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A COMPREHENSIVE REVIEW ON SIX SIGMA IMPLEMENTATION ON THE MANUFACTURING INDUSTRY

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ABSTRACT
Manufacturing companies are constantly seeking ways to enhance their competitive edge in today's fast-paced and ever-evolving business landscape. One effective approach to achieving this goal is through the implementation of Six Sigma methodologies. By leveraging Six Sigma's data-driven approach and toolkit, companies can refine their processes, boost productivity, and elevate product quality, ultimately leading to increased customer satisfaction and reduced production costs. The digital revolution has brought about unprecedented demands for adaptability and process optimization. Manufacturing companies must be agile and responsive to changing market conditions, customer needs, and technological advancements. Six Sigma provides a framework for achieving this agility, enabling companies to streamline processes, eliminate defects, and attain near-perfect quality. This paper synthesizes research from various journals, showcasing the efficacy of Six Sigma methods in improving product quality and productivity. By harnessing Six Sigma's toolkit, businesses can identify and address process inefficiencies, reduce variability, and enhance overall performance. The methodology's focus on data-driven decision-making ensures that improvements are targeted and effective. This study provides an in-depth examination of Six Sigma's impact on the manufacturing sector, highlighting its potential to revolutionize productivity, quality, and efficiency. Through a comprehensive review of existing research, this paper demonstrates the value of Six Sigma in driving business excellence and competitiveness. The findings unequivocally demonstrate the efficacy of Six Sigma in improving productivity, quality, and customer satisfaction.
Keywords: six sigma, quality, production, productivity, manufacturing

Introduction
Six Sigma is a methodology used in manufacturing to improve the quality of processes and products. It aims to reduce defects and variations, resulting in increased customer satisfaction and cost savings. Six Sigma is a data-driven approach to quality management that aims to reduce defects and variations in processes, products, and services. In a manufacturing industry, Six Sigma implementation involves defining critical quality issues and setting goals, measuring current processes, analyzing data to identify root causes of defects and variations, improving processes by implementing solutions, and controlling and maintaining improved processes.

Literature
A comprehensive overview of Six Sigma implementation in the manufacturing industry reveals its transformative impact, with versatile applications across various sectors, bringing advantages like enhanced efficiency, reduced defects, and improved customer satisfaction, but also disadvantages like high implementation costs, resource intensity, and potential employee resistance. Despite this, its future scope promises continuous improvement, innovation, and global competitiveness, as supported by insights from renowned journal papers, providing a thorough understanding of Six Sigma's role in shaping the manufacturing landscape and mentioned them, below:
Daniela Oliveiraa al., [1] The article discusses a case study where a Portuguese wind turbine blade manufacturer faced challenges with defects and repair time, causing production delays. To address this, the company used the Six Sigma DMAIC approach combined with Business Process Management

(BPM) to improve process quality and reduce defects and repair time. The study demonstrates the effectiveness of combining BPM with the DMAIC methodology in enhancing process quality and efficiency. The use of data visualization tools and visual management techniques facilitated communication and improvement. The results exceeded the project's goals, showing a significant reduction in defects and repair time. Overall, the study showcases the successful application of the Six Sigma DMAIC approach combined with BPM in a wind turbine blade manufacturing company, achieving significant improvements in process performance, quality, and efficiency.

Anshu Gupta et.al., [2] The article presents a case study on the implementation of Six Sigma in a Micro Small Medium Enterprise (MSME) in India. The study aims to develop a hybrid Six Sigma framework for quality improvement in MSMEs, integrating operations research methods and tools. The case study is about a small-scale manufacturing firm in India that produces portable amplifiers. The firm faced problems of low productivity and high costs due to high rejection rates and repairs. The study applied the hybrid Six Sigma framework to improve the screen-printing process. The results showed a significant reduction in defects (51%) and an improvement in the sigma level of the process (from 3.64 to 4.54). The study demonstrates the effectiveness of the hybrid Six Sigma framework in improving quality and reducing defects in MSMEs. The study contributes to the existing literature on Six Sigma implementation in MSMEs and provides a roadmap for successful implementation. The hybrid framework can be applied to other MSMEs facing similar challenges, and the study's findings can be generalized to other industries and contexts. Overall, the article demonstrates the potential of Six Sigma in improving quality and reducing defects in MSMEs, and highlights the need for a structured and systematic approach to quality improvement in these organizations.

Attia Hussien Goma, [3] The article presents a systematic review of Lean Six Sigma (LSS) in the manufacturing domain, focusing on its applications, tools, and success factors. LSS is a continuous improvement methodology that combines Lean and Six Sigma principles to enhance quality, efficiency, and competitiveness. The study analysed 52 papers from 2014 to 2023 and identified the most popular topics, gaps, and success factors in LSS implementation. The objectives of LSS in manufacturing include reducing defect ratios, improving sigma levels, reducing cycle times, improving production rates, reducing process wastes, and reducing production costs. The study found that LSS has been applied in various industries, including small and medium-sized enterprises (SMEs), food industry, maintenance operations, supply chain management, and automotive industry. The most commonly used LSS tools and techniques include process mapping, defect analysis, value stream mapping, seven quality control tools, lean wastes, visual control, and standardized work. The study concludes that LSS is an effective methodology for manufacturing companies to achieve continuous improvement and competitiveness. The proposed LSS-DMAIC framework provides a structured approach for companies to implement LSS and achieve sustainable results. Overall, the article provides a comprehensive review of LSS in manufacturing, highlighting its applications, tools, and success factors. The proposed framework offers a valuable resource for manufacturing organizations seeking to implement LSS and improve their performance.

