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IMPLEMENTATION OF SIX SIGMA METHODOLOGY FOR MANFATURING INDUSTRIES - A REVIEW

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Abstract
The implementation of Six Sigma methodology in manufacturing industries has gained widespread recognition as a transformative approach for process improvement and defect reduction. By adopting data-driven strategies and rigorous problem-solving techniques, Six Sigma aims to achieve near - perfect levels of quality and efficiency by identifying and eliminating defects and process variations. The impact of Six Sigma on manufacturing industries is noteworthy. By reducing defects and process variations, organizations experience improved product quality, increased customer satisfaction, and reduced operational costs due to decreased rework and waste. Focuses on the remarkable impact of Six Sigma in reducing defects and its role in enhancing process efficiency, improving product quality, and increasing profitability for manufacturing organizations**.**
Keywords: Six Sigma, Defect Reduction, Process Improvement, Quality, Efficiency.

I. Introduction

Six Sigma is a set of techniques and tools for process improvement. It was introduced by American engineer “Bill Smith” while working at Motorola in 1986. Six Sigma strategies seek to improve manufacturing quality by identifying and removing the causes of defects and minimizing variability in manufacturing and business processes. Six Sigma methodology has emerged as a powerful tool for achieving operational excellence and process improvement in manufacturing industries. With its data-driven approach and focus on reducing defects and variations, Six Sigma has garnered widespread attention and adoption across various sectors. This review aims to provide a comprehensive assessment of the implementation of Six Sigma in manufacturing industries, exploring its significance, benefits, challenges, and lessons learned. Through the analysis of case studies and research articles, this review aims to offer valuable insights into successful strategies for implementing Six Sigma effectively, leading to improved product quality, enhanced productivity, and sustained competitive advantage in the dynamic manufacturing landscape.

In Six Sigma, there are primarily two main types or methodologies used to improve processes and achieve quality excellence:

DMAIC: DMAIC stands for Define, Measure, Analyze, Improve, and Control. This is the most commonly used Six Sigma methodology and is employed when a process is already in place but is not meeting the desired quality levels. DMAIC is a structured problem-solving approach that aims to identify the root causes of defects, reduce process variations, and bring the process to a state of statistical control. It involves defining the problem, measuring the current performance, analyzing data to identify areas for improvement, implementing solutions, and putting controls in place to sustain the improvements shown in fig-1.

- Define – this stage within the DMAIC process involves defining the team’s role; project scope and boundary; customer requirements and expectations; and selected project goals.
- Measure – this stage includes selecting the measurement factors to be improved and providing a structure to evaluate current performance as well as assessing, comparing and monitoring subsequent improvements and their capability.
- Analyse – this stage centers on determining the root cause of problems (defects) understanding why defects have taken place, and comparing and prioritizing opportunities

for advance betterment.

- Improve – this step focuses on the use of experimentation and statistical techniques to generate possible improvements to reduce the amount of quality problems and/or defects.
- Control – finally, this last stage within the DMAIC process ensures that the improvements are sustained and that ongoing performance is monitored. Process improvements are also documented and institutionalized.

DMADV/DFSS: DMADV stands for Define, Measure, Analyze, Design, and Verify, while DFSS stands for Design for Six Sigma. This methodology is used when a new process, product, or service is being developed, and the goal is to ensure that it meets customer requirements and is capable of delivering high-quality results from the start. DMADV/DFSS focuses on understanding customer Needs, designing the process or product to meet those needs, and verifying the design through testing and validation before implementation.

- Define: In this initial phase, the project goals and customer requirements are defined and documented. The focus is on understanding the problem or opportunity, as well as the expectations of the stakeholders.
- Measure: Once the project is well-defined, the next step is to measure the current state of the process or product. This involves gathering data on the performance metrics, quality levels, and other relevant parameters. The Measure phase aims to quantify the existing performance and identify potential areas of improvement.
- Analyze: The Analyze phase involves a thorough analysis of the data collected during the Measure phase. The objective is to identify the root causes of any issues or defects and to understand the factors influencing the process or product performance
- Design: In the Design phase, potential solutions are developed based on the analysis conducted in the previous phases. The aim is to create a new process or product design that meets customer requirements and addresses the root causes of defects or issues
- Verify: The final phase, Verify, involves the implementation of the new process or product design on a larger scale. The goal is to validate the effectiveness of the improvements and ensure that they meet the desired objectives shown in fig-1.

