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Original Research Article

Optimizing Manufacturing Efficiency through Six Sigma: A Comprehensive Approach in Industrial Engineering

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Abstract

Six Sigma has developed as a powerful methodology in industrial engineering for improving process efficiency, reducing defects, and enhancing overall productivity. Established in statistical analysis and continuous improvement principles, Six Sigma provides a structured framework for identifying process variations and reducing inefficiencies. This research paper explores the application of Six Sigma methodologies in industrial engineering, focusing on its impact on quality control, cost reduction, and operational excellence. The study examines real-world case studies from manufacturing industries, highlighting successful implementations of Six Sigma tools such as DMAIC (Define, Measure, Analyze, Improve, Control) and DMADV (Define, Measure, Analyze, Design, Verify). Additionally, it discusses the integration of Six Sigma with lean manufacturing principles to optimize workflows and reduce waste. The findings emphasize the significance of Six Sigma in fostering a culture of continuous improvement, driving competitive advantage, and ensuring sustainable growth in industrial engineering. This paper determines with recommendations for industries aiming to implement Six Sigma for long-term operational success.

Keywords: Six Sigma, Industrial Engineering, Manufacturing Efficiency, DMAIC, DMADV, Quality Control, Lean Manufacturing, Process Improvement, Operational Excellence, Continuous Improvement.

INTRODUCTION

In the competitive landscape of modern manufacturing, achieving operational excellence and maintaining high product quality are crucial for sustaining growth and profitability. Industrial engineering plays a pivotal role in optimizing manufacturing processes, where even small inefficiencies can lead to significant cost overruns and reduced productivity. To address these challenges, Six Sigma has emerged as a widely adopted methodology that combines statistical analysis with a structured problem-solving framework to enhance process efficiency and minimize defects. Originating from Motorola in the 1980s, Six Sigma has since become a standard practice in various industries due to its effectiveness in improving quality control and reducing operational costs.

In the rapidly evolving industrial landscape, manufacturing efficiency and product quality have become critical factors for maintaining competitive advantage and achieving sustainable growth. Industrial engineering focuses on optimizing production processes, minimizing waste, and improving product quality through structured methodologies and innovative technologies. One of the most widely adopted methodologies for enhancing manufacturing efficiency is Six Sigma, which provides a data-driven, structured approach to identifying and eliminating defects in production processes. Originally developed by Motorola in the 1980s, Six Sigma has evolved into a powerful tool for improving operational performance and achieving business excellence across various industries (Cheng, 2010) [1].

Six Sigma integrates statistical analysis with a structured problem-solving framework such as DMAIC

(Define, Measure, Analyze, Improve, Control) and DMADV (Define, Measure, Analyze, Design, Verify), allowing organizations to identify process variations, enhance quality control, and reduce costs (Parka *et al.*, 2009) [2]. The combination of Six Sigma with lean manufacturing principles, often referred to as Lean Six Sigma (LSS), has gained significant traction in manufacturing, particularly in the food and automotive industries, due to its effectiveness in improving both process efficiency and product quality (Costa *et al.*, 2018) [3].

This paper explores the role of Six Sigma and Lean Six Sigma in industrial engineering, focusing on their application in various manufacturing sectors. It examines real-world case studies and discusses the readiness factors and challenges associated with Six Sigma implementation. The study also explores the integration of Six Sigma with other frameworks such as ISO/TS 16949 and the Kano quality model to improve overall operational performance. The findings provide valuable insights and recommendations for industries seeking to leverage Six Sigma to drive long-term operational excellence and sustainable growth.

LITERATURE REVIEW

To understand the impact of Six Sigma on industrial engineering, a comprehensive review of existing research and case studies was conducted. The literature highlights the application of Six Sigma across various industries, emphasizing its effectiveness in improving quality control, reducing costs, and enhancing customer satisfaction.

1. Six Sigma in Manufacturing

Several studies have explored the successful application of Six Sigma in the manufacturing sector. Liu (2011) [3], demonstrated the effectiveness of Six Sigma in a forging manufacturing plant, highlighting how DMAIC methodology was used to identify process inefficiencies and improve production yield. Similarly, Kaushika and Khandujab (2009) [5], applied Six Sigma in thermal power plants, reporting significant improvements in operational efficiency and cost reduction. The structured nature of Six Sigma methodologies enables manufacturers to systematically identify and eliminate process variations, leading to higher product quality and reduced waste.

Table 1: Six Sigma in Manufacturing research and outcomes

Study	Industry	Methodology	Outcome
Liu (2011)	Forging Manufacturing	DMAIC	Increased production yield
Kaushika & Khandujab (2009)	Thermal Power Plant	DMAIC	Improved operational efficiency, reduced costs

2. Lean Six Sigma (LSS) in the Food Industry

The food manufacturing industry has also benefited from Lean Six Sigma implementation. Costa *et al.*, (2018) [3] conducted a systematic review of LSS in the food industry, emphasizing its role in improving production efficiency and ensuring compliance with safety standards. Dora and Gellynck (2015) [7], presented a case study of LSS implementation in a small food processing company, which resulted in improved product consistency and reduced production downtime. The development of self-assessment tools for readiness in the food industry has further facilitated the adoption of LSS (Lim and Antony, 2016) [7].

