X. Zu, L. D. Fredendall, and T. J. Douglas, "The evolving theory of quality management: The role of Six Sigma," *J. Oper. Manage.*, vol. 26, no. 5, pp. 630-650, Feb. 2008, doi: 10.1016/j.jom.2008.02.001.

[14] M. Gupta et al., "Integrating Theory of Constraints, Lean and Six Sigma: a framework development and its application," *Prod. Plan. Control*, vol. 35, no. 3, pp. 238-261, May 2022, doi:10.1080/09537287.2022.2071351.

[15] R. Ben Ruben, S. Vinodh, and P. Asokan, "Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study," *Prod. Plan. Control*, vol. 28, no. 15, pp. 1193-1211, Jul. 2017, doi:10.1080/09537287.2017.1357215.

[16] V. Arumugam, J. Antony, and M. Kumar, "Linking learning and knowledge creation to project success in Six Sigma projects: An empirical investigation," *Int. J. Prod. Econ.*, vol. 141, no. 1, pp. 388-402, Jan. 2013, doi: 10.1016/j.ijpe.2012.09.003.

[17] N. Kumar, G. Kumar, and R. K. Singh, "Prioritization of functional areas in manufacturing sector for BDA application," in *Emerging Trends in Mechanical and Industrial Engineering*, pp. 467-476, 2023, doi: 10.1007/978-981-19-6945-4_34.

[18] A. Mittal and P. Gupta, "An empirical study on enhancing product quality and customer satisfaction using quality assurance approach in an Indian manufacturing industry," *Int. J. Math. Eng. Manage. Sci.*, vol. 6, no. 3, pp. 878-893, Jun. 2021, doi:10.33889/ijmems.2021.6.3.052.

[19] H. Erbiyik and M. Saru, "Six Sigma implementations in supply chain: An application for an automotive subsidiary industry in Bursa in Turkey," *Procedia - Soc. Behav. Sci.*, vol. 195, pp. 2556-2565, Jul. 2015, doi: 10.1016/j.sbspro.2015.06.447.

[20] D. Oliveira, L. Teixeira, and H. Alvelos, "Integration of process modeling and Six Sigma for defect reduction: A case study in a wind blade factory," *Procedia Comput. Sci.*, vol. 232, pp. 3151-3160, 2024, doi: 10.1016/j.procs.2024.02.131.

[21] A. Prashar, "Adoption of Six Sigma DMAIC to reduce cost of poor quality," *Int. J. Prod. Perform. Manage.*, vol. 63, no. 1, pp. 103-126, Jan. 2014, doi: 10.1108/IJPPM-01-2013-0018.

[22] L. Leathers, "Customer satisfaction and retention improves with Six Sigma," in *Customising Stakeholder Management Strategies*, pp. 101-116, doi: 10.1007/3-540-31319-2_8.

[23] Y. H. Kwak and F. T. Anbari, "Benefits, obstacles, and future of six sigma approach," *Technovation*, vol. 26, no. 5-6, pp. 708-715, May 2006, doi: 10.1016/j.technovation.2004.10.003.

[24] N. Kumar, G. Kumar, and R. K. Singh, "Big data analytics application for sustainable manufacturing operations: analysis of strategic factors," *Clean Technol. Environ. Policy*, vol. 23, no. 3, pp. 965-989, Jan. 2021, doi: 10.1007/s10098-020-02008-5.

[25] J. Antony et al., "A multiple case study analysis of Six Sigma practices in Indian manufacturing companies," *Int. J. Qual. Reliab. Manage.*, vol. 33, no. 8, pp. 1138-1149, Sep. 2016, doi: 10.1108/IJQRM-10-2014-0157.