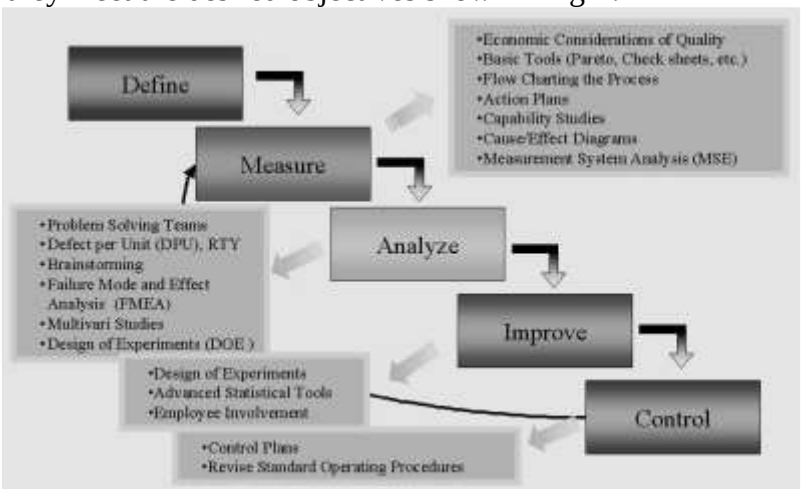

Fig. 1. DMAIC methodology for running Six Sigma projects

- The main objective of Six Sigma is to reduce the costs of quality, which can be divided into tangible and intangible costs. Tangible costs are the visible costs, such as inspection and warranty costs. Intangible costs are the hidden costs, such as lost productivity and customer dissatisfaction.

- The tools and methodology of Six Sigma can be used to reduce both the tangible and intangible costs of quality. This can lead to significant improvements in profitability and customer satisfaction.

II. Literature

There are two types of methods in six sigma and we studied some of those papers and those are mentioned as follows:

G. Hema sriram et al. [1] Conducted Six Sigma in cylinder line to improve the quality in a manufacturing plant. The DMAIC method to identify and eliminate the root causes of defects, resulting in a significant increase in the original equipment (OE) percentage of cylinder liners. The usage of variety of tools and techniques, including fishbone diagrams, Pareto charts, and process capability studies, to analyze the data and identify the root causes of defects. These actions included changes to the manufacturing process, the use of new tools and equipment, and the implementation of new training programs. The results of the project were very successful. The OE percentage of cylinder liners increased from 85% to 97%, and the number of defects per million chances (DPMO) decreased from 1,200 to 300. The company an estimated $1 million per year in rework and scrap costs. This project validates the power of Six Sigma to improve quality and reduce costs.

M.Sokovie et al. [2] paper discusses how Six Sigma can be applied to automotive parts manufacture, with a focus on the DMAIC (Define-Measure-Analyze-Improve-Control) approach. Six Sigma project that was conducted in an automotive parts manufacturing plant. The DMAIC approach to identify and eliminate the root causes of defects in the manufacturing process. As a result of the project, the number of defects per million opportunities (DPMO) was reduced by 50%, and the overall quality of the automotive parts was improved. Six Sigma is a methodology that can be used to improve the quality of automotive parts. The benefits of using Six Sigma to improve the quality of automotive parts include increased customer satisfaction, reduced costs, improved productivity, and enhanced brand reputation. The challenges of implementing Six Sigma in automotive parts production include the need for a strong commitment from management, the need for a skilled and experienced workforce, and the need for a well-defined process.

J.A.Kumar et al. [3] the use of Six Sigma procedure to reduce defects in the manufacturing of rubber gloves. The paper begins by providing an overview of Six Sigma, including its history, principles, and tools. The paper then discusses how Six Sigma can be applied to the manufacturing of rubber gloves, with a focus on the DMAIC (Define-Measure-Analyze-Improve-Control) approach. The number of defects per million opportunities (DPMO) was reduced from 195,095 to 83,750, and the overall quality of the rubber gloves was improved. the successful application of Six Sigma and DMAIC methodologies in a rubber gloves manufacturing process, focusing on how these approaches lead to significant defect reduction, improved production efficiency, and enhanced product quality.

Jirasukprasert. P et al. [4] Six Sigma approach to reduce defects in camshaft manufacturing. Six Sigma, a comprehensive management approach, aims to minimize process variability and achieve a Sigma level of 3.4 defects per million opportunities. By implementing Six Sigma tools and techniques, organizations can identify and eliminate root causes of defects, leading to improved quality, reduced costs, and increased customer satisfaction. The paper presents a case study demonstrating the successful application of Six Sigma in the camshaft manufacturing process, highlighting the specific defects identified, the DMAIC (Define, Measure, Analyze, Improve, Control) steps taken, and the resulting improvements achieved. Through the use of statistical analysis, process mapping, and other Six Sigma methodologies, the defects in camshaft production were systematically addressed, leading to reduced defect rates, enhanced process efficiency, and improved overall value for the organization. This paper underscores the value of Six Sigma in the pursuit of defect reduction, showcasing how it can drive operational excellence, deliver cost savings, and uphold customer-centric values in the manufacturing industry.