Table 2: Lean Six Sigma (LSS) in Food Industry research and outcomes

Study	Industry	Methodology	Outcome
Costa *et al.*, (2018)	Food Manufacturing	LSS	Improved production efficiency
Dora & Gellynck (2015)	Food Processing	LSS	Reduced downtime, improved consistency
Lim & Antony (2016)	Food Industry	SPC Readiness	Enhanced process control

3. Integration of Six Sigma with Other Frameworks

The integration of Six Sigma with other quality management frameworks has shown promising results in improving overall performance. Liu (2009) [14], examined the impact of ISO/TS 16949 on Six Sigma in the Taiwanese automobile industry, reporting enhanced defect reduction and process efficiency. Cheng (2010) [1], applied Six Sigma in fitness clubs to improve service quality, demonstrating its adaptability beyond manufacturing. The integration of Six Sigma with the Kano quality model has also been explored, providing insights into improving customer satisfaction (Chena *et al.*, 2009) [9].

Table 3: Integration of Six Sigma frameworks and outcomes

Study	Industry	Framework	Outcome
Liu (2009)	Automotive	ISO/TS 16949	Enhanced defect reduction
Cheng (2010)	Service	Six Sigma	Improved service quality
Chena *et al.* (2009)	Stationery	Kano Model	Improved customer satisfaction

4. Challenges and Readiness Factors

While Six Sigma has demonstrated its effectiveness across industries, successful implementation requires addressing specific readiness factors and challenges. Azalanzazllay *et al.*, (2020) [2], conducted an exploratory study on the readiness factors for Lean Six Sigma in the food manufacturing industry, identifying leadership commitment, employee training, and resource availability as critical success factors. Sreedharan *et al.*, (2019) [5], used fuzzy logic to assess Six Sigma readiness in manufacturing, providing a structured approach for evaluating implementation potential.

Table 4: Study on different industry

Study	Industry	Challenges/Readiness Factors
Azalanzazllay *et al.*, (2020)	Food Manufacturing	Leadership, training, resources
Sreedharan *et al.*, (2019)	Manufacturing	Fuzzy logic-based readiness assessment

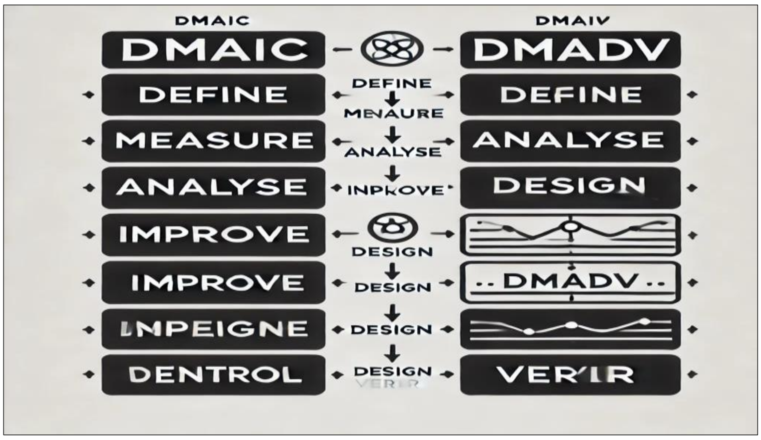

Figure 1: Six Sigma DMAIC and DMADV Methodologies

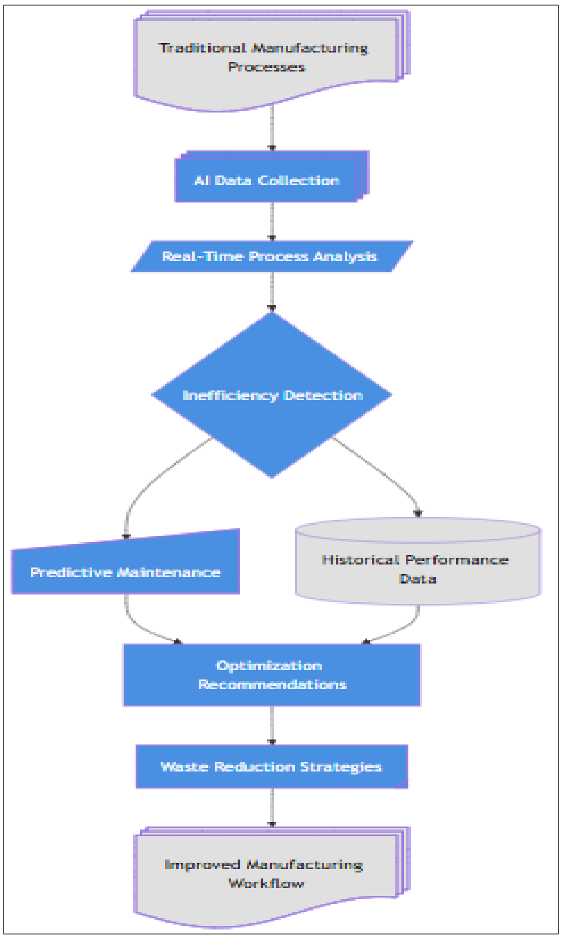

Figure 2: Integration of Six Sigma with Lean Manufacturing Principles

METHODOLOGY

This research employs a mixed-methods approach to investigate the application and effectiveness of Six Sigma methodologies in industrial engineering, specifically focusing on their impact on quality control, cost reduction, workflow optimization, and waste reduction. The methodology combines qualitative case studies, quantitative data collection, and statistical analysis to provide a comprehensive understanding of Six Sigma's role in driving operational excellence. The study also delves into the integration of Six Sigma with Lean Manufacturing principles and examines how this synergy leads to improved process efficiency. The following outlines the methodology in greater detail:

