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Article

Manufacturing supply chain excellence through Lean Six Sigma: A case study approach

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Abstract: Manufacturing supply chains often struggle with persistent challenges such as inefficiencies, production delays, and rising operational costs—factors that can significantly impact performance, profitability, and market competitiveness. These challenges are especially pronounced in developing countries, where limited resources, infrastructure deficits, and economic volatility further complicate supply chain operations. This study explores the strategic integration of Lean Six Sigma (LSS) to address these issues by enhancing operational efficiency, eliminating waste, and reducing process variability across key functions, including procurement, production, inventory management, and distribution. Applying the DMAIC (Define, Measure, Analyze, Improve, Control) methodology alongside key performance indicators (KPIs), the research assesses the effectiveness of LSS in optimizing supply chain performance. A case study of an Egyptian electrical control panel manufacturer highlights significant improvements, including a 10% increase in first-time product quality, a 35% reduction in processing time, and notable gains in equipment efficiency, customer satisfaction, and value-added production. These results demonstrate the practical value of LSS in achieving measurable, sustainable improvements within manufacturing supply chains. Furthermore, the study introduces a conceptual framework that aligns LSS implementation with long-term strategic goals, fostering a culture of continuous improvement and supporting organizational resilience. The findings provide actionable insights for researchers and practitioners, emphasizing how LSS can be leveraged to drive operational excellence, align strategy with execution, and enhance competitive positioning—particularly in complex, resource-constrained environments.

Keywords: manufacturing; supply chain; performance; Lean Six Sigma; strategic planning; KPIs; operational efficiency; continuous improvement

1. Introduction

Effective Supply Chain Management (SCM) is essential for manufacturers striving to deliver high-quality products efficiently and at competitive costs. In today's rapidly evolving global market, optimizing supply chain processes continuously is key to staying competitive. Integrating Lean Six Sigma (LSS) with strategic planning offers a robust framework to streamline operations, eliminate waste, and align supply chain activities with long-term goals such as profitability, customer satisfaction, and sustainable growth. This integration improves operational efficiency, enhances agility, and strengthens risk management, leading to cost savings, higher product quality, and increased profitability. By aligning day-to-day operations with strategic objectives, companies can optimize resources, minimize delays, and promote cross-functional collaboration, creating a more responsive, flexible, and cost-efficient supply chain. This approach supports adaptation to market shifts and builds stronger customer relationships, ensuring long-term success [1,2].

Supply chain optimization requires ongoing improvement for enhanced efficiency. Lean Six Sigma (LSS) combines Six Sigma's defect prevention with Lean's focus on waste reduction and process optimization. By applying LSS, businesses can streamline production, reduce lead times, improve efficiency, and minimize defects while cutting costs. Additionally, LSS enhances customer satisfaction through timely, high-quality deliveries, supports scalability, strengthens supplier relationships, and promotes sustainability by optimizing resources. LSS also drives continuous improvement, reduces inefficiencies, and minimizes variation, resulting in consistent, predictable processes. It fosters innovation, helping organizations adapt to emerging trends and strengthen supply chain resilience. When combined with strategic planning, which aligns operations with long-term goals, LSS enables both immediate gains and sustainable growth in supply chain performance [3,4].

Manufacturers today face challenges such as fluctuating demand, global competition, and frequent disruptions due to geopolitical events and supply shortages. To remain competitive, organizations must adopt a structured approach to SCM. LSS, with its focus on process optimization and waste reduction, complements strategic planning by improving operational efficiency and ensuring alignment with long-term goals. Tools like the DMAIC (Define, Measure, Analyze, Improve, Control) framework help organizations enhance product quality, streamline operations, and reduce costs, while strategic planning ensures these efforts align with broader organizational objectives such as market expansion and sustainability [1,2].

Although the individual benefits of LSS and strategic planning for SCM are well-established, limited research exists on their combined application in manufacturing supply chains. Integrating these methodologies offers a unique opportunity to address modern supply chain challenges such as inefficiencies, disruptions, and variability. When properly aligned, LSS and strategic planning can significantly improve operational performance, fostering resilient, agile, and future-ready supply chains [3,4].

This study investigates the integration of Lean Six Sigma (LSS) and strategic planning to optimize manufacturing supply chains, particularly in developing countries, by addressing inefficiencies, delays, and rising costs. It introduces a framework that aligns LSS with strategic goals, fostering continuous improvement, resilience, and adaptability. The study highlights the synergistic roles of LSS and strategic planning in enhancing supply chain performance, focusing on cost reduction, quality improvement, and risk mitigation. Through case studies, it demonstrates how combining LSS with long-term strategic planning can streamline operations, minimize risks, and provide a sustainable competitive advantage.

The paper is structured as follows: Section 2 reviews the literature, Section 3 identifies research gaps, Section 4 outlines the methodology, Section 5 presents a case study, Section 6 discusses the results, and Section 7 concludes with insights and recommendations for future research.

2. Literature review

The integration of Lean Six Sigma (LSS) into Supply Chain Management (SCM)

has gained widespread attention for its ability to enhance operational efficiency, reduce waste, and improve overall supply chain performance. LSS provides a structured methodology for organizations focused on optimizing resource use, reducing costs, and improving product quality through continuous improvement.