Shashank Soni et al. [5] applying Six Sigma methodologies to minimize welding defects in a manufacturing process. The study aims to utilize the DMAIC (Define, Measure, Analyze, Improve, Control) approach to define specific improvement objectives, measure critical performance indicators, analyze data to identify root causes of welding defects, implement targeted improvements, and establish control measures to sustain the defect reduction. The values emphasized in this matter include a commitment to quality, data-driven decision-making, continuous improvement, and a focus on process optimization in welding operations. By leveraging Six Sigma techniques, the research seeks to achieve higher welding quality, reduced defects, increased efficiency, and cost savings in the manufacturing process, ultimately contributing to improved product reliability and customer satisfaction. The study underscores the importance of systematic problem-solving and data-driven strategies to enhance the welding process and overall manufacturing performance, promoting a culture of excellence and continuous improvement in the organization.

Gourav Kolhe et al. [6] leading research to explore the implementation of Six Sigma methodologies in a specific industry. The study aims to investigate how Six Sigma is adopted and utilized to drive process improvement, enhance efficiency, reduce defects, and optimize resource utilization in the chosen industry. The values emphasized in this matter include data-driven decision-making, systematic analysis, and a commitment to quality and continuous improvement. By studying the implementation of Six Sigma in the industry, the research seeks to provide valuable insights into its effectiveness, challenges, and potential benefits, guiding decision-makers and practitioners in adopting and customizing the methodology to improve quality, efficiency, and overall performance in their respective organizations. The study contributes to the broader understanding of process improvement methodologies and their practical applications, ultimately promoting a culture of excellence, productivity, and continuous improvement in the industry.

Serbin Micleaa et al. [7] To Improve The Assembly Process In An Automotive Company" to explore and present the application of Six Sigma methodology in enhancing the assembly process within an automotive company. This paper will discuss the various stages of the DMAIC (Define, Measure, Analyze, Improve, Control) framework and how they were implemented to identify and address defects, bottlenecks, and inefficiencies within the assembly process. The study will provide insights into the tools, techniques, and statistical analysis utilized to measure process performance, analyze root causes of defects, and implement improvement strategies. Furthermore, the paper will present the outcomes and benefits achieved through the Six Sigma implementation, such as reduced defects, enhanced efficiency, improved quality, and increased customer satisfaction. The journal paper will provide a comprehensive understanding of how the application of Six Sigma methodology can lead to significant improvements in the assembly process of an automotive company.

D.Rama Prasad et al. [8] Application of the Six Sigma approach in the manufacturing process of a wire rod mill in a steel plant, with the goal of minimizing downtime. The Six Sigma methodology, widely recognized for its effectiveness in improving process performance and reducing variations, is employed to identify and eliminate the root causes of downtime occurrences. The paper discusses the various stages of the Six Sigma approach, including defining the problem, measuring the current process, analyzing data, implementing improvements, and controlling the process. Through the implementation of Six Sigma tools such as DMAIC (Define, Measure, Analyze, Improve, and Control), statistical analysis, and process mapping, the study illustrates how the wire rod mill's downtime can be systematically identified and addressed. The presented findings demonstrate the effectiveness of using Six Sigma in reducing downtime, which ultimately leads to increased productivity, efficiency, and cost savings. Overall, this journal paper serves as a comprehensive guide for implementing the Six Sigma approach for process improvement in the wire rod manufacturing industry.

Nitesh Kumar.Sahool et al. [9] the importance of reducing rework and rejection on the shop floor to enhance overall efficiency. Rework and rejection significantly impact productivity, costs, and customer satisfaction in manufacturing operations. The various causes and consequences of rework

and rejection, highlighting their negative effect on cycle time, throughput, and quality. It further explores the potential solutions and strategies to minimize rework and rejection incidents, including process optimization, training programs, quality control measures, and continuous improvement methodologies such as Lean and Six Sigma. By implementing these approaches, organizations can streamline production processes, identify root causes of defects, and proactively address quality issues. Real-world case studies and success stories where companies have successfully reduced rework and rejection rates, resulting in increased operational efficiency, reduced costs, and improved customer satisfaction.