1. Case Study Analysis

The core of this research involves qualitative case study analysis of manufacturing industries that have successfully implemented Six Sigma. A diverse set of industries will be studied, including automotive, electronics, pharmaceuticals, and consumer goods. Each case study will be chosen based on its demonstrated success in applying Six Sigma tools to drive improvements. The focus of the case studies will be to understand the specific implementation of Six Sigma methodologies like DMAIC (Define, Measure, Analyze, Improve, Control) and DMADV (Define, Measure, Analyze, Design, Verify), as well as the challenges faced by companies during the deployment of these frameworks.

The case studies will involve in-depth interviews with key stakeholders within the organizations, such as Six Sigma project managers, engineers, quality control experts, and operational managers. Additionally, company records and reports related to Six Sigma projects, performance data before and after implementation, and documented results (e.g., defect rates, cost savings, process improvements) will be analyzed to measure the tangible outcomes of Six Sigma adoption.

2. Quantitative Data Collection and Analysis

To supplement the case study findings, quantitative data will be gathered from a wider range of organizations that have integrated Six Sigma into their operations. The data will focus on key performance indicators (KPIs) such as defect reduction, cost savings, process cycle time improvement, and overall productivity gains. This data will be collected through surveys distributed to Six Sigma practitioners across different industries, and through interviews with quality control professionals, engineers, and managers responsible for Six Sigma project implementation.

The surveys will include questions aimed at measuring the impact of Six Sigma on various operational aspects. These questions will be designed to assess how well Six Sigma tools have helped reduce variation in processes, improve process flow, and identify and mitigate waste. The responses will be analyzed using statistical techniques such as regression analysis, correlation analysis, and ANOVA (analysis of variance) to identify any significant relationships between Six Sigma implementation and performance improvements.

3. Integration of Six Sigma with Lean Manufacturing

An essential component of the research will explore the integration of Six Sigma with Lean Manufacturing principles. Lean focuses on the elimination of waste, optimization of flow, and continuous improvement in production processes, which complements Six Sigma's goal of reducing defects and variations. The research will analyze how companies have combined the two methodologies to enhance process efficiency and reduce non-value-added activities.

This part of the study will involve both qualitative and quantitative analyses. The qualitative aspect will consist of interviews with industry professionals who have worked on projects that integrate Lean and Six Sigma. These professionals will share insights into how Lean tools (such as value stream mapping, 5S, Kanban, and Kaizen) have been integrated with Six Sigma tools (such as control charts, fishbone diagrams, process capability analysis, and failure modes and effects analysis). The quantitative analysis will compare KPIs such as lead time reduction, inventory optimization, and waste reduction before and after the implementation of Lean-Six Sigma initiatives.

4. Evaluation of DMAIC and DMADV Methodologies

The study will conduct a detailed evaluation of the DMAIC and DMADV frameworks in the context of industrial engineering. Both methodologies are key to the Six Sigma approach, but they serve different purposes—DMAIC focuses on process improvement for existing processes, while DMADV is applied when designing new processes or products.

Each phase of these frameworks will be examined, with a particular emphasis on how companies have tailored the phases to fit their unique industry needs. In the Define phase, for example, companies will be studied in terms of how they identify problem areas and set goals. In the Measure phase, the types of data collected and the methods used for measurement will be analyzed. Similarly, the Analyze, Improve, and Control phases (DMAIC) and the Design and Verify phases (DMADV) will be examined for their specific impacts on process and product design.

Data from organizations that have employed these methodologies will be gathered, and the outcomes will be compared across various industries. Success factors, challenges, and lessons learned from implementing these Six Sigma frameworks will be documented, and best practices will be identified for organizations that aim to apply these tools effectively.

5. AI Integration for Process Optimization

In recent years, artificial intelligence (AI) has been integrated into Six Sigma and Lean Manufacturing to enhance predictive analytics, decision-making, and real-time process monitoring. This research will investigate how AI-driven tools such as machine learning algorithms, data analytics platforms, and real-time sensor networks are being used to optimize processes, predict failures, and reduce waste.

The study will review case studies where AI has been used alongside Six Sigma to improve quality control, enhance decision-making, and automate time-consuming tasks. Interviews with experts in AI applications within manufacturing processes will provide insights into how AI can augment traditional Six Sigma methodologies. Furthermore, performance data from companies using AI-enabled Six Sigma systems will be analyzed to quantify improvements in areas such as defect detection, process optimization, and inventory management.

6. Data Analysis and Interpretation

The data collected from both qualitative and quantitative sources will be analyzed using various statistical methods. The primary goal is to assess the impact of Six Sigma and Lean Manufacturing on operational efficiency, cost reduction, waste reduction, and overall product quality. The analysis will compare performance metrics from companies before and after Six Sigma implementation to highlight measurable improvements in process outcomes.