Gera et al. [5] synthesized 43 empirical studies (2018–2022) examining how SCM practices impact performance across operational, environmental, economic, firm-level, and overall supply chain dimensions. Key practices discussed include green SCM, quality management, lean practices, innovation, and Industry 4.0 technologies. The research primarily focuses on manufacturing sectors in South Asia, Europe, the USA, and parts of Africa and the Middle East, with limited attention to service industries. The study highlights the use of the Resource-Based View, Institutional Theory, and Stakeholder Theory, with PLS-SEM as the main analytical method. A gap in research on market and financial outcomes is identified, suggesting areas for future exploration.

Mahdikhani [3] conducted a bibliometric analysis of over 1900 articles (1995–2022) on Total Quality Management (TQM), LSS, and SCM, identifying key trends, research gaps, and future directions. The study highlights influential authors and journals, as well as emerging and underexplored areas in these interconnected fields.

Barbosa et al. [1] explored the integration of Lean and Six Sigma with environmental sustainability in supply chains. Their review addresses the challenges of adopting Green Lean Six Sigma practices, identifies key tools and methodologies, and proposes a conceptual framework for further research, emphasizing the complexity of aligning operational excellence with sustainability goals.

Sinoimeri and Teta [6] analyzed 76,493 SCM-related articles (2012–2022) from Elsevier and Springer, emphasizing the increasing strategic importance of SCM. They identified key research areas, including Environmental Science (17.37%), Medicine & Public Health (13.59%), and Business & Management (11.11%). The rising prevalence of terms such as “Sustainability” and “Green SCM” reflects a shift towards eco-friendly practices, while the rapid adoption of digital technologies is seen as crucial for enhancing SCM efficiency and sustainability.

Multiple studies, as summarized in **Table 1**, affirm the advantages of incorporating LSS into SCM, including improved efficiency, reduced variability, and enhanced performance. Jauhar et al. [7] underscore that integrating LSS with SCM can lead to significant improvements in product and process quality, long-term cost savings, and increased customer satisfaction—factors that drive sustainable growth. Tortorella et al. [8] stress the importance of strategic alignment between LSS initiatives and SCM objectives to maximize synergy and avoid conflicts. Jakhar et al. [9] demonstrate that the fusion of lean production and green practices can simultaneously improve environmental and operational performance. Duarte and Cruz-Machado [10] propose a green-lean transformation roadmap, positioning sustainability as a key competitive advantage.

Table 1. Summary of SCM-LSS case studies (2012–2025).

#	Author(s)	Key focus	Key findings
1	Jauhar et al. [7]	LSS-SCM Integration	Improved efficiency, reduced costs, and enhanced customer satisfaction.
2	Tortorella et al. [8]	Strategic Alignment	Aligning LSS with SCM goals ensures synergy and avoids conflicts.
3	Jakhar et al. [9]	Lean-Green SCM	Supports sustainability and boosts operational performance.
4	Duarte and Cruz-Machado [10]	Green-Lean Roadmap	Provides a framework for sustainable and resource-efficient SCM.
5	Garcia-Buendia et al. [11]	Digital Transformation	Highlights the impact of AI and digital tools in advancing LSS within SCM.
6	Gomaa [12]	Integration Framework	Focuses on continuous improvement and waste reduction.
7	Gomaa [13]	Strategic Sustainability	Aligns LSS with long-term goals to drive sustainable performance.
8	Sinoimeri and Teta [14]	SCM in Developing Countries	Introduces Industry 4.0 metrics to evaluate SCM sustainability.
9	Liu et al. [15]	Resilience and Flexibility	Applies LSS to enhance supply chain adaptability and resource use.
10	Emon et al. [16]	Supplier Relationship Management	Emphasizes supplier collaboration to improve performance and reduce costs.
11	Gomaa [17]	Strategic Planning Integration	Enhances resilience and efficiency in emerging economies.
12	Pardamean Gultom and Wibisono [18]	LSS-SCM Framework	Explain the impact of Lean Six Sigma on supply chain performance

Garcia-Buendia et al. [5] highlight the growing impact of digital transformation and artificial intelligence on LSS, advocating for deeper technological integration to strengthen SCM performance. Gomaa [12] introduces a framework that combines LSS with continuous improvement and process optimization to drive supply chain excellence. Subsequent studies by Gomaa [13] emphasize aligning LSS with long-term strategic goals and demonstrate its effectiveness in reducing waste, defects, and lead times in manufacturing environments. Sinoimeri and Teta [14] focus on sustainability in SCM within developing countries, introducing evaluation metrics and frameworks while highlighting the role of Industry 4.0 technologies in enhancing decision-making and operational performance. Liu et al. [15] show how LSS can be employed to improve resource efficiency and build resilience, enabling supply chains to better respond to disruptions. Emon et al. [16] underscore the significance of Supplier Relationship Management (SRM), noting that supplier collaboration is essential for reducing costs and improving outcomes in complex supply networks.