S.m. Yaswal et al. [10] the implementation of the Six Sigma methodology for quality improvement in various industrial sectors. Six Sigma is a data-driven approach that aims to minimize defects and variations in processes, leading to improved quality and customer satisfaction. The fundamental principles and key components of Six Sigma, including its DMAIC (Define, Measure, Analyze, Improve, and Control) framework. It further explores the critical steps involved in the successful implementation of Six Sigma, such as project selection, team formation, data collection and analysis, process improvement strategies, and statistical tools utilization. The benefits of implementing Six Sigma, including reduced defects, improved process efficiency, cost savings, and enhanced customer loyalty, are highlighted through real-life case studies and examples. The implementation of the Six Sigma method for quality improvement, serving as a valuable resource for organizations looking to adopt and leverage this methodology to enhance their quality control practices.

Virender verma et al. [11] the title "Utilization of Six Sigma (DMAIC) Approach for Reducing Casting Defects" delves into the application of the Six Sigma DMAIC approach to address and minimize casting defects in manufacturing processes. This study emphasizes the importance of defining clear objectives and problem areas related to casting defects, measuring critical performance indicators to assess the extent of the issue, analyzing data to identify root causes, implementing targeted improvements, and establishing robust control measures. By employing Six Sigma methodologies, the goal is to achieve significant reductions in casting defects, leading to improved product quality, increased efficiency, reduced waste, and enhanced customer satisfaction. This approach fosters a data-driven and systematic problem-solving methodology to optimize casting processes, ultimately contributing to higher productivity and greater value generation for the organization.

Sachin S et al. [12] Six Sigma Methodology for Improving Manufacturing Process in a Foundry Industry" explores the implementation of Six Sigma principles to enhance the manufacturing process in foundry industries. This study focuses on applying the DMAIC (Define, Measure, Analyze, Improve, and Control) approach to identify and address key challenges in the foundry manufacturing process. By defining clear objectives, measuring critical performance metrics, analyzing data to identify root causes, implementing targeted improvements, and establishing robust control measures, the goal is to achieve significant enhancements in the foundry's productivity, efficiency, and product quality. Through the utilization of Six Sigma methodologies, this research aims to reduce defects, optimize resource utilization, minimize variability, and foster a culture of continuous improvement in the foundry industry, leading to improved competitiveness and sustainable growth.

Dr. Vivek Yakkundi et al.[13] The title "Application of Six Sigma Methodology in Welding Process of Boilers for Quality Improvement" investigates the implementation of Six Sigma methodologies to enhance the welding process of boilers and achieve significant quality improvement. By utilizing the DMAIC (Define, Measure, Analyze, Improve, and Control) approach, this study aims to define specific quality improvement goals, measure critical welding performance indicators, analyze data to identify root causes of defects or inconsistencies, implement targeted improvements to optimize the welding process, and establish robust control measures to sustain the achieved quality standards. The application of Six Sigma in the welding process of boilers is expected to result in reduced defects, increased weld integrity, improved product reliability, and enhanced safety, leading to greater customer satisfaction and increased competitiveness in the boiler manufacturing industry.