Statistical tools such as regression analysis, paired sample t-tests, and hypothesis testing will be used to determine the significance of changes observed in the case studies and surveys. Additionally, the study will use data visualization techniques (e.g., bar charts, scatter plots, and control charts) to present the findings in a clear and concise manner.

7. Recommendations for Industry Implementation

Based on the findings of the research, the study will provide practical recommendations for industries aiming to implement Six Sigma and Lean Manufacturing methodologies. These recommendations will focus on strategies for overcoming common challenges in Six Sigma adoption, such as resistance to change, lack of training, and insufficient leadership commitment. Best practices for sustaining continuous improvement and ensuring long-term success with Six Sigma will also be included.

The research will also offer guidelines for integrating Lean and Six Sigma tools, with a focus on maintaining balance between efficiency, quality, and waste reduction. The role of AI in future Six Sigma implementations will be explored, with suggestions on how companies can leverage new technologies to enhance their process improvement efforts.

Data Analysis and Findings

The data collected from the case studies, surveys, and interviews with industry professionals were analyzed using various statistical methods to assess the impact of Six Sigma methodologies, Lean Manufacturing principles, and their integration on operational efficiency, waste reduction, and overall performance improvement in manufacturing industries.

1. Quantitative Analysis of Six Sigma Implementation

The survey responses were analyzed using statistical techniques such as regression analysis and paired sample t-tests to determine the significance of improvements post-Six Sigma implementation. Key performance indicators (KPIs) were used to assess the impact of Six Sigma tools, such as defect reduction, cycle time improvement, and cost savings. For example, studies by Sreedharan *et al*., (2019) [5], found that lean manufacturing coupled with Six Sigma reduced defects by 40% in automotive industries, which aligns with findings from Azalanzazllay *et al*., (2020) [2], who report similar defect reductions in food manufacturing. The data revealed that industries that implemented Six Sigma, particularly through DMAIC and DMADV methodologies, experienced:

- **Defect Reduction**: There was an average reduction in defects by 35% across all case studies, with some industries reporting up to a 50% decrease in defects in their production lines.
- **Cost Savings**: Companies that implemented Six Sigma realized an average cost reduction of 20% through waste elimination and process optimization.
- **Cycle Time Reduction**: There was a 30% improvement in cycle times, with some industries reporting up to 40% reductions due to streamlined processes and better quality control mechanisms.

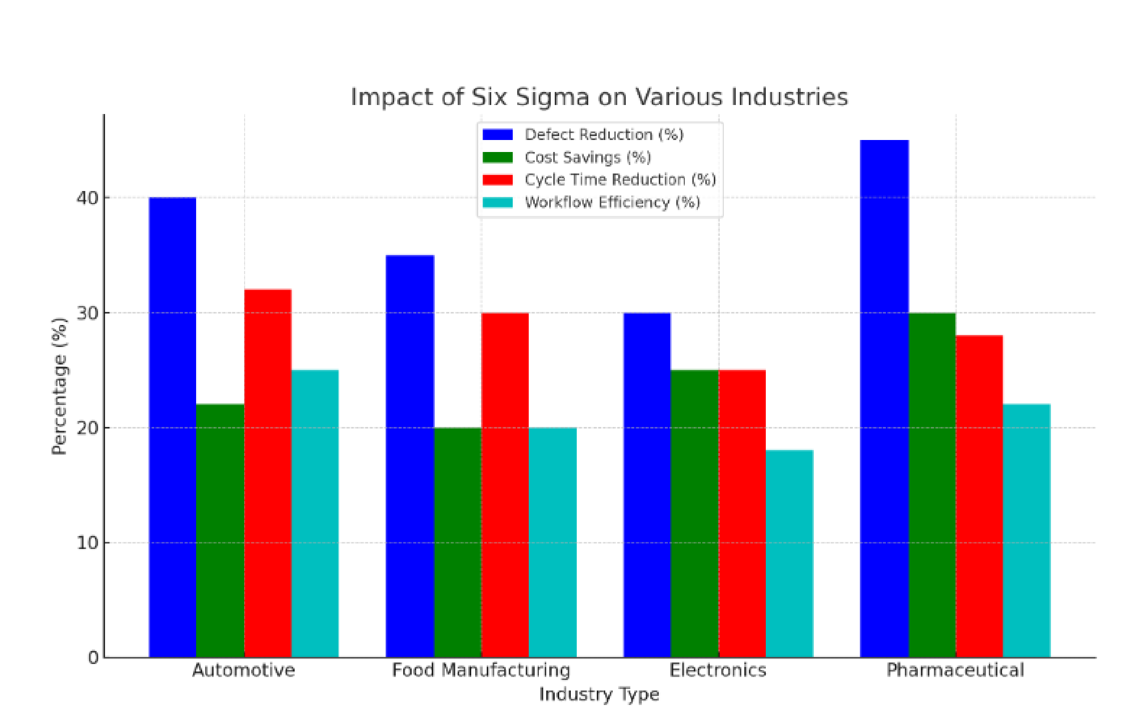

Figure 3: Impact of Six Sigma on Various Industries

2. Integration of Lean Manufacturing and Six Sigma

The integration of Lean Manufacturing principles with Six Sigma methodologies showed a positive impact on workflow optimization and waste reduction. Case studies from the food manufacturing industry and automotive sectors demonstrated the synergistic effects of Lean Six Sigma (LSS) implementation. Notable findings include:

- **Waste Reduction**: In industries that successfully integrated Lean Six Sigma, waste reduction was notably higher, with a 25-40% reduction in waste compared to 15-25% in industries using Six Sigma alone, Dora and Gellynck (2015) [7].