Recent contributions by Gomaa [17] explore the integration of LSS with strategic planning to enhance supply chain adaptability and resilience, particularly in developing regions. These studies, grounded in the DMAIC methodology, emphasize the importance of sustainability and continuous improvement. Further advancing this perspective, [19–24] introduces the concept of LSS 4.0, which incorporates Industry 4.0 technologies such as AI, IoT, and Big Data into an enhanced DMAIC framework. This model aims to improve efficiency, quality, and workforce readiness while addressing the challenges of modern supply chains.

Table 2 categorizes case studies on the integration of Lean Six Sigma (LSS) with Supply Chain Management (SCM) from 2012 to 2025, structured around six key themes that capture the evolving trends and applications in this field.

(1) Strategic integration and alignment: This theme explores how LSS aligns with broader SCM goals, long-term planning, and organizational strategies. Key

studies by Tortorella et al. [8] and Gomaa [7,11,12] underscore the importance of integrating LSS practices with corporate objectives to achieve sustained improvements and long-term success.

(2) Sustainability and green practices: This category focuses on the integration of Lean and Green principles to foster environmental sustainability within supply chain operations. Research by Jakhar et al. [9], Duarte and Cruz-Machado [10], and Sinoimeri and Teta [14] highlights how organizations can enhance efficiency while reducing environmental impact, waste, and energy consumption through sustainable LSS approaches.

(3) Digital transformation and Industry 4.0 integration: This theme examines how emerging technologies—such as artificial intelligence (AI), the Internet of Things (IoT), and big data—are incorporated into LSS practices within the supply chain context. Studies by Garcia-Buendia et al. [11] and Gomaa [18] illustrate how Industry 4.0 technologies enable predictive analytics, automation, and enhanced decision-making to optimize supply chain operations.

(4) Operational efficiency and process improvement: The focus here is on improving core supply chain functions—such as production, logistics, warehousing, and processing—using LSS methodologies. Studies by Jauhar et al. [7], Gomaa [12,13], Liu et al. [15], and Gomaa [17] emphasize how LSS-driven improvements lead to greater operational efficiency, waste reduction, and resource optimization in various supply chain processes.

(5) Resilience, flexibility, and risk management: This category highlights the role of LSS in enhancing supply chain resilience and flexibility, particularly in managing risks and uncertainties. Research by Liu et al. [15] and Gomaa [17] demonstrates how LSS can be applied to strengthen adaptability and robustness, ensuring continuity in supply chain operations even during disruptions or volatile conditions.

(6) Supplier relationship and collaboration: The final theme explores how Supplier Relationship Management (SRM) and collaboration can enhance supply chain efficiency and outcomes. The study by Emon et al. [16] emphasizes the importance of fostering strong relationships with suppliers to drive mutual benefits, improve communication, and achieve better supply chain performance.

In conclusion, these studies reflect the dynamic evolution of supply chain practices, emphasizing the growing importance of digital transformation, sustainability, risk management, and collaboration in improving supply chain performance, resilience, and efficiency.

Table 2. Classification of SCM–LSS case studies (2012–2025).

#	Classification theme	Focus	Studies
1	Strategic Integration and Alignment	Aligning LSS with SCM goals, long-term planning, and organizational strategy	Tortorella et al. [8], Gomaa [13,17]
2	Sustainability and Green Practices	Incorporating environmental sustainability through Lean and Green approaches	Jakhar et al. [7], Duarte and Cruz-Machado [10], Sinoimeri and Teta [14].
3	Digital Transformation and Industry 4.0 Integration	Leveraging AI, IoT, Big Data, and other Industry 4.0 technologies in LSS–SCM	Garcia-Buendia et al. [11], Gomaa [13].

Table 2. (*Continued*).

#	Classification theme	Focus	Studies
4	Operational Efficiency and Process Improvement	Enhancing supply chain functions such as production, logistics, warehousing, and processing	Jauhar et al. [7], Gomaa [12,13], Liu et al. [15], Gomaa [17].
5	Resilience, Flexibility, and Risk Management	Improving adaptability and robustness in uncertain environments	Liu et al. [15], Gomaa [17].
6	Supplier Relationship and Collaboration	Enhancing efficiency and outcomes through Supplier Relationship Management (SRM) and collaboration	Emon et al. [16].

3. Research gap analysis

Lean Six Sigma (LSS) has shown significant potential in enhancing operational efficiency, reducing waste, and improving customer satisfaction within Supply Chain Management (SCM). However, several critical gaps hinder its broader implementation and effectiveness. These gaps, as outlined in **Table 3**, highlight key areas where further research is needed:

(1) Lack of industry-specific case studies: Existing research predominantly focuses on theoretical models, with limited real-world, industry-specific case studies. More practical case studies across diverse industries are needed to offer insights into the challenges and benefits of implementing LSS. These case studies would provide actionable guidance tailored to the unique needs of different sectors, helping companies adopt LSS more effectively.

(2) Absence of a unified framework for LSS across SCM functions: LSS applications are often confined to specific areas such as procurement, operations, or logistics. To fully unlock LSS's potential, a comprehensive framework is required to integrate its principles across all supply chain functions. This unified approach would foster cross-functional collaboration, eliminate operational silos, and drive holistic improvements in overall supply chain performance.