Additionally, this research fosters a data-driven and systematic problem-solving culture, encouraging continuous improvement and efficiency throughout the welding process.
Pranav Bharara et al.[14] The overall matter of the given title "Implementation of DMAIC Methodology for Reduction of Weighted-Defects in a Vehicle Assembly Process" centers around the application of the DMAIC (Define, Measure, Analyze, Improve, Control) methodology to address and minimize weighted-defects in the vehicle assembly process. The study values systematic problem-solving and data-driven decision-making to define specific goals, measure the severity and frequency of weighted-defects, analyze data to identify root causes, implement targeted improvements, and establish effective control measures. By employing DMAIC in the vehicle assembly process, the research aims to achieve higher product quality, increased customer satisfaction, reduced warranty costs, and improved overall efficiency in delivering vehicles to customers. The focus on continuous improvement and optimization in the assembly process underscores the importance of quality enhancement, waste reduction, and ensuring customer-centric values in the automotive industry.
J. Antony et al.[15] The overall matter of the given title "Gearing Six Sigma into UK Manufacturing SMEs" revolves around the integration and implementation of Six Sigma principles in small and medium-sized manufacturing enterprises (SMEs) in the UK. The focus is on promoting the adoption of Six Sigma methodologies to drive process improvement, enhance efficiency, reduce defects, and optimize resource utilization in these SMEs. The values emphasized in this matter include a commitment to quality, data-driven decision-making, continuous improvement, and the pursuit of excellence in manufacturing processes. By leveraging Six Sigma practices, UK manufacturing SMEs aim to enhance their competitiveness, achieve higher levels of customer satisfaction, and establish a culture of continuous improvement to foster sustainable growth and success in the dynamic business landscape.
Yanamandra Ramakrishna et al. [16] the overall matter of the given title "Empirical Investigation of Mediating Role of Six Sigma" involves conducting a research study to explore and understand the mediating role of Six Sigma in a specific context or scenario. The study aims to empirically investigate and analyze how Six Sigma practices and principles act as mediators between certain variables or factors to influence outcomes or relationships. The values emphasized in this matter include the importance of data-driven research, empirical evidence, and rigorous analysis to provide valuable insights into the impact of Six Sigma implementation on mediating relationships. The study may shed light on the effectiveness and significance of Six Sigma in mediating various organizational processes, decisions, or factors, thereby contributing to the broader understanding of its applications and potential benefits in diverse domains.
Bhavin D. Pandya et al.[17] The overall matter of the given title "A Systematic Literature Review of Six Sigma Implementation in Services Industries" involves conducting a comprehensive and structured examination of existing literature to explore the implementation of Six Sigma methodologies specifically in service industries. The systematic review aims to synthesize and analyze the findings from various studies to gain a deeper understanding of how Six Sigma is applied in the services sector. The values emphasized in this matter include rigorous research methodologies, evidence-based insights, and a data-driven approach to examine the effectiveness, challenges, and potential benefits of integrating Six Sigma in service industries. By providing a comprehensive review of the literature, this study contributes to the knowledge base surrounding Six Sigma practices in services, guiding decision-makers and practitioners in adopting and customizing the methodology to improve quality, efficiency, and customer satisfaction in the service sector.
E. V. Gijoa et al. [18] the overall matter of the given title "Application of Six Sigma Methodology to Reduce Defects of a Grinding Process" focuses on utilizing the Six Sigma methodology to address and minimize defects in a grinding process. The study aims to apply the DMAIC (Define, Measure, Analyze, Improve, Control) approach to define specific improvement objectives, measure and assess defects, analyze data to identify root causes, implement targeted improvements, and establish control measures to sustain the defect reduction. The values emphasized in this matter include data-driven

decision-making, process optimization, and continuous improvement to achieve higher product quality, increased efficiency, and reduced waste in the grinding process. The study underscores the importance of systematic problem-solving and the application of statistical tools to drive quality enhancement and process efficiency, ultimately contributing to improved performance and customer satisfaction in the manufacturing context.

Kunal Ganguly el at. [19] Application of the DMAIC (Define, Measure, Analyze, Improve, and Control) Six Sigma approach to enhance the performance of a rolling mill. Rolling mills play a crucial role in the steel industry, and any inefficiencies or variations in the process can lead to reduced productivity, increased costs, and compromised product quality. The improvement phase, where process modifications and optimizations are implemented to address the identified issues. Additionally, control measures are established to sustain the improvements and ensure long-term success. The effectiveness of the DMAIC Six Sigma approach in improving the rolling mill process is demonstrated through real-world case studies and measurable outcomes, such as reduced defects, improved cycle time, and enhanced overall performance. This journal paper serves as a comprehensive guide for organizations seeking to implement the DMAIC Six Sigma approach for process improvement in rolling mills, providing valuable insights and practical recommendations based on proven industry practices.

Pallawi B Sangode et al. [20] Manufacturing industries face during the implementation of Six Sigma methodologies. Six Sigma is a widely adopted approach for process improvement in various industries, including manufacturing. The paper identifies common barriers such as resistance to change, lack of management commitment, inadequate training and knowledge, organizational culture, and integration challenges. The study explores these barriers in detail, providing insights into their impact on successful Six Sigma implementation. Furthermore, the paper discusses strategies and recommendations to overcome these barriers, including effective change management, leadership involvement, comprehensive training programs, cultural transformation initiatives, and alignment of Six Sigma with overall business goals. By addressing these barriers and adopting proactive measures, manufacturing industries can improve the chances of successful implementation and maximize the benefits offered by Six Sigma methodologies.

Michał Zasadzien et al. [21] the application of the Six Sigma methodology for enhancing maintenance processes in various industries. It discusses the different phases of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) methodology as applied to maintenance, including defining the problem areas, measuring key performance indicators, analyzing data, implementing improvements, and establishing control measures. The utilization of statistical tools for identifying and eliminating sources of wastage and variation in maintenance processes. Real-world case studies and examples are presented to showcase the successful application of Six Sigma in improving maintenance processes, resulting in reduced downtime, increased equipment reliability, enhanced safety, and cost savings. It provides recommendations for overcoming these challenges, including effective change management, proper training, and fostering a culture of continuous improvement.