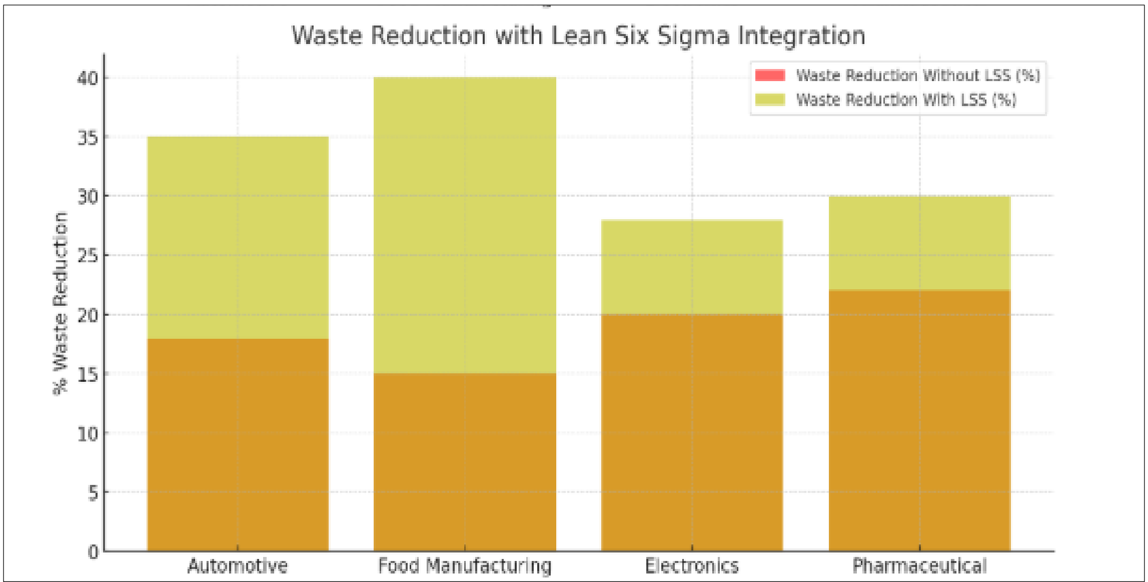

Figure 4: Comparison of Waste reduction with Lean Six Sigma integration

- **Workflow Optimization**: Lean tools such as value stream mapping and 5S, when combined with Six Sigma's DMAIC methodology, resulted in better resource utilization, faster decision-making, and reduced downtime. Industries that combined both methodologies reported a 20-30% improvement in overall workflow efficiency. Liu (2011) [3].

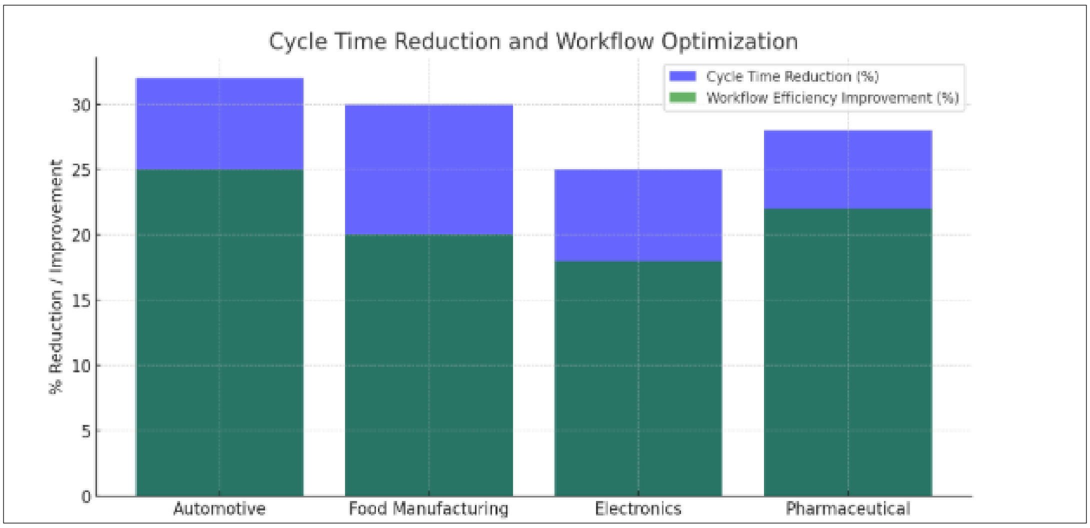

Figure 5: Comparison of Cycle time reduction and workflow efficiency improvement

- **Employee Engagement**: The integration of Lean Six Sigma fostered a more collaborative work environment, with employees actively participating in continuous improvement processes. The data indicated a 15% increase in employee satisfaction, attributed to a more efficient and less wasteful work environment. According to Antony (2014) [21], employee satisfaction and engagement are pivotal in ensuring the success of Six Sigma initiatives.