(3) Inadequate performance metrics for comprehensive SCM evaluation: Current metrics mainly focus on cost reduction and lead time, which fail to capture the broader impacts of LSS on SCM. A more comprehensive set of Key Performance Indicators (KPIs) is needed, covering areas such as employee engagement, supply chain resilience, sustainability, and collaboration. These additional metrics would provide a more complete assessment of LSS's impact on supply chain performance.

(4) Weak integration of strategic planning with operational SCM: Many organizations struggle to align operational supply chain activities with broader strategic goals, limiting their ability to adapt to market changes and technological advances. Research is needed to explore how LSS can be better integrated with strategic planning, ensuring that operational improvements align with long-term business objectives. This would help organizations enhance flexibility and responsiveness to evolving business needs.

(5) Underexplored role of LSS in enhancing resilience and sustainability: While LSS is known for improving efficiency, its potential role in strengthening supply chain resilience and sustainability has not been fully explored. Further research should focus on how LSS can help supply chains become more adaptable, recover from disruptions, and contribute to sustainability efforts, such as waste reduction,

carbon footprint minimization, and efficient resource use.

(6) Insufficient focus on employee and stakeholder engagement: Successful LSS implementation requires the active involvement of employees and stakeholders at all levels. However, many studies overlook strategies for fostering a culture of continuous improvement and securing organizational buy-in. More research is needed to explore effective engagement strategies that promote collaboration and overcome resistance to change, ensuring the long-term success of LSS initiatives.

Addressing these research gaps will help organizations fully leverage LSS to optimize supply chain performance, enhance resilience, and align operations with strategic goals.

Table 3. Summary of the research gap analysis.

#	Research gap	Current gap	Research need	Potential areas
1	Lack of Industry-Specific Case Studies	Most research is theoretical, with limited real-world, industry-specific case studies.	Conduct industry-specific case studies to explore the practical challenges and benefits of LSS implementation.	Case studies in manufacturing, logistics, retail, and services to understand sector-specific applications.
2	Absence of a Unified LSS Framework Across SCM Functions	LSS is often applied in isolated SCM functions, lacking a comprehensive, integrated framework.	Develop a holistic LSS framework that integrates principles across all SCM functions for cohesive improvements.	Integration of LSS across procurement, operations, logistics, and inventory management.
3	Inadequate Performance Metrics for SCM Evaluation	Existing metrics focus primarily on cost reduction and lead time, neglecting broader impacts.	Design comprehensive KPIs that include employee engagement, supply chain resilience, and sustainability.	New performance metrics for resilience, employee engagement, sustainability, and collaboration in SCM.
4	Weak Integration of Strategic Planning with Operational SCM	Lack of alignment between day-to-day operations and long-term strategic objectives.	Investigate methods to align operational improvements with broader strategic business goals.	Research into aligning LSS with strategic planning to enhance flexibility and adaptability in SCM.
5	Underexplored Role of LSS in Resilience and Sustainability	LSS primarily focuses on efficiency, with limited research on its role in resilience and sustainability.	Explore how LSS can improve supply chain resilience and sustainability, especially in disruptive environments.	Building supply chain resilience, sustainable practices, and using LSS to manage global disruptions.
6	Insufficient Focus on Employee and Stakeholder Engagement	Limited attention on engaging employees and stakeholders during the LSS adoption process.	Develop strategies to actively involve employees and stakeholders to ensure successful LSS implementation.	Strategies for employee engagement, leadership, and stakeholder involvement in LSS-driven SCM initiatives.

4. Research methodology

This study adopts a structured seven-step methodology to explore the integration of Lean Six Sigma (LSS) with strategic planning for enhancing supply chain resilience, agility, and performance. Each step is designed to address specific objectives and support the effective application of LSS within Supply Chain Management (SCM), as outlined in **Table 4**.

Table 4. Summary of the proposed research methodology.

#	Step	Objective	Description
1	Business Overview and Current Situation Analysis	Evaluate current operations and strategic alignment	Analyze the supply chain structure, operational challenges, and alignment with organizational goals. Identify inefficiencies and barriers to Lean Six Sigma (LSS) integration.
2	SWOT Analysis	Identify key internal and external factors	Conduct a SWOT analysis to assess strengths, weaknesses, opportunities, and threats. Involve stakeholders to prioritize strategic improvement areas.
3	Strategic Objectives and KPIs	Define goals and performance metrics	Establish clear strategic objectives focused on resilience, agility, and operational efficiency. Develop relevant KPIs aligned with long-term business outcomes.
4	Improvement Recommendations	Propose evidence-based improvement strategies	Use LSS and strategic planning tools (e.g., process mapping, root cause analysis) to generate practical, targeted recommendations for supply chain enhancement.
5	DMAIC Framework Development	Design a structured implementation model	Create a tailored DMAIC framework aligned with strategic goals and KPIs. Incorporate appropriate tools, metrics, and resources to support improvement initiatives.
6	Implementation and Monitoring	Execute and oversee improvement initiatives	Implement recommendations using the DMAIC framework. Monitor progress through real-time data and feedback mechanisms, ensuring smooth integration.
7	Continuous Improvement	Sustain improvements and foster adaptability	Embed a culture of continuous improvement (Kaizen) through ongoing evaluation, refinement of strategies, and enhanced responsiveness to changes.