Deri Maryadi et al. [22] this journal paper explores the application of Lean Six Sigma methodologies in the context of supply chain management. Supply chain management plays a crucial role in optimizing the flow of materials, information, and resources across organizational boundaries. Supply chains face various challenges such as bottlenecks, delays, errors, and waste, which can impact overall efficiency, customer satisfaction, and profitability. Real-world case studies are presented to demonstrate the successful application of Lean Six Sigma in improving supply chain operations, resulting in reduced lead times, increased productivity, improved quality, and cost savings. The challenges associated with implementing Lean Six Sigma n supply chain management, such as resistance to change, organizational and upstream-downstream coordination. Recommendations for overcoming these challenges, including strong leadership support, cross-functional collaboration, employee engagement, and performance measurement systems. Paper provides valuable insights and practical guidance for organizations looking to leverage Lean Six Sigma methodologies to optimize

their supply chain processes, enabling them to achieve higher levels of efficiency, responsiveness, and competitiveness in the global marketplace.

Dr. P.Ramasubramanian et al. [23] Six Sigma methodologies in educational institutions. Traditionally used in manufacturing and service industries, Six Sigma offers a structured approach to process improvement and quality management. The key principles and phases of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, and Control) methodology and provides real-world examples to highlight its successful implementation in educational environments. It offers recommendations for overcoming these challenges, such as obtaining leadership support, providing training and resources, and fostering a culture of continuous improvement. Paper offers valuable insights and practical guidance for educational institutions seeking to leverage Six Sigma to drive operational excellence and achieve higher levels of quality, efficiency, and student success.

Purba, H.H et al. [24] The implementation of Six Sigma methods to increase Sigma levels in productivity improvement and achieve industrial sustainability in the manufacturing industry. Sigma levels, a measure of process capability, indicate the extent to which a process deviates from its desired outcomes. Higher Sigma levels signify lower variation and increased process efficiency. It discusses the key components of Six Sigma, including defining the problem, measuring process performance, analyzing data, implementing improvements, and establishing control measures. Real-world case studies and examples are provided to illustrate the successful application of Six Sigma in different manufacturing contexts, leading to increased Sigma levels and improved productivity. Challenges associated with implementing Six Sigma in the manufacturing industry, such as resistance to change, organizational culture, and data collection processes, are discussed, and recommendations are provided to overcome these challenges.

Lamesa Bulto et al. [25] the integration of Total Quality Management (TQM) with Six Sigma methodologies for achieving operational success in project management. TQM and Six Sigma are two widely recognized approaches for improving quality and efficiency in various industries. It discusses the fundamental principles of TQM and Six Sigma, including customer focus, process improvement. The benefits of integrating TQM and Six Sigma in project management, such as improved stakeholder satisfaction, reduced defects, enhanced process efficiency, and increased project success rates. Case studies and examples are presented to illustrate successful implementations of this integrated approach, showcasing its impact on project outcomes. The challenges faced in integrating TQM and Six Sigma, such as cultural resistance, organizational alignment, and resource allocation, are addressed, and recommendations are provided to overcome these obstacles.

Anna Trubetskaya et al. [26] investigates the application of methodology in the context of strategic space management. Effective space utilization is crucial for organizations to optimize their operations and achieve strategic objectives. The explores how (DFLSS) Design for Lean Six Sigma can be utilized to improve space management processes by integrating design principles, and Six Sigma tools. The successful application of DFLSS in strategic space management, leading to improved utilization, reduced costs, enhanced workflow, and increased operational efficiency. The challenges associated with implementing DFLSS in space management, such as complex space requirements, stakeholder alignment, and change management, providing recommendations to overcome these challenges. Paper offers valuable insights and practical guidance for organizations aiming to incorporate DFLSS into their space management strategies, enabling them to achieve optimal space utilization and support their strategic goals.

Mr. Suraj.s et al. [27] "Implementation of Six Sigma Methodology for Piston Rod Manufacturing" involves applying the Six Sigma methodology to optimize the manufacturing process of piston rods. The study focuses on using the DMAIC (Define, Measure, Analyze, Improve, and Control) approach to define specific objectives, measure critical performance indicators, analyze data to identify root causes of defects or inefficiencies, implement targeted improvements, and establish control measures for sustaining the enhancements. By leveraging Six Sigma practices, the goal is to achieve higher product quality, reduced defects, increased efficiency, and cost savings in the manufacturing process,

ultimately contributing to customer satisfaction and the competitiveness of the company in the automotive or machinery industries.