Attia Hussien Goma, [4] The article presents a case study on the implementation of Lean Six Sigma (LSS) in a spare parts company in Egypt to improve quality and reduce waste in a machining process. The study uses various tools and techniques, such as brainstorming, process mapping, and statistical analysis, to develop a generic LSS-DMAIC framework for manufacturing. The study follows the LSS-DMAIC framework, which consists of five phases: Define, Measure, Analyse, Improve, and Control. In the Define phase, the project scope and problems are identified. In the Measure phase, the current state of the system is documented, and important metrics related to product quality and process performance are identified. In the Analyse phase, the root cause of problems and system inefficiencies are identified. In the Improve phase, recommendations and solutions are developed and implemented.

In the Control phase, a control plan is developed to monitor and maintain the improvement plan. The article highlights the importance of using data-driven approaches to identify and address defects and wastes in manufacturing processes. The study's findings and results can be applied to other manufacturing processes and industries, making it a valuable contribution to the field of quality management and process improvement. Overall, the article provides a comprehensive case study on the implementation of LSS in a manufacturing process, highlighting its benefits and results. The proposed LSS framework can be used by production managers and leaders to improve quality, reduce waste, and enhance overall performance.

Minh Ly Duc et.al., [5] The article presents a case study on the application of a Hybrid Six Sigma method to improve the induction heat treatment process in a mechanical factory. The study combines fuzzy Multi-Attribute Decision Making (MADM), Industry 4.0, and digital numerical control (DNC) to reduce production costs and improve product quality. The study follows the DMAIC framework, which consists of five phases: Define, Measure, Analyse, Improve, and Control. In the Define phase, the problem is identified, and the project scope is defined. In the Measure phase, data is collected to understand the current process. In the Analyse phase, experts are invited to conduct brainstorming and interviews to identify key criteria for improvement. In the Improve phase, solutions are proposed, and a new process is designed. In the Control phase, a new system is implemented to monitor and control the process. The article highlights the benefits of using fuzzy MADM in decision-making and the importance of involving experts in the improvement process. The study also demonstrates the potential of Industry 4.0 technology in improving production efficiency and reducing costs. Overall, the article provides a comprehensive case study on the application of a Hybrid Six Sigma method in a mechanical factory, highlighting its benefits and results. The proposed method can be used by manufacturing companies to improve their production processes and reduce costs.

Fatima Ezzahra Achibat et.al., [6] The article presents a study on the impact of Six Sigma and Lean Manufacturing on the performance of companies in Morocco. The study aimed to investigate the effectiveness of these methodologies in improving quality, productivity, and customer satisfaction. A questionnaire was sent to various Moroccan companies, and 45 responded. The study analysed financial and operational performance using SPSS software. The results showed that the use of Lean Manufacturing and Six Sigma methodologies has a significant impact on company performance. The study found that companies that use both methodologies experience more significant improvements in quality, productivity, and financial performance. The combination of Lean Manufacturing and Six Sigma is ideal and complementary, leading to better financial and operational performance. The article highlights the importance of quality improvement in companies and the effectiveness of Six Sigma and Lean Manufacturing methodologies in achieving this goal. The study provides valuable insights for companies seeking to improve their performance and competitiveness. Overall, the article provides a comprehensive study on the impact of Six Sigma and Lean Manufacturing on company performance, highlighting the benefits and results of implementing these methodologies. The study's findings can be applied to companies in various industries, making it a valuable contribution to the field of quality management and process improvement.

Ayyappan Solaiyappan, [7] The article presents a case study on the implementation of Lean Six Sigma (LSS) methodology in a refractory company to improve the manufacturing process capability of the Shaft kiln process. The DMAIC approach was used to identify the Critical to Quality (CTQ) characteristics and determine the root causes of productivity issues. The study began with the Define phase, where key metrics were identified, and data collection was developed and executed to understand the process in detail. The Measure phase established a standard measuring system to set specification limits for factors contributing to low productivity. The Analysis phase used Cause and Effect analysis and Failure Mode and Effect Analysis to identify potential causes, and the Improve

phase concentrated on improving and optimizing factors impacting temperature values. The Control phase ensured that the process continued to work well and maintained quality levels. The study found that raw crude from mines, moisture content, and frequency of using Temperature calibration equipment were the main factors responsible for lowering productivity. Recommendations included changing the raw crude, increasing the frequency of measuring oil feeding calibration equipment, and decreasing moisture content to increase productivity. Overall, the article provides a comprehensive case study on the implementation of LSS in a refractory company, highlighting the benefits and results of using this methodology to improve manufacturing processes. The study's findings can be applied to other industries and processes, making it a valuable contribution to the field of quality management and process improvement.

Santosh B. Rane et.al., [8] The article presents a case study on the integration of Lean Six Sigma (LSS) with Internet of Things (IoT) technology to improve productivity in the contactor manufacturing industry. The study aimed to reduce rejection rates and production costs using the DMAIC approach and IoT technology. The study began with the Define phase, where the problem was identified, and data was collected to understand the process. The Measure phase involved collecting data on rejection rates, and the Analyse phase used tools like Pareto charts and Fishbone diagrams to identify root causes. The Improve phase suggested measures to address these causes, and the Control phase implemented and monitored these measures. The study found that poor surface quality and excessive pick-up voltage were the main reasons for rejection, and addressed these issues by increasing abrasive grain size and implementing IoT technology for real-time monitoring and control. The results showed significant improvements in productivity, with a reduction in rejection rates and production costs. The study demonstrates the effectiveness of integrating LSS with IoT technology in improving manufacturing processes. Overall, the article provides a comprehensive case study on the integration of LSS and IoT technology in the contactor manufacturing industry, highlighting the benefits and results of using this approach to improve productivity and quality.