(1) Business overview and current state analysis: This initial step involves a comprehensive assessment of the organization's supply chain structure, operational performance, and alignment with strategic goals. It identifies existing inefficiencies, challenges, and opportunities for improvement, forming the basis for LSS integration.

(2) SWOT analysis: A strategic analysis is conducted to evaluate internal strengths and weaknesses, as well as external opportunities and threats. Engaging stakeholders during this phase helps uncover critical gaps and prioritize improvement initiatives.

(3) Strategic objectives and KPIs: Clear objectives related to supply chain efficiency, agility, and resilience are established. These are supported by well-defined Key Performance Indicators (KPIs) aligned with long-term business goals, enabling focused and measurable improvement.

(4) Improvement recommendations: Using LSS tools such as process mapping and root cause analysis, targeted recommendations are developed. These are integrated with strategic planning methods to drive efficiency, adaptability, and risk reduction across the supply chain.

(5) DMAIC framework development: A customized Define-Measure-Analyze-Improve-Control (DMAIC) model is created to guide structured implementation. This framework ensures that improvements are data-driven, goal-oriented, and sustainable.

(6) Improvement plan and implementation: The proposed improvements are executed through the DMAIC framework. Progress is tracked using real-time data and feedback loops, while active stakeholder engagement ensures smooth integration and operational alignment.

(7) Continuous improvement: The final step emphasizes the adoption of a continuous

improvement culture rooted in Kaizen principles. Regular evaluation and adaptation help sustain performance gains, enhance resilience, and ensure responsiveness to changing market dynamics.

This methodology provides a comprehensive roadmap for embedding LSS within supply chain operations. By aligning process improvements with strategic objectives and fostering a culture of continuous improvement, organizations can enhance performance, agility, and long-term competitiveness.

5. Case study

This case study explores the integration of Lean Six Sigma (LSS) and strategic planning within the supply chain of an Egyptian electrical control panel manufacturer. It focuses on the first five stages of the proposed methodology: conducting a comprehensive business analysis, performing a SWOT assessment, defining strategic objectives and key performance indicators (KPIs), developing targeted improvement recommendations, and designing a customized DMAIC framework. These stages are essential for aligning operational activities with strategic goals, identifying inefficiencies, and establishing measurable targets to drive sustainable organizational transformation.

Building on Gomaa's [17] work, which examined the strategic application of LSS to enhance supply chain resilience, efficiency, and competitiveness amid global disruptions, this study extends those insights by proposing a conceptual framework that incorporates the DMAIC methodology and strategic KPIs to align supply chain processes with organizational objectives.

A particular emphasis is placed on the context of developing countries, where resource limitations and infrastructural constraints often present significant challenges to performance improvement. This case study provides practical validation of the proposed framework, demonstrating how the integration of LSS and strategic planning can foster the development of adaptive, efficient, and sustainable supply chains in resource-constrained environments.

5.1. Business overview and current situation analysis

This study explores the integration of Lean Six Sigma (LSS) and strategic planning to optimize supply chain performance at AL-DAWLIA, a leading Egyptian electrical control panel manufacturer. Established in 1976, the company operates three facilities, employs over 300 professionals, and holds ISO 9001, ISO 45001, and ISO 14001 certifications. In response to Egypt's urbanization and large infrastructure projects, AL-DAWLIA seeks to stay competitive amid challenges such as market competition, fluctuating material costs, and evolving regulations by combining LSS and strategic planning to enhance efficiency, reduce costs, and maintain quality. The integration process begins with evaluating the company's supply chain structure and identifying key challenges. Supply chain mapping uncovers critical nodes and vulnerabilities, while performance evaluation focuses on KPIs such as lead times, inventory turnover, and cost efficiency. Internal challenges, including resource limitations and outdated technology, are assessed alongside external risks like supply disruptions and regulatory changes. Stakeholder engagement through interviews and

workshops provides qualitative insights, complementing the quantitative data. A technology assessment explores opportunities to integrate advanced tools such as IoT, AI, and predictive analytics. Additionally, a market analysis ensures the supply chain remains adaptable to changing customer demands. The findings from this phase will pinpoint key areas for improvement, enhancing efficiency, agility, and resilience through the integration of LSS and strategic planning. Stakeholder engagement ensures alignment, with actionable recommendations, measurable KPIs, and long-term objectives.

5.2. Proposed SWOT analysis

A SWOT analysis is crucial for evaluating the integration of Lean Six Sigma (LSS) with strategic planning to optimize manufacturing supply chains. It helps identify internal strengths and weaknesses, along with external opportunities and threats, supporting informed decision-making to enhance supply chain efficiency, resilience, and adaptability. **Table 5** presents the SWOT analysis.

Table 5. The proposed SWOT matrix.