Kishorekumar Pateli et al. [28] linking the implementation of the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology to enhance the quality of cylinder liners in a manufacturing process by reducing the occurrence of black dots, which are defects or imperfections on the surface of the liners. The study aims to define clear improvement objectives, measure critical quality indicators, and analyze data to identify root causes of black dots, implement targeted improvements, and establish control measures to sustain the defect reduction. The values emphasized in this matter include a systematic problem-solving, and continuous improvement to achieve higher product quality, reduced defects, increased efficiency, and customer satisfaction. The research focuses on fostering a culture of quality excellence, standardization, and waste reduction in the cylinder liner manufacturing process, ultimately contributing to the organization's competitiveness, reputation, and long-term success in the automotive.

Teja prasana et al. [29] a comprehensive review of the implementation of Six Sigma in manufacturing industries. Six Sigma, a well-known quality management methodology, aims to minimize process variation and achieve a Sigma level of 3.4 defects per million opportunities. The review also discusses common challenges and success factors in implementing Six Sigma, such as strong leadership support, employee engagement, data-driven decision-making, and a continuous improvement mind-set. By understanding and applying the principles of Six Sigma, manufacturing industries can achieve operational excellence, foster a culture of quality, and sustain long-term success in a highly competitive market. This paper serves as a valuable resource for practitioners, researchers, and organizations looking to gain insights into successful Six Sigma implementation practices and the value it offers across manufacturing industries.

Michal zasadzien et al.[30] Application of the Six Sigma Method for Improving Maintenance involves utilizing the Six Sigma methodology to enhance maintenance practices in a specific context or industry .The study aims to apply the DMAIC (Define, Measure, Analyze, Improve, Control) approach to define specific improvement objectives, measure critical performance indicators, analyze data to identify root causes of maintenance issues, implement targeted improvements, and establish control measures to sustain the improvements achieved. By leveraging Six Sigma practices, the research seeks to optimize maintenance processes, reduce downtime, minimize defects, and enhance equipment reliability, ultimately contributing to cost savings, increased productivity, and customer satisfaction in the respective industry.

C. Kobia et all.[31] Assessment of Lean Manufacturing and Six Sigma Operation with Design Making based on the Analytic Hierarchy Process involves evaluating and comparing the implementation of Lean Manufacturing and Six Sigma methodologies using the Analytic Hierarchy Process (AHP) as a decision-making tool. The study aims to assess the effectiveness and suitability of Lean and Six Sigma in a specific context or industry by considering various criteria and factors in a hierarchical manner. By utilizing the AHP, the research seeks to provide valuable insights into selecting the most suitable methodology, leading to higher efficiency, reduced waste, improved product quality, and overall performance in the respective context. The study contributes to the broader understanding of process improvement methodologies and guides decision-makers in implementing the most effective approach for sustainable success and competitive advantage.

Utomo et all.[32] conducting a comprehensive and structured examination of existing literature to explore the implementation of Six Sigma methodologies specifically in service industries The values emphasized in this matter include rigorous research methodologies, evidence-based insights, and a data-driven approach to examine the effectiveness, challenges, and potential benefits of integrating Six Sigma in service industries. By providing a comprehensive review of the literature, this study contributes to the knowledge base surrounding Six Sigma practices in services, guiding decision-makers and practitioners in adopting and customizing the methodology to improve quality, efficiency, and customer satisfaction in the service sector.

Rajeev Rathi et al. [33] the application and impact of Lean Six Sigma methodologies in the healthcare industry. The study to examine how the combination of Lean principles, which focus on waste reduction and process efficiency, and Six Sigma principles, which aim to reduce defects and variation, can be effectively utilized to improve healthcare processes, patient outcomes, and overall efficiency in healthcare organizations. The values emphasized in this matter include a commitment to quality patient care, data-driven decision-making, continuous improvement, and the pursuit of excellence in healthcare delivery. By leveraging Lean Six Sigma practices, the research seeks to optimize healthcare processes, reduce medical errors, enhance patient safety, and improve overall healthcare performance, ultimately contributing to better patient experiences and outcomes in the healthcare sector.

Rohin Titmarsh et al. [34] An Industry 4.0 Perspective involves investigating and highlighting the role of Lean Six Sigma methodologies in meeting sustainable manufacturing requirements, considering the context of Industry 4.0. By leveraging Lean Six Sigma practices within the Industry 4.0 framework, the research seeks to identify how manufacturers can achieve higher levels of sustainability, reduce waste, enhance process efficiency, and optimize resource utilization, ultimately contributing to a greener and more responsible approach to manufacturing while remaining competitive in the global market. The study also underscores the importance of aligning Lean Six Sigma practices with the principles of Industry 4.0, emphasizing the value of innovation, adaptability, and technological integration for sustainable and successful manufacturing practices.