Zahran Abd Elnaby et.al., [9] The article presents a case study on improving plastic manufacturing processes by integrating Six Sigma and machine learning techniques. The study aimed to enhance product quality, reduce defects, and optimize production processes in a plastic bottle manufacturing company. The study used the DMAIC approach, which consists of five phases: Define, Measure, Analyse, Improve, and Control. In the Define phase, the problem was identified, and project goals and objectives were defined. In the Measure phase, data was collected to understand the process and identify areas for improvement. In the Analyse phase, data was analysed to determine the root causes of defects. In the Improve phase, potential solutions were generated and tested, and the best solutions were implemented. In the Control phase, the process was monitored and documented to ensure sustainability. The article demonstrates the benefits of using data-driven approaches to improve manufacturing processes. The study's findings can be applied to other industries and processes, making it a valuable contribution to the field of quality management and process improvement. Overall, the article provides a comprehensive case study on the integration of Six Sigma and machine learning techniques in plastic bottle manufacturing, highlighting the benefits and results of using this approach to improve product quality and reduce waste.

Mehmet Altug, [10] The article presents a case study on the application of Six Sigma principles to improve the efficiency and quality management of a fastener manufacturing company. The study aimed to reduce defects in the coating process, which were resulting in wasted time and excessive costs. The study used the DMAIC (Define, Measure, Analyse, Improve, Control) model to identify and address the root causes of defects. In the Define phase, the problem was defined, and the scope and objectives of the improvement project were established. In the Measure phase, data was collected to understand the process and identify areas for improvement. In the Analyse phase, data was analysed

to determine the root causes of defects. In the Improve phase, potential solutions were generated and tested, and the best solutions were implemented. In the Control phase, the process was monitored and documented to ensure sustainability. Overall, the article provides a comprehensive case study on the application of Six Sigma principles in fastener manufacturing, highlighting the benefits and results of using this approach to improve product quality and reduce waste. The study demonstrates the effectiveness of Six Sigma in improving process efficiency, reducing waste, and increasing customer satisfaction. The use of deep learning and Taguchi experimental design added value to the study by providing a robust and data-driven approach to process improvement.

Indra Setiawan et.al., [11] The article presents a case study on the application of the DMAIC (Define, Measure, Analyse, Improve, Control) method to reduce defects in the roof panel packaging process at PT Toyota Motor Manufacturing Indonesia. The study aimed to improve the quality of the packaging process by minimizing defective products. The study used the Six Sigma DMAIC method to identify and address the root causes of defects. In the Define phase, the problem was defined, and the scope and objectives of the improvement project were established. In the Measure phase, data was collected to understand the process and identify areas for improvement. In the Analyse phase, data was analysed to determine the root causes of defects. In the Improve phase, potential solutions were generated and tested, and the best solutions were implemented. In the Control phase, the process was monitored and documented to ensure sustainability. The results of the study showed a decrease in the defect rate from 33,500 units to 31,450 units and an increase in the Sigma Level from 3.33 to 4.37. The study demonstrates the effectiveness of the DMAIC method in improving process quality and reducing defects. Overall, the article provides a comprehensive case study on the application of the DMAIC method in the automotive industry, highlighting the benefits and results of using this approach to improve product quality and reduce waste. The study suggests that future research can focus on applying the Lean Six Sigma method to reduce waste and defects further. The Lean Six Sigma method integrates Lean principles with the Six Sigma DMAIC method to eliminate waste and improve process efficiency.

Thi Bao Tram Nguyen et.al., [12] The article presents a case study on the implementation of Lean Six Sigma (LSS) in a paper production company in Nigeria. The study aimed to evaluate and improve productivity and reduce manufacturing wastes in the company. The study used a case study approach, gathering data on machine functionality, materials, and labour flow to identify areas for improvement. The results showed that the current production process was below standard, with low process cycle efficiency, high lead time, and high manufacturing wastes. The article highlights the importance of academic-industry collaboration in improving production processes. The collaboration between industry experts, academic faculty, and students was crucial to the project's success. Overall, the article provides a comprehensive case study on the implementation of LSS in a paper production company, highlighting the benefits and results of using this approach to improve product quality and reduce waste. The study suggests that LSS can be applied to other industries and processes, making it a valuable contribution to the field of quality management and process improvement. The article provides valuable insights for manufacturing companies seeking to improve their processes and reduce defects. The study's findings can be applied to other industries and processes, making it a valuable contribution to the field of quality management and process improvement.

Iskandar Zulkarnaen et.al., [13] The article presents a case study on the application of Lean Six Sigma in a push-belts manufacturing company for the automotive industry. The company experienced product quality issues, despite having a 100% inspection rate. The study aimed to identify and remove the root cause of the problem and reduce the defect rate to 0%. The study used the DMAIC (Define, Measure, Analyse, Improve, Control) cycle to address the problem. In the Define phase, SIPOC analysis was used to understand the process better. In the Measure phase, data was collected to identify the affected

area and calculate the defect rate and sigma level. In the Analyse phase, a cause-and-effect diagram was used to analyse the possible root causes of the problem. In the Improve phase, two root causes were identified and addressed: the combination of three factors creating the failure mode in the fine blanking machine, and the AOI system not being designed to detect defective elements. In the Control phase, standardized improved methods and monitoring mechanisms were introduced to maintain the project results. Overall, the article provides a comprehensive case study on the application of Lean Six Sigma in the automotive industry, highlighting the benefits and results of using this approach to improve product quality and reduce waste.