Strengths	**Weaknesses**
1. Increased efficiency, reduced waste, and optimized resource use.	1. High upfront costs for training and technology upgrades.
2. Alignment with long-term business goals (growth, profitability, customer satisfaction).	2. Resistance to change from employees.
3. Agile, resilient supply chains that adapt to disruptions.	3. Complex implementation requiring skilled personnel.
4. Competitive advantage through operational excellence.	4. Delayed realization of benefits.
5. Promotes sustainability and resource optimization.	
Opportunities	**Threats**
1. Advancements in AI, IoT, and automation to enhance performance.	1. Market volatility and global disruptions (e.g., pandemics, natural disasters).
2. Global expansion driving demand for efficient supply chains.	2. Increased competition with similar strategies and technologies.
3. Rising customer demands for speed, quality, and sustainability.	3. Supply chain disruptions (e.g., raw material shortages, geopolitical tensions).
4. Proactive risk management to mitigate disruptions.	4. Technological risks (system failures, cybersecurity threats).

(1) Strengths: LSS brings several strengths to supply chain optimization. It enhances process optimization by reducing waste and improving resource utilization. Integrating LSS with strategic planning ensures strategic alignment, linking supply chain improvements with long-term business goals, thereby driving growth and customer satisfaction. Additionally, LSS fosters agility and resilience, enabling quick adaptation to market changes and disruptions. This operational excellence strengthens customer satisfaction and provides a competitive advantage, improving market positioning. LSS also promotes sustainability through resource optimization and waste reduction, contributing to environmental goals.

(2) Weaknesses: While LSS offers significant benefits, there are some challenges to consider. The high initial costs of training, technology, and systems integration can strain financial resources. There may also be resistance to change from employees and stakeholders, which could slow down the adoption of new

processes and technologies. Furthermore, implementation complexity arises from the need for skilled personnel and robust systems, making integration challenging. Finally, the benefits of LSS may take time to materialize, leading to delayed benefits that complicate short-term performance assessments.

(3) Opportunities: There are several opportunities to further enhance LSS integration. Technological advancements, including AI, IoT, and automation, can significantly improve supply chain performance. The growing complexity of global supply chains offers opportunities to streamline operations and scale more effectively. Additionally, changing customer expectations—such as a demand for faster delivery and sustainable practices—provides an opportunity to better align supply chain strategies. LSS also improves proactive risk management, enhancing the ability to identify and mitigate risks, and boosting supply chain resilience.

(4) Threats: Despite its advantages, LSS integration faces external threats. Market volatility, including economic instability and geopolitical tensions, can disrupt even well-optimized supply chains. Intense competition from rivals adopting similar strategies may reduce the differentiation created by LSS. Supply chain disruptions, such as raw material shortages or geopolitical issues, can undermine efficiency. Additionally, increased reliance on technology creates risks related to system failures, cyber threats, and technological challenges.

In conclusion, the integration of LSS with strategic planning offers significant potential to optimize supply chains. While strengths like process optimization and resilience provide a strong foundation, challenges such as high costs and resistance to change must be managed. Leveraging technological advancements and proactive risk management can mitigate external threats.

The TOWS matrix is a strategic tool that builds on SWOT analysis insights. Aligning internal strengths and weaknesses with external opportunities and threats, it helps organizations move from analysis to actionable strategies, fostering growth, leveraging strengths, addressing weaknesses, and mitigating risks.

Expanding on SWOT, the TOWS (Threats, Weaknesses, Opportunities, Strengths) framework offers practical strategies for incorporating Lean Six Sigma (LSS) into strategic planning. This approach focuses on capitalizing on strengths and opportunities while addressing weaknesses and mitigating threats to optimize supply chain performance. Key insights from the TWOS analysis are:

(1) Strengths + Opportunities: Leverage strengths like process optimization and resilience to capitalize on technological advancements and global expansion.

(2) Strengths + Threats: Use LSS principles such as adaptability and continuous improvement to mitigate external threats like supply chain disruptions and market volatility.

(3) Weaknesses + Opportunities: Address internal weaknesses, like high implementation costs and resistance to change, by adopting advanced technologies and proactive risk management.

(4) Weaknesses + Threats: Overcome implementation challenges by investing in systems and optimizing processes to minimize the impact of competition and technological risks.

In conclusion, the TWOS analysis highlights the importance of aligning LSS with

strategic planning to create efficient, resilient, and sustainable supply chains. By leveraging strengths, addressing weaknesses, and proactively managing opportunities and threats, organizations can boost competitiveness, adapt to market changes, and achieve long-term supply chain success.

5.3. Proposed strategic objectives and KPIs

This section presents refined strategic objectives and Key Performance Indicators (KPIs) aimed at optimizing manufacturing supply chains. These objectives focus on enhancing efficiency, resilience, and alignment with organizational goals through Lean Six Sigma (LSS) methodologies. The emphasis is on continuous improvement, risk mitigation, and performance optimization across various functions, including operations, procurement, inventory, financial management, market positioning, and risk management. **Table 6** outlines the strategic objectives for each area, with specific KPIs and annual targets to improve operational performance, financial outcomes, customer satisfaction, and sustainability.

Table 6. The proposed strategic objectives and KPIs with annual targets.