Nedra Abbes et al.[35] the development and application of a novel assessment model for evaluating an organization's readiness to implement Lean Six Sigma methodologies, using fuzzy logic as a decision-making tool. The study aims to create a comprehensive and data-driven approach to assess an organization's preparedness for Lean Six Sigma adoption, considering multiple criteria and uncertainties using fuzzy logic. Continuous improvement to ensure effective Lean Six Sigma implementation. By leveraging the New Lean Six Sigma Readiness Assessment Model, the research seeks to provide valuable insights into an organization's capability to adopt and successfully implement Lean Six Sigma, identify potential areas of improvement, and guide decision-makers in tailoring strategies for process optimization, waste reduction, and enhanced overall performance. The study contributes to the advancement of Lean Six Sigma practices and the integration of fuzzy logic for decision-making, ultimately leading to higher levels of efficiency, productivity, and quality in organizations.

Adefemi Adeodua et al. [36] Development of an Improvement Framework for Warehouse Processes using Lean Six Sigma (DMAIC) Approach" The study aims to develop a systematic and data-driven improvement process to identify areas of inefficiency, reduce waste, and optimize resource utilization in warehouse operations. The values emphasized in this matter include a commitment to continuous improvement, data-driven decision-making, and a focus on customer needs and satisfaction. By leveraging Lean Six Sigma, the research seeks to achieve higher levels of warehouse efficiency, reduced lead times, improved inventory management, and enhanced overall performance. The study contributes to fostering a culture of continuous improvement and operational excellence, creating a more efficient and effective warehouse environment that adds value to the organization, its stakeholders, and customers.

Anna Luisa C. Guevarra et al. [37] Employees Preference Analysis on Lean Six Sigma Program Coaching Attributes Using a Conjoint Analysis Approach involves conducting a study to understand employees' preferences and priorities regarding coaching attributes in a Lean Six Sigma program. The research aims to utilize the conjoint analysis approach to assess how different coaching attributes are perceived and valued by employees participating in a Lean Six Sigma program. The values emphasized in this matter include a data-driven approach, systematic analysis, and a focus on employee engagement and satisfaction. The research contributes to the understanding of employee perspectives in Lean Six Sigma implementation, promoting a more personalized and efficient coaching experience that aligns with employees' needs and expectations.

Ankesh Mittal et al. [38] Performance Improvement Analysis Using Six Sigma DMAIC Methodology: A Case Study on an Indian Manufacturing Company" involves conducting a performance analysis and improvement study using the Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) methodology. The research focuses on a specific Indian manufacturing company and aims to systematically identify areas for improvement, measure critical performance indicators, analyze data to pinpoint root causes of issues, implement targeted improvements, and establish control measures to sustain the enhancements achieved.

Murilo Riyuzo Vendrame et al. [39] Small- and Medium-Sized Enterprises in the Plumbing Industry in the United States" involves examining the benefits of implementing Six Sigma methodologies in small- and medium-sized enterprises (SMEs) in the plumbing industry in the United States. The research aims to explore how SMEs can leverage the Six Sigma methodology to achieve process improvement, optimize resource utilization, reduce defects, enhance product quality, and increase overall efficiency. The study contributes to promoting the adoption of Six Sigma practices and methodologies in SMEs, fostering a culture of continuous improvement, and driving sustainable success in the plumbing industry and other small businesses across various sectors.

Ioana-Catalina Enache et al.[40] Reducing the Scrap Rate on a Production Process Using Lean Six Sigma Methodology involves the application of Lean Six Sigma methodologies to address and minimize the scrap rate in a production process. The values emphasized in this matter include a commitment to quality, data-driven decision-making, continuous improvement, and a focus on process optimization. By leveraging Lean Six Sigma practices, the research seeks to achieve higher product quality, reduced waste, increased efficiency, and cost savings in the production process, ultimately contributing to improved productivity and customer satisfaction. The study underscores the importance of waste reduction and process optimization in manufacturing, fostering a culture of continuous improvement and efficiency in the organization.

III. Conclusion

The implementation of Six Sigma methodology has proven to be a game-changer for manufacturing industries, revolutionizing their processes, enhancing product quality, and driving overall success. By development a culture of data-driven decision-making improvement, Six Sigma enables organizations to stay ahead of the competition and deliver superior products to their customers. The success stories presented in this review highlight the transformative impact of Six Sigma on manufacturing processes, leading to improved customer satisfaction, higher product reliability, and enhanced competitiveness in the global market. Emphasizing a data-driven decision-making process, Six Sigma enables manufacturers to make informed choices, optimize their production systems, and continuously strive for excellence, making it a valuable tool for ensuring sustainable growth and success in the manufacturing sector. While challenges exist, the benefits far outweigh the effort invested, making Six Sigma a tool for any manufacturing industry seeking excellence and growth.

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