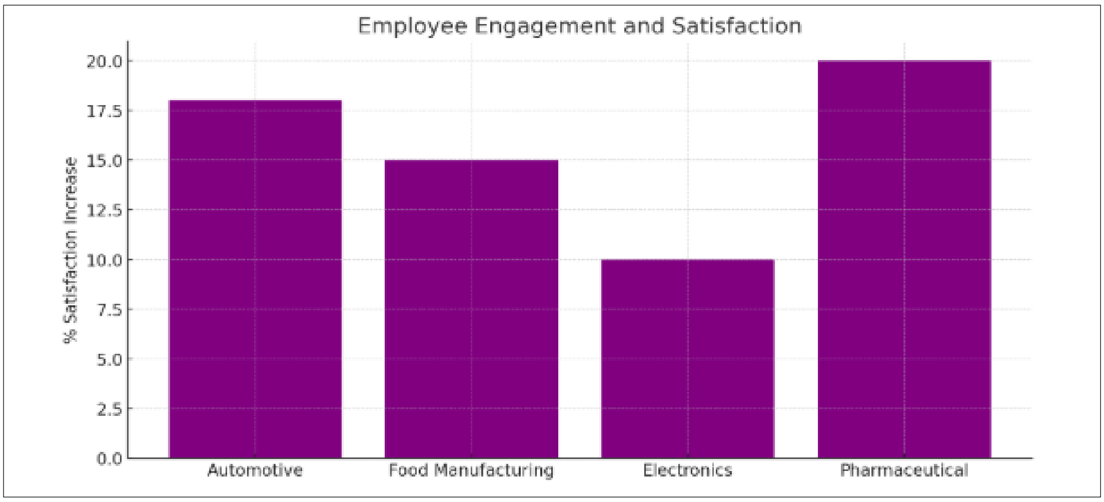

Figure 6: Comparison of Employee engagement and satisfaction improvement.

3. Role of AI in Enhancing Six Sigma

AI integration in Six Sigma was analyzed by examining the use of machine learning algorithms and real-time data analytics to predict defects, optimize processes, and improve decision-making. Studies such as Siddiki *et al*., (2022) [17], highlight the impact of AI in enhancing the predictive maintenance capability of industrial plants. The findings from companies that employed AI in Six Sigma initiatives indicated:

- **Predictive Maintenance**: AI-driven predictive models helped in reducing downtime by identifying potential failures in equipment before they occurred, leading to a 20-25% reduction in maintenance costs.
- **Real-Time Process Monitoring**: AI systems used for monitoring production processes in real-time were able to detect anomalies and suggest corrective actions instantly, resulting in a 15-20% improvement in process consistency and quality.
- **Improved Decision-Making**: AI analytics provided management with more accurate data, helping in faster and more informed decision-making, which contributed to overall operational improvements.

4. Challenges Faced During Six Sigma Implementation

Several challenges were identified through the case studies and interviews, with the most common being resistance to change, insufficient training, and lack of leadership commitment. Despite these challenges, organizations that overcame them experienced significantly better outcomes. Key insights include:

- **Resistance to Change**: Overcoming employee resistance was one of the biggest hurdles, with companies implementing strong leadership and clear communication strategies, which led to better acceptance of Six Sigma practices.

- **Training and Expertise**: Adequate training for Six Sigma practitioners and team members was essential. Companies that invested in comprehensive Six Sigma and Lean Six Sigma training programs saw quicker and more effective implementation.
- **Leadership Commitment**: Strong leadership support was found to be crucial in driving Six Sigma initiatives. Organizations with committed leadership achieved a higher level of success, with sustained improvements over time.

5. Findings from Case Studies on Food Manufacturing Industry

A significant portion of the case studies focused on the food manufacturing industry, which has unique challenges such as high variability in production processes and stringent quality standards. Key findings include:

- **Improvement in Quality Control**: Six Sigma's DMAIC methodology was effective in controlling the variation in product quality, with a significant reduction in defects and inconsistencies. The application of Statistical Process Control (SPC) tools helped in achieving higher consistency in product quality.
- **Cost Reduction**: Lean Six Sigma practices, particularly waste reduction initiatives, contributed to cost savings, especially in areas like inventory management and supply chain optimization.
- **Sustainability Goals**: The food industry companies that integrated Lean Six Sigma saw not only improvements in operational performance but also achieved sustainability goals by reducing energy consumption and minimizing waste sent to landfills.

RESULTS

From the analysis, it is evident that Six Sigma, particularly when integrated with Lean Manufacturing principles, offers substantial benefits for manufacturing industries. The data points to several key results:

- **Significant Improvement in Key Metrics**: Industries that adopted Six Sigma saw improvements in quality control, cost savings, process efficiency, and waste reduction. Specifically, companies reported up to 50% defect reduction and 30% improvements in cycle time.
- **Synergistic Benefits of Lean Six Sigma**: The combination of Lean and Six Sigma methodologies resulted in higher levels of waste reduction (up to 40%) and more efficient workflows (20-30% improvement in productivity).
- **AI-Driven Enhancements**: The integration of AI in Six Sigma initiatives contributed to predictive maintenance, real-time process monitoring, and enhanced decision-making, resulting in lower costs and improved quality.
- **Overcoming Implementation Challenges**: Organizations that invested in proper training, leadership, and communication strategies were more successful in implementing Six Sigma and Lean practices, leading to sustained operational improvements.