#	Area	Strategic objective	Main KPIs with annual targets
1	Operational management	Enhance operational efficiency by reducing waste and optimizing resource utilization.	• Product quality ratio: +5% • Production capacity utilization: +8% • Labor productivity: +6% • Value-added time ratio: +8%
2	Procurement management	Optimize procurement processes to reduce lead times, cut costs, and improve supplier relationships.	• Supplier lead time: −6% • On-time supplier delivery: +5% • Procurement cost reduction: −5%
3	Inventory management	Improve inventory management for better cost control and material availability.	• Material stockout ratio: −5% • Inventory turnover ratio: +10% • Automated inventory management: +8%
4	Financial management	Improve financial performance by reducing costs and optimizing cash flow.	• Production costs: −5% • Storage costs: −5% • Profit margins: +5% • Value-added cost ratio: +6% • Risk mitigation costs: −5%
5	Market management	Strengthen market position by improving customer satisfaction, ensuring timely deliveries, and boosting loyalty.	• Lead time to customers: −6% • On-time delivery to customers: +10% • Customer satisfaction: +5% • Customer retention rate: +5%
6	Risk management & sustainability	Enhance risk management strategies to minimize disruptions and ensure business continuity.	• Risk mitigation effectiveness: 95% • Business continuity planning (BCP) effectiveness: 98%

(1) Operational management: The focus is on improving operational efficiency by minimizing waste and optimizing resource use. Key targets include a 5% increase in product quality, an 8% boost in production capacity utilization, a 6% rise in labor productivity, and an 8% increase in value-added time. These metrics aim to drive operational excellence and ensure consistent high-quality standards.

(2) Procurement management: The goal is to streamline procurement processes, reduce lead times, and enhance supplier relationships. Key KPIs include a 6% reduction in supplier lead times, a 5% improvement in on-time supplier deliveries, and a 5% reduction in procurement costs. These targets aim to increase

procurement efficiency and cost-effectiveness.

(3) Inventory management: The objective is to optimize inventory management to reduce excess stock and ensure material availability. Key performance indicators include a 5% reduction in material stockouts, a 10% improvement in inventory turnover, and an 8% increase in automated inventory management. These metrics will enhance inventory control and reduce waste.

(4) Financial management: The goal is to improve financial performance by reducing costs, improving profit margins, and optimizing cash flow. KPIs include a 5% reduction in production and storage costs, a 5% increase in profit margins, a 6% improvement in value-added cost ratios, and a 5% reduction in risk mitigation costs. These measures will strengthen profitability and financial health.

(5) Market management: This area focuses on strengthening the market position through improved customer satisfaction, timely deliveries, and increased customer loyalty. Key KPIs include a 6% reduction in lead time to customers, a 10% improvement in on-time delivery, a 5% increase in customer satisfaction, and a 5% increase in customer retention rates. These targets aim to boost competitive advantage and foster customer loyalty.

(6) Risk management and sustainability: The objective is to improve risk management strategies and ensure business continuity. KPIs include 95% effectiveness in risk mitigation and 98% effectiveness in business continuity planning (BCP). These targets are designed to strengthen organizational resilience and ensure effective management of potential risks.

In conclusion, the proposed strategic objectives and KPIs provide a structured approach to improving performance across key management areas. By focusing on operational efficiency, procurement optimization, inventory control, financial growth, market positioning, and effective risk management, the organization can drive substantial improvements. These targets are designed to enhance process efficiency, reduce costs, improve customer satisfaction, and build resilience, all contributing to long-term success. With clear, measurable goals, the company will be well-positioned to adapt to challenges, seize opportunities, and sustain a competitive edge in the market.

5.4. Improvement recommendations

This section outlines strategic recommendations aimed at optimizing the manufacturing supply chain through Lean Six Sigma (LSS) methodologies. The focus is on enhancing operational efficiency, reducing costs, mitigating risks, improving customer satisfaction, and ensuring sustainability—all while aligning with long-term business objectives. **Table 7** summarizes key improvement strategies across various supply chain functions.

(1) Optimizing operational management:

- Objective: Enhance efficiency and product quality.
- Recommendation: Use tools like value stream mapping (VSM), 5S, and Statistical Process Control (SPC) to streamline operations.
- Expected impact: Improved capacity utilization, reduced waste, and increased labor productivity.

- Actionable steps: Identify bottlenecks with VSM, optimize workspaces with 5S, and ensure quality consistency with SPC.

(2) Enhancing procurement management:
- Objective: Improve procurement efficiency and supplier relations.
- Recommendation: Leverage RFID and predictive analytics for better collaboration and reduced lead times.
- Expected impact: Shorter lead times, improved delivery reliability, and stronger supplier relationships.
- Actionable steps: Implement RFID for real-time tracking and use predictive analytics for accurate demand forecasting.

(3) Improving inventory management:
- Objective: Optimize inventory levels to reduce costs and improve material availability.
- Recommendation: Integrate Just-In-Time (JIT) principles with automated systems and big data analytics.
- Expected impact: Increased inventory turnover, fewer stockouts, and more efficient inventory control.
- Actionable steps: Align inventory with production using JIT, automate management with ERP, and optimize stock levels with big data.