Vikas Swarnakar et.al., [14] This paper presents a case study on reducing painting defects in the four-wheeled vehicle industry using the Lean Six Sigma-DMAIC approach. The study aimed to identify and analyse root causes of painting defects, provide solutions, improve process capabilities, and increase the sigma level in the painting process. The study used the DMAIC approach, which consists of five stages: Define, Measure, Analyse, Improve, and Control. In the Define stage, a production check sheet was used to determine the percentage of defects. In the Measure stage, data was processed to calculate the sigma level. In the Analyse stage, a fishbone diagram was used to identify root causes of defects. In the Improve stage, corrective actions were taken to address the root causes. In the Control stage, data was processed to evaluate the effectiveness of the corrective actions. The study found that the dominant defect in the painting section was the orange peel defect. The study identified several root causes of the defect, including human factors, machine factors, material factors, method factors, and environmental factors. The study implemented several corrective actions, including tightening supervision of painting section operators, improving operator training, and modifying the painting process. The study resulted in a significant reduction in painting defects, from 32.6% to 12.1%. The sigma level also improved from 2.5 to 3.5. The study demonstrates the effectiveness of the Lean Six Sigma-DMAIC approach in improving quality and reducing defects in the automotive industry. Overall, the article provides a comprehensive case study on the application of Lean Six Sigma-DMAIC in the automotive industry, highlighting the benefits and results of using this approach to improve product quality and reduce waste.

Vo Ngoc Mai Anh et.al., [15] The article presents a study on the benefits of Lean Six Sigma (LSS) in manufacturing organizations in India. LSS combines the waste reduction of Lean manufacturing with the variation reduction of Six Sigma. The study aimed to assess the impact of LSS on quality, cost, delivery, production capacity, net earnings, customer satisfaction, and other key performance indicators. The study was conducted in three Indian manufacturing organizations using surveys and statistical analysis. The results showed that LSS implementation had a positive impact on all 10 benefits identified, with "reduce overall defects in product" having the strongest impact. The study used the Relative Importance Index technique to rank the LSS attributes in order of importance. The study suggests that LSS principles can be applied to solve major issues or problems in manufacturing organizations and provide an extra effort to implement Lean Six Sigma in their processes. Overall, the article provides a comprehensive study on the benefits of Lean Six Sigma in manufacturing organizations in India, highlighting the importance of LSS in improving quality, reducing waste, and increasing customer satisfaction.

Dr. Jaskiran Arora et.al., [16] The paper presents a case study of an e-commerce industry that struggled with timely delivery for its premium subscription customers. The study used the Six Sigma methodology to optimize the delivery process. The Six Sigma approach was used to identify and analyse the problems faced by the e-commerce industry, and to develop solutions to address them. The study used various Six Sigma tools and techniques, including design of experiments, Pareto charts, SIPOC diagrams, process mapping, and cause-and-effect diagrams. The study analysed over 800 data sets and identified the root causes of the delivery issues. The study found that the main causes of the

delivery issues were related to process inefficiencies, inadequate resources, and poor communication. The study proposed solutions to address these issues, including process improvements, resource optimization, and communication enhancements. The study concluded that the Six Sigma methodology was effective in improving process capability and quality, and that it can be used to optimize delivery time and address other business challenges. The study also emphasized the importance of using a systematic approach to problem-solving, and the need for organizations to adopt a data-driven approach to decision-making.

Tharisya Sanrio Putri et.al., [17] The paper presents a case study of a garment company that produces collared shirts and T-shirts for the upper middle market segment. The company faced issues with high defect rates, with 5.4% of collared shirts and 4.6% of T-shirts having defects. The study aimed to identify the types of defects, analyse the causes, and suggest improvements using the Six Sigma DMAIC methodology. The study used various tools and techniques, including fishbone diagrams, why-why analysis, FMEA, and control charts. The study found that the main types of defects were holed, dirty, cut, and oblique defects. The fishbone diagram and FMEA analysis identified the causes of these defects, including machine issues, human error, and material quality problems. The study proposed improvements, including machine maintenance, training, written regulations, and additional equipment. The implementation of these improvements resulted in a decrease in defect percentages and an increase in sigma levels, indicating improved process quality. The study concluded that the Six Sigma methodology was effective in identifying and addressing defects, and improving quality in the production process. The study also highlighted the importance of continuous monitoring and control to ensure sustained quality improvement.

Rajeev Trehan et.al., [18] The paper presents a case study of a large-scale industry in India that implemented the Lean Six Sigma (LSS) framework to reduce defects and increase customer satisfaction. The company, which manufactures LED tubes, was facing customer complaints about product reliability and was struggling to maintain market share. The LSS framework was applied to identify and address the root causes of defects in the manufacturing process. The study used the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to identify and validate the problem, collect data, analyse the root causes, propose solutions, and implement improvements. The study found that the main causes of defects were related to the soldering and depaneling operations, and that the driver component was critical to the reliability of the LED tube. The team proposed solutions to overcome the problems, including conducting aging tests, removing extra flux from the PCB, and improving housekeeping and cleaning practices. The implementation of the LSS framework resulted in significant improvements, including a reduction in aging failure rate from 9.4% to 0.13%, a reduction in non-functioning driver rate from 12.6% to 1.6%, and a decrease in defects per unit (DPU) from 0.23 to 0.02. The improvements were achieved with minimal investment and were recovered in less than a month. The study concluded that the LSS framework was effective in reducing defects and improving customer satisfaction, and that it can be applied to other industries to achieve operational excellence. The study also highlighted the importance of commitment from top management and active participation from employees at all levels to make LSS an integral part of the organization's work culture.

Jiju Antonya et.al., [19] The paper presents a case study of a Six Sigma project implemented in an automotive manufacturing process to improve the first pass yield of a match grinding process. The project used the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to identify and address the root causes of defects in the process. The project resulted in a significant improvement in the first pass yield, from 85% to 99.4%, and reduced the defect rate to 5715 ppm. The project also resulted in annualized savings of $70,000 and improved customer perception. The paper highlights the importance of using advanced statistical tools and techniques to analyse data and identify solutions. The project used tools such as cause-and-effect diagrams, gauge repeatability and reproducibility

studies, and regression analysis to identify the root causes of defects and validate solutions. The paper concludes that the Six Sigma methodology is a powerful tool for improving process quality and reducing defects, and that it can be applied to a wide range of industries and processes. The paper also highlights the importance of sustaining improvements over time, and notes that the success of the project encouraged the management to implement Six Sigma methodology for all improvement initiatives in the organization.