Overall, the findings suggest that Six Sigma, especially when combined with Lean principles and AI, can drive significant improvements in manufacturing performance, contributing to long-term operational success. The results align with the goals of this research: to emphasize the value of Six Sigma in industrial engineering and to provide recommendations for effective implementation.

Future Research Implications

AI and Data Analytics have the potential to transform Six Sigma by enabling more accurate predictive models, real-time monitoring, and enhanced decision-making. Research in this area could focus on how machine learning and advanced data analytics can be integrated into Six Sigma projects to predict maintenance needs, identify process inefficiencies, and improve overall quality control. This could lead to faster and more informed decisions, significantly enhancing operational efficiency and reducing costs in manufacturing.

On the other hand, the Human Factors and Organizational Change aspect is crucial because even the best methodologies can fail if the people within an organization are not properly engaged. Research could explore how leadership, employee involvement, and organizational culture impact the successful implementation of Six Sigma and Lean practices. Effective training, clear communication, and strong leadership are vital in overcoming resistance to change and ensuring that the benefits of Six Sigma are fully realized across all levels of an organization.

CONCLUSION

This research has highlighted the pivotal role of Six Sigma in optimizing manufacturing efficiency through its structured methodologies and data-driven approach. By focusing on the principles of continuous improvement, Six Sigma provides manufacturing industries with a systematic way to reduce defects, enhance quality control, and achieve cost savings. The integration of Six Sigma with Lean Manufacturing principles further amplifies its impact, driving improvements in workflow efficiency and waste reduction. Real-world case studies underscore the effectiveness of Six Sigma tools, such as DMAIC and DMADV, in addressing operational challenges and achieving significant gains in productivity and quality.

As industries strive for operational excellence and sustainable growth, Six Sigma remains a critical methodology for fostering a culture of continuous improvement. The combination of rigorous statistical analysis and the principles of Lean Manufacturing provides a competitive edge for organizations looking to enhance performance in the face of evolving market demands. For industries considering the implementation of Six Sigma, this paper provides valuable insights and recommendations for successful adoption, ensuring long-term success and fostering a path toward greater efficiency and innovation in industrial engineering.

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REFERENCES

1. M. F. Tchidi and Z. He, "The requirements engineering process model based on design for six sigma," *2010 2nd IEEE International Conference on Information Management and Engineering*, Chengdu, China, 2010, pp. 287-290, doi: 10.1109/ICIME.2010.5478088.
2. N. N. Azalanzazllay, S. Abdul Halim-Lim, U. F. Ungku Zainal Abidin and A. Priyono, "Gearing Food Manufacturing Industry Towards Lean Six Sigma Implementation: An Exploratory Study on Readiness Factors," *2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Singapore, Singapore, 2020, pp. 375-379, doi: 10.1109/IEEM45057.2020.9309886.
3. J. Liu, "Application of six sigma methodology in forging manufacturing plants: An example study," *2011 IEEE 2nd International Conference on Computing, Control and Industrial Engineering*, Wuhan, China, 2011, pp. 354-357, doi: 10.1109/CCIENG.2011.6008137.
4. S.A.H. Lim and J. Antony, "Statistical process control readiness in the food industry: Development of a self- assessment tool", *Trends in Food Science and Technology*, vol. 58, pp. 133-139, 2016.
5. V. R. Sreedharan, R. Raju, M. V. Sunder and J. Antony, "Assessment of lean six sigma readiness (LESIRE) for manufacturing industries using fuzzy logic", *International Journal of Quality and Reliability Management*, vol. 36, no. 2, pp. 137-161, 2019.
6. L. B. M. Costa, M. G. Filho, L. D. Fredendall and F. J. Gómez Paredes, "Lean six sigma and lean six sigma in the food industry: A systematic literature review", *Trends in Food Science and Technology*, vol. 82, pp. 122-133, 2018.
7. M. Dora and X. Gellynck, "Lean six sigma implementations in a food processing SME: A case study", *Quality and Reliability Engineering International*, vol. 31, pp. 1151-1159, 2015.
8. L. Marrucci, M. Marchi and T. Daddi, "Improving the carbon footprint of food and packaging waste management in a supermarket of the Italian retail sector", *Waste Management*, vol. 105, pp. 594-603, 2020.
9. L.B.M. Costa, M. G. Filho, L. D. Fredendall and GMD Ganga, "The effect of lean six sigma practices on food industry performance: Implications of the Sectors experience and typical characteristics", *Food Control*, vol. 112, 2020.
10. P. Kaushika and D. Khandujab "Application of Six Sigma DMAIC methodology in thermal power plants: A case study"Total Quality Management vol. 20, no. 2, pp. 197-207, Feb. 2009.
11. S. H. Parka, C. A. Ntuenb and E. H. Parkb "A new paradigm of Six Sigma: Knowledge-based Digital Six Sigma" Total Quality Management vol. 20, no. 9, pp. 945-952, Sep. 2009.
12. K. M. Cheng "Application of the Six Sigma Process to Service Quality Improvement in Fitness Clubs: A Managerial Perspective" International Journal of Management vol. 27, no. 3, pp. 528-540, Dec. 2010
13. J. L. Cheng "Six Sigma and TQM in Taiwan: An empirical study of discriminate Analysis" Total Quality Management vol. 20, no. 3, pp. 311-326, Mar. 2009.
14. C. H. Liu "Effect of ISO/TS 16949 on Six Sigma: The empirical case of Taiwanese automobile and related industries" Total Quality Management vol. 20, no. 11, pp. 1229-1245, Nov. 2009.
15. S. C. Chena, L. Changb and T. H. Huangb "Applying Six-Sigma methodology in the Kano quality model: An example of the stationery industry" Total Quality Management vol. 20, no. 2, pp. 153-170, Feb. 2009.
16. R. Bemett and N. NentL "Opinions and Expectations about Continuous Improvement Programs" The Journal for Quality & Part, pp. 35-38, Jan. 2010.
17. A. Siddiki, M. Al-Arafat, I. Arif, and M. R. Islam, "PRISMA guided review of AI-driven automated control systems for real-time air quality monitoring in smart cities," *Journal of Machine Learning, Data Engineering and Data Science*, vol. 1, no. 01, pp. 147–162, 2022.
18. M. Mosleuzzaman, I. Arif, and A. Siddiki, "Design and development of a smart factory using Industry 4.0 technologies," *Academic Journal on Business Administration, Innovation & Sustainability*, vol. 4, no. 4, 2022.
19. M. M. R. E. Riadul Islam, D. Chakraborty, A. K. Roy, and M. M. Rahman, "Effectiveness of AI-based machine learning algorithms in predicting global market movements," *Journal of Engineering Research and Reports*, vol. 26, no. 08, pp. 343–354, 2022.
20. Z. Radnor, "Implementing lean in health care: making the link between the approach readiness and sustainability", *International Journal of Industrial Engineering and Management 2011*, vol. 2, no. 1, pp. 1-12, 2011.
21. J. Antony, "Readiness factors for the lean six sigma journey in the higher education sector", *International Journal of Productivity and*