Gijo et.al., [20] The paper presents a case study of the application of Lean Six Sigma (LSS) in an IT support services department of a large electrical equipment manufacturing company in India. The company was facing customer complaints regarding the resolution time of IT-related issues, and LSS was chosen as a methodology to address the root causes and improve the process. The study followed the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to identify and address the root causes of delays in complaint resolution. The team identified non-value-added activities, potential causes, and root causes, and implemented solutions to address them. The improvements resulted in a reduction of resolution time from 12.49 hours to 8.47 hours, with a standard deviation reduction from 28.01 hours to 17.368 hours. The paper also emphasizes the importance of leadership commitment and employee involvement in the success of LSS projects. The study demonstrates that LSS can be used as a catalyst for small- and large-scale improvements in any business, leading to sustainable bottom-line results. Overall, the paper provides a comprehensive case study of the application of LSS in IT support services, highlighting its benefits and challenges.

Muhammad Tahir Khan Farooqi et.al., [21] The study explores the impact of Six Sigma practices on teaching-learning effectiveness at the University of Okara. Six Sigma, a quality control methodology, has been widely adopted in various fields, including education, to achieve high-quality services, processes, and products. The study aims to investigate the implementation of Six Sigma in the higher education sector and its impact on teaching-learning effectiveness. The study found that faculty members at the University of Okara are unaware of Quality Management Systems (QMS) like Six Sigma, which affects the quality of higher education. While teachers are able to define and analyse problems, they neglect the improvement and control phases of Six Sigma. The study concludes that using Six Sigma approaches can enhance teaching effectiveness, but there is a need for awareness and training on how to apply Six Sigma in the teaching-learning process. Overall, the study highlights the potential benefits of applying Six Sigma practices to teaching effectiveness and suggests areas for improvement in the university's teaching practices. The findings of this study can be useful for educational institutions seeking to enhance the quality of higher education and improve teaching-learning effectiveness.

Ahmad Yusuf Fimahali et.al., [22] PT. Sidogiri Mandiri Utama, a bottled drinking water company in Indonesia, faced quality control issues, resulting in defective products exceeding standards. To address this, the company employed the Six Sigma DMAIC approach and Failure Mode and Effect Analysis (FMEA) to reduce defects. The study aimed to improve product quality using these methods. The Six Sigma DMAIC approach identified four defects in the production process: less volume, dirty water, damaged packaging, and untidy covers. Measurements revealed a high defect rate, with 2121 products per million opportunities (DPMO) and an average sigma value of 4.36, falling short of the 6σ target. The Analyze stage used fishbone diagrams to determine the root causes of defects, including poor raw material quality, inadequate machine maintenance, human negligence, and improper storage methods. The Improve stage applied FMEA to calculate the Risk Priority Number (RPN) and propose recommendations for improvements. The study concluded that the Six Sigma DMAIC approach and FMEA method effectively reduced defects and improved product quality. The company can enhance product quality and move towards world-class standards by implementing these improvements. Future researchers can consider these findings and recommendations for further study.

Mrigendra Nath Mishra, [23] The paper explores the critical success factors for implementing integrated Green and Lean Six Sigma methodologies. Through a literature review and survey of selected organizations, the study identifies five key success factors: dedicated management and

employee commitment, organizational readiness, project selection and prioritization, resource allocation and skills development, and performance measurement and results. The study highlights the importance of integrating Green, Lean, and Six Sigma approaches to achieve sustainable performance and address the limitations of individual methodologies. The findings show that dedicated management and employee commitment are crucial for long-term success, followed by organizational readiness, project selection and prioritization, and resource allocation and skills development. The study's results can be used by organizations to develop strategies for implementing integrated Green and Lean Six Sigma, focusing on the critical success factors identified. By prioritizing dedicated management and employee commitment, organizational readiness, project selection and prioritization, resource allocation and skills development, and performance measurement and results, organizations can ensure successful implementation and achieve sustainable performance.

Bengt Klefsjoe et.al., [24] The paper discusses Six Sigma as a valuable methodology within the broader framework of Total Quality Management (TQM). While some view Six Sigma as a rehash of old ideas, the authors argue that it offers a fresh and strategic approach to driving improvement. Six Sigma originated at Motorola in the 1980s as a quality improvement approach, focusing on reducing variation in processes and achieving near-perfect quality. The methodology is top-down, disciplined, data-oriented, and typically includes four stages: measure, analyse, improve, and control. Six Sigma programs have common features, including a focus on processes, variation, and customer satisfaction, and use statistical tools and techniques. The authors believe that Six Sigma is an effective application of statistical techniques, delivered in an innovative manner, and that it is not just a fad or a technically rigorous approach, but a valuable methodology for achieving business success. The authors conclude that Six Sigma is a powerful methodology for achieving business excellence by reducing variation and improving processes. Its structured and systematic approach, combined with efficient statistical tools and techniques, has proven to be highly effective in achieving significant cost savings and quality improvements. By understanding the history, principles, and context of Six Sigma, organizations can harness its potential to drive operational excellence and achieve strategic goals, ultimately leading to enhanced customer satisfaction and financial performance.

H Henny et.al., [25] The study applied the Lean Six Sigma approach to minimize waste in the production of chili sauce and shrimp sauce. The researchers used the DMAIC (Define, Measure, Analyse, Improve, Control) methodology to identify and reduce waste. In the Define stage, waste was identified and categorized into 7 types. In the Measure stage, calculations of Defect Per Million Opportunities (DPMO) and sigma levels were performed to assess process performance and capability. The study identified critical waste in the production of chili sauce, including moving a labelling table close to the sauce palette, repetition activities from inspection of firmness of closure, and closing defects. Proposed solutions included rearranging the packing area layout, standardizing the process of checking firmness, and replacing manual lid binding with an automatic machine. In the production of shrimp sauce, critical waste included manual resorting and skin stripping, cleaning raw materials, and waiting for downtime. Proposed solutions included determining and standardizing RPM and release rubber, using hopper funnels, and scheduling services and replacing components. The study concluded that the Lean Six Sigma approach can be used to minimize waste and optimize production efficiency. By identifying and addressing critical waste, companies can reduce defects and improve process capability. The study provides a framework for applying the Lean Six Sigma approach in the food industry to improve quality and reduce waste.

Manuel Baro et.al., [26] The paper discusses the application of the 6 Sigma methodology in the automotive assembly industry, specifically in the production of forklifts. The methodology uses the DMAIC (Define, Measure, Analyse, Improve, Control) process to reduce problems classified as quality-critical, transportation-critical, or cost-critical. The paper explains each stage of the DMAIC process and the quality tools used to achieve the objectives of each stage. The case study presented in the paper aims to increase the efficiency of the forklift production line and reduce the number of defects. The Define stage identified the problems and variables affecting the product or process, and

set goals for improvement. The Measure stage measured the number of defects in the production line using process capacity indices. The Analyse stage identified the root cause of the problems using tools like value stream maps, 5 Whys, and Ishikawa diagrams. The Improve stage implemented solutions to address the root causes, and verified the effectiveness of the improvements through pilot tests and training. The Control stage monitored and controlled the improved process using statistical process control, control charts, and continuous monitoring. The paper also highlights the importance of identifying and addressing the root causes of problems, and the need for continuous monitoring and control to ensure sustained improvements. The case study demonstrates the effectiveness of the 6 Sigma methodology in improving efficiency and reducing defects in the automotive assembly industry.
Shamsuzzaman et.al., [27] The paper presents a case study on the application of Lean Six Sigma (LSS) methodology to improve productivity in a metal can manufacturing industry. The study used the DMAIC (Define, Measure, Analyse, Improve, Control) framework to identify and address the root causes of low productivity. The Define phase identified the problem areas and formed a project implementation team. The Measure phase collected data on defectives/scraps and total production quantity and constructed Laney's P´ chart to ensure the process is statistically in-control. The Analyse phase analysed the factors responsible for low productivity and identified the root causes. The Improve phase recommended solutions to address the root causes, including implementing a specific sampling plan and lab testing for incoming raw material quality, following a preventive maintenance policy, and documenting procedures and solutions for future reference. The Control phase monitored maintenance activities and submitted monthly performance reports. The study resulted in an annual productivity improvement of 511,992 non-defective products, equivalent to an annual increased sales of $25,600. The improvement is expected to enhance customer satisfaction, minimize production cost, and maximize company's goodwill and profit. The study demonstrates the effectiveness of the LSS methodology in solving quality-related problems in the metal can manufacturing industry.
Hanshuo Zhao, [28] The paper presents a case study on the application of Six Sigma methodology to improve the quality of generator sets at Company A. The company experienced quality problems, including zero-kilometer failures, which prompted the use of Six Sigma methods to reduce defects and improve customer satisfaction. The Analyse phase identified three main areas of problems: exterior bumping and rusting, oil leakage, and inability to start, using tools like Pareto diagrams and fishbone diagrams. The Improve phase implemented timely improvements, including using appropriate PE film, adding fluorescent agents to detect oil leaks, and revising standard operating instructions for battery installation. The Control phase standardized the improvement process, updated quality management system documents, and continuously monitored the improvement process, resulting in a 56% reduction in zero-kilometer failure PPM. The study demonstrates the effectiveness of the Six Sigma methodology in improving product quality and reducing defects in the generator set industry. The paper concludes that the Six Sigma methodology is a valuable tool for companies to improve efficiency, customer satisfaction, and brand image.
K. Kanyinda et.al., [29] The paper presents a case study on the application of the Six Sigma DMAIC approach to reduce energy consumption in a commercial building in South Africa. The study aimed to identify the factors contributing to increased electricity consumption and implement measures to reduce energy usage. The Define phase identified the problem of high energy consumption in the building, while the Measure phase collected data on energy usage from the energy supplier and an eGauge installed in the main supply DB. The Analyse phase used statistical tools to identify the root causes of high energy consumption, revealing that the boiler was the main contributor, accounting for 38.33% of energy usage. The Improve phase implemented measures to reduce energy consumption, including adjusting the boiler's temperature setup, which resulted in a 6% reduction in energy consumption. The Control phase ensured that the improvements were sustained by implementing control measures, such as introducing an automatic system device to regulate the boiler's temperature. The paper highlights the importance of energy efficiency in commercial buildings, citing the United Nations' Sustainable Development Goal 7, which emphasizes the need for affordable and accessible

clean energy. The study's findings contribute to the growing body of research on energy efficiency in buildings, demonstrating the potential for quality management tools to drive sustainable practices in the built environment.

Nandita Priya et.al., [30] The paper presents a case study on the application of the Six Sigma DMAIC method to improve the quality of plastic sacks produced by a recycling company. The company experienced a high defect rate of 3.12% over six months, exceeding the tolerance limit of 2%. The study aimed to identify and analyse defects in the production process, calculate the defect rate, and propose solutions to reduce waste. The study demonstrates the effectiveness of the Six Sigma DMAIC method in improving product quality and reducing defects in the plastic sack production process. The findings highlight the importance of identifying and addressing root causes of defects, and implementing control measures to sustain improvements. The study's results can be applied to similar initiatives in other industries. The paper highlights the importance of quality control in maintaining product quality, and the need for continuous improvement to reduce waste and increase consumer attractiveness. The study's findings contribute to the growing body of research on quality management and Six Sigma methodologies in various industries.