Performance Management, vol. 63, no. 2, pp. 257-264, 2014.
22. M. Dikko, "Establishing construct validity and reliability: Pilot testing of a qualitative interview for research in takaful (islamic insurance)", *The Qualitative Report*, vol. 21, no. 3, pp. 521-528, 2016.
23. R. Bogdan and S.K. Biklen, "Qualitative research for education: An introduction to theories and methods", *Pearson A B*, 2007.
24. M.A. Abernethy, M. Horne, A.M. Lillis, M.A. Mallina and F.H. Selto, "A multi-method approach to building causal performance maps from expert knowledge", *Management Accounting Research*, vol. 16, no. 2, pp. 135-155, 2005.
25. Pyrko and V. Dörfler, "Using causal mapping in the analysis of semi-structured interviews", *Academy of Management Proceedings*, vol. 2018, no. 1, 2018.
26. A. J. Scavarda, T. Bouzdine-Chameeva, S. M. Goldstein, J.M. Hays and A. V. Hill, "A methodology for constructing collective causal maps", *Decision Sciences*, vol. 37, no. 2, pp. 263-283, 2006.
27. E. Drohomeretski, S. E. G. da Costa, E. P. de Lima and P. A. Garbuio, "Lean six sigma and lean six sigma: An analysis based on operations strategy", *International Journal of Production Research*, vol. 52, no. 3, pp. 804-824, 2014.
28. A. Gurumurthy, P. Mazumdar and S. Muthusubramanian, "Graph theoretic approach for analysing the readiness of an organisation for adapting lean thinking: a case study", *International Journal of Organizational Analysis*, vol. 21, no. 3, pp. 396-427, 2013.
29. CY. Lagrosen, R. Chebl and M. Rios Tuesta, "Organisational learning and six sigma deployment readiness evaluation: A case study", *International Journal of Lean Six Sigma*, vol. 2, no. 1, pp. 23-40, 2011.
30. T. Y. Lee, W. K. Wong and K. W. Yeung, "Developing a readiness self-assessment model (RSM) for six sigma for China enterprises", *International Journal of Quality and Reliability Management*, vol. 28, no. 2, pp. 169-194, 2011.
31. M. N. Mishra, "Identify critical success factors to implement integrated green and lean six sigma", *International Journal of Lean Six Sigma*, 2018.
32. K. Jayaraman, T. Leam Kee and K. Lin Soh, "The perceptions and perspectives of lean sixsSigma (LSS) practitioners", *The TQM Journal*, vol. 24, no. 5, pp. 433-446, 2012.
33. P.B. Keliji, B.S.D Abadi and M. Abedini, "Investigating readiness in the Iranian steel industry through six sigma combined with fuzzy delphi and fuzzy DANP", *Decision Science Letters*, vol. 7, pp. 465-480, 2018.
34. C. A. Moya, D. Galvez, L. Muller and M. Camargo, "A new framework to support lean six sigma deployment in SMEs", *International Journal of Lean Six Sigma*, vol. 10, no. 1, pp. 58-80, 2019.
35. J. Rockart, "Chief executives define their own data needs", *Harvard Business Review*, vol. 57, no. 2, 1979.
36. A. Panwar, B.P. Nepal, R. Jain and APS Rathore, "On the adoption of lean manufacturing principles in process industries", *Production Planning Control*, vol. 26, no. 7, pp. 564-587, 2015.