Do Ngoc HIEN et.al., [31] The paper presents a case study on integrating Industry 4.0 technology into a manufacturing process to enhance productivity and quality. The study proposes a simplified methodology for integrating Industry 4.0 systems into the Six Sigma DMAIC method, which includes using IoT technology to collect data, automation systems to measure and record data, artificial intelligence and data analytics to analyse factors affecting quality and performance, automation technology to improve production processes, and automation and control systems to maintain and control the production process. The study highlights the benefits of Industry 4.0 technologies in improving efficiency, accuracy, and product quality. However, it also notes challenges and limitations, such as financial investment, data security, and the need for proper training and support. The proposed solutions aim to address these challenges and improve the overall manufacturing process. The study concludes that the successful implementation of Industry 4.0 technologies can lead to reduced lead times, fewer defects, and improved customer satisfaction. The paper also highlights the importance of considering challenges such as financial investment, data security, and training when implementing ERP and RFID in manufacturing.

Suwanda, [32] The paper examines the role of the Six Sigma method in controlling and improving product quality in the processing industry. The research uses a qualitative descriptive approach, analysing secondary literature to uncover the benefits and impact of Six Sigma on product quality. The study finds that Six Sigma has a significant positive impact on product quality, enabling companies to control process variability, focus on customer satisfaction, and use statistical methods for data analysis. This leads to increased product consistency, customer loyalty, and fact-based decision-making. The DMAIC concept, a core component of Six Sigma, provides a structured framework for continuous improvement, while cross-functional employee involvement fosters a collaborative culture and shared ownership of improvement goals. The study concludes that Six Sigma is a comprehensive quality management approach that supports business sustainability and competitiveness by ensuring high-quality products and services. The paper contributes to the growing body of research on Six Sigma and its applications in industry, highlighting its effectiveness in controlling and improving product quality. The findings provide insights into the benefits and impact of Six Sigma, emphasizing its importance in achieving operational excellence, increasing efficiency, reducing defects, and improving customer satisfaction.

Radosław WOLNIAK et.al., [33] The paper explores the benefits and challenges of combining Six Sigma with Industry 4.0 technologies like IoT, AI, and big data analytics. The integration of Six Sigma's data-driven approach with Industry 4.0's advanced technologies can improve quality, efficiency, and customer satisfaction. The benefits of this integration include better quality control, data-driven decision-making, and competitive advantage. The paper also highlights the importance of effective change management and a balanced approach to integrating Six Sigma and Industry 4.0. It

emphasizes the need for organizations to adapt and optimize processes to ensure efficiency, quality, and customer satisfaction in the rapidly evolving industrial landscape. The study concludes that the integration of Six Sigma and Industry 4.0 offers a powerful synergy that enhances quality, efficiency, and competitiveness. While there are challenges to overcome, such as data overload and technology integration, the benefits of this integration include improved quality control, enhanced decision-making, and cost reduction, leading to higher customer satisfaction and competitive advantage.

Yaman Parid et.al., [34] The paper presents a systematic literature review of Six Sigma implementation in the automotive component industry. The study aims to analyze current research on Six Sigma in the industry and identify opportunities for further research. A systematic literature search was conducted using specific inclusion and exclusion criteria, resulting in 50 scientific articles. The study found that research on the impact of Six Sigma implementation is the most popular, with 47 articles published in recent years. This research focuses on the effects of Six Sigma on business performance, quality performance, and sustainability performance. In contrast, research on the development of Six Sigma is scarce, with only three articles published. The study identifies two main categories of research goals: Six Sigma impact and Six Sigma development. Six Sigma impact encompasses the effects of Six Sigma implementation, while Six Sigma development includes the expansion of Six Sigma scope, integration with other systems, and digitalization. The study concludes that there is a significant body of research on the complete Six Sigma methodology in the automotive component industry, particularly on the impact of implementing Six Sigma. However, there is a lack of research on Six Sigma development, especially in the area of digitalization.

M. A. K. Tengtarto et.al., [35] The paper presents a comprehensive review of the Six Sigma methodology, covering its development and applications from 1904 to 2022. The study uses bibliometric analysis to examine the use of Six Sigma in various fields, with data collected from Scopus. The results show that Six Sigma has been widely used in engineering (21.4%), business, management, and accounting (11.9%), and chemistry (8.8%). The number of publications on Six Sigma has increased significantly over the years, with a peak in 2021. The study also identifies areas that require further research, including chemical engineering (3%), biochemistry (4.2%), and medicine (5.6%). Additionally, the paper highlights the importance of considering the location of case studies in future research to determine the development of Six Sigma in different countries. The paper concludes that Six Sigma plays a crucial role in improving product quality, particularly in the engineering and manufacturing fields. The methodology has been widely adopted across various industries, and its benefits include cost reduction, productivity improvement, market share growth, cycle time reduction, customer satisfaction, defect reduction, work culture change, and product or service development.

Namrata Prakash et.al., [36] The paper explores the role of Total Quality Management (TQM) and Six Sigma in the manufacturing industry. TQM focuses on continuous improvement, customer satisfaction, and employee involvement, while Six Sigma is a data-driven approach to reduce errors and variability. The study aims to identify the benefits of implementing TQM and Six Sigma in the manufacturing sector. The paper presents the results of an empirical study, where 210 respondents were surveyed to gather their views on the role of TQM and Six Sigma in the manufacturing industry. The data analysis reveals that the majority of respondents agree that TQM and Six Sigma implementation leads to enhanced product quality, cost reduction, reduced waste, and improved manufacturing processes. Additionally, the study finds that TQM and Six Sigma implementation results in better staff engagement and motivation. The paper concludes that TQM and Six Sigma are powerful approaches that can significantly improve the quality and effectiveness of industrial processes. While Six Sigma focuses on statistical analysis to identify and eliminate process flaws, TQM emphasizes continuous improvement through employee involvement. The study highlights the benefits of implementing TQM and Six Sigma, including improved product quality, increased customer satisfaction, and enhanced productivity.

Genett Jimenez-Delgado et.al., [37] The textile industry is a significant contributor to the global economy, but it faces challenges in improving productivity and quality. Lean Six Sigma (LSS) is a methodology that can help address these challenges. This paper presents a case study of a small textile company in Colombia that implemented LSS to reduce lead time and improve quality. The company, which manufactures sportswear, faced issues with prolonged lead times and high rates of non-conforming products. The LSS team used the DMAIC (Define, Measure, Analyse, Improve, Control) framework to identify the root causes of these problems and develop solutions. In the Define phase, the team identified the key processes and stakeholders involved in the manufacturing process. In the Measure phase, they collected data on cycle times and non-conforming products. In the Analyse phase, they used tools such as Value Stream Mapping and cause-and-effect analysis to identify the causes of the problems. In the Improve phase, the team developed and implemented six improvement plans, including reassigning operators, defining optimal batch sizes, implementing 5S methodology, and adopting visual control techniques. In the Control phase, they established a control plan to monitor and sustain the improvements. The results of the implementation showed significant reductions in lead time and non-conforming products. The company was able to reduce its cycle time by 30% and its non-conforming products by 25%. The study demonstrates the effectiveness of LSS in improving productivity and quality in the textile industry, particularly in small companies.

Adefemi Adeodu et.al., [38] The paper presents a case study of a paper production company in Nigeria that implemented Lean Six Sigma (LSS) to improve productivity and reduce manufacturing wastes. The company faced issues with low process cycle efficiency, high lead time, and high manufacturing wastes, leading to customer dissatisfaction. The study used a case study approach, gathering data on machine functionality, materials, and labour flow to identify areas for improvement. The data was analysed using Lean tools such as Value Stream Mapping (VSM), Process Cycle Efficiency (PCE), Kanban, Poka-Yoke, 5S, Pareto chart, and analysis. The results showed that the current production process was below standard, with low process cycle efficiency, high lead time, and high manufacturing wastes. The LSS team identified areas for improvement and implemented changes, resulting in significant improvements in productivity and reductions in manufacturing wastes. The study demonstrates the effectiveness of LSS in improving productivity and reducing wastes in the paper production industry. The collaboration between industry experts, academic faculty, and students was crucial to the project's success, highlighting the importance of academic-industry collaboration.

Jakfat Haekal, [39] The paper presents a case study of a pharmaceutical company in Indonesia that applied Six Sigma and KAIZEN techniques to reduce non-conformities in the primary packaging product process (filling) of infusion bottles. The company faced issues with high reject rates, with paracetamol infusion products having the most rejects at 2,303 pieces over three months. The study used the DMAIC (Define, Measure, Analyse, Improve, Control) method and KAIZEN techniques to identify the root causes of the reject quality and propose solutions. The research found that the main quality issues were fibre, dirt, and packaging rejects, with fibre rejects being the most common. The cause-and-effect diagram revealed that human error, specifically operator mistakes, were the primary cause of rejects. The study concluded that the application of Six Sigma and KAIZEN techniques can significantly reduce non-conformities in the pharmaceutical industry. The research highlights the importance of identifying and addressing the root causes of quality issues and proposes practical solutions to improve productivity and reduce rejects.

Erysa Putri Vara Afifa et.al., [40] The paper presents a case study of a washing machine manufacturer, PT XYZ, in Indonesia that implemented Six Sigma to reduce defects in its twin tub washing machine production, specifically in the wash motor part. The company faced quality issues with a sigma level of 4.99 and aimed to reduce defects using the Six Sigma DMAIC method. The study identified four dominant defect types: rivet loose, rusty, noise, and no function. The Six Sigma approach was used to analyse the causes of these defects and suggest improvements based on the 5-M checklist (man, machine, method, material, and environment). The DMAIC phases were used to identify Critical to Quality (CTQ) characteristics, measure the current process performance, analyse the causes of defects,

improve the process, and control the improvements. The study found that the dominant defect types were caused by various factors, including human error, machine issues, and material quality. The study concluded that the Six Sigma approach can support quality control and improve product quality by providing alternative solutions to suppliers. The company can consider providing suggestions for improvements to the supplier to be implemented based on existing improvement priorities.

Conclusion

In conclusion, the implementation of Six Sigma in manufacturing companies has proven to be an effective approach to improving competitiveness through continuous improvement in process planning, productivity, and product quality. The digital revolution demands adaptability and process optimization for efficiency, quality, and customer satisfaction with minimal cost and efforts. This study has demonstrated that the application of Six Sigma methods can significantly improve product quality, productivity, and customer satisfaction, while reducing production costs. The results of this research reveal that Six Sigma is a valuable tool for controlling and improving productivity, production quality, and customer satisfaction in the manufacturing industry, ultimately leading to increased efficiency and competitiveness. the implementation of Six Sigma methodologies in manufacturing companies is a highly effective strategy for achieving operational excellence and enhancing competitiveness. By leveraging Six Sigma's data-driven approach and toolkit, companies can significantly improve product quality, productivity, and customer satisfaction, while reducing production costs and minimizing defects. The findings of this study unequivocally demonstrate the value of Six Sigma in driving business excellence and competitiveness, making it an indispensable tool for manufacturing companies seeking to thrive in today's fast-paced and ever-evolving business landscape. Ultimately, Six Sigma's focus on continuous improvement and data-driven decision-making enables companies to achieve near-perfect quality, reduced variability, and enhanced overall performance, positioning them for long-term success and sustainability.

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