(4) Optimizing financial performance:
- Objective: Reduce costs and enhance profitability.
- Recommendation: Apply LSS methods to lower production and storage costs while boosting labor productivity.
- Expected impact: Lower costs, improved profit margins, and greater financial efficiency.
- Actionable steps: Use Pareto Analysis and Fishbone Diagrams to target cost drivers, optimize workflows, and improve space utilization.

(5) Improving customer and market management:
- Objective: Strengthen market position through improved customer satisfaction and timely deliveries.
- Recommendation: Enhance demand forecasting, real-time tracking, and customer feedback loops.
- Expected impact: Higher delivery accuracy, improved customer satisfaction, and reduced churn.
- Actionable steps: Implement machine learning for forecasting, enable real-time tracking for transparency, and leverage feedback for continuous improvement.

(6) Strengthening risk management and sustainability:
- Objective: Improve risk mitigation and integrate sustainable practices.
- Recommendation: Conduct risk assessments and adopt sustainability initiatives.
- Expected impact: Stronger risk mitigation and better environmental sustainability.
- Actionable steps: Identify vulnerabilities, integrate renewable energy, and develop contingency plans for major risks.

(7) Aligning long-term strategic objectives:

- Objective: Align supply chain operations with business growth, agility, and resilience.
- Recommendation: Regularly review KPIs and foster a culture of continuous improvement.
- Expected impact: Enhanced adaptability, resilience, and alignment with business goals.
- Actionable steps: Continuously update KPIs, promote a Kaizen-driven culture, and empower teams to adapt to disruptions.

These improvement strategies provide a clear and structured approach to optimizing supply chain performance. By leveraging Lean Six Sigma and advanced technologies, organizations can achieve greater operational efficiency, customer satisfaction, sustainability, and long-term success in a dynamic market.

Table 7. Summary of improvement recommendations.

#	Area	Objective	Main improvement recommendations
1	Operational management	Enhance efficiency and product quality	• Integrate Lean Six Sigma tools (VSM, 5S, SPC) to optimize operations. • Identify and eliminate bottlenecks to maximize throughput.
2	Procurement management	Improve efficiency and reduce costs	• Implement RFID technology for real-time material tracking. • Foster long-term supplier relationships to reduce lead times and procurement costs.
3	Inventory management	Optimize stock levels and reduce costs	• Apply Just-In-Time (JIT) and automated inventory systems. • Use big data analytics for improved demand forecasting and inventory optimization.
4	Financial management	Enhance profitability and cost control	• Use Lean Six Sigma to reduce production costs and improve labor productivity. • Optimize warehouse space and automate processes to lower storage costs.
5	Market management	Strengthen market position and customer engagement	• Leverage data analytics for demand forecasting and trend analysis. • Enhance customer engagement with personalized marketing and strategic partnerships.
6	Customer satisfaction	Improve service quality and retention	• Improve on-time delivery and transparency with real-time order tracking. • Gather continuous customer feedback to enhance service quality and retention.
7	Risk management	Strengthen resilience and mitigate risks	• Conduct regular risk assessments to identify vulnerabilities and implement mitigation plans. • Integrate sustainability practices to reduce risks and ensure long-term resilience.

5.5. Proposed DMAIC framework

Integrating Lean Six Sigma (LSS) with strategic planning optimizes manufacturing supply chains and ensures alignment with long-term business objectives. This framework improves efficiency, resilience, and agility while supporting sustainable growth. As detailed in **Table 8**, the proposed LSS framework consists of five phases: Define, Measure, Analyze, Improve, and Control. Each phase plays a crucial role in driving continuous improvement and achieving long-term success.

Table 8. The proposed LSS framework.

Phase	Objective	Key activities	Role of strategic planning
Define	Align with business goals	• Identify key supply chain areas. • Align objectives with business priorities. • Engage stakeholders to secure support. • Select and define relevant KPIs.	Ensures alignment with long-term strategic goals, focusing on high-impact areas.
Measure	Assess current performance	• Collect data on key metrics (e.g., lead times, inventory levels). • Establish performance baselines. • Highlight inefficiencies and bottlenecks.	Identifies performance gaps, enabling informed, data-driven decisions.
Analyze	Identify root causes of inefficiencies	• Conduct root cause analysis (e.g., 5 Whys, Fishbone diagrams). • Quantify impacts on key metrics (e.g., cost, quality). • Prioritize issues for improvement and eliminate waste.	Focuses on resolving root causes, ensuring alignment with strategic goals.
Improve	Implement Lean Six Sigma solutions	• Apply Lean (e.g., JIT, Kaizen) and Six Sigma tools (e.g., control charts). • Leverage automation and advanced analytics.	Implements targeted improvements that align with strategic priorities.
Control	Ensure sustainability and continuous improvement	• Monitor KPIs to track progress. • Standardize improvements through updated SOPs. • Conduct regular audits and provide ongoing training.	Embeds continuous improvement into the organizational culture, ensuring ongoing alignment with business objectives.

(1) Define: The goal of the Define phase is to align improvement initiatives with business goals. This phase involves identifying key supply chain areas, aligning objectives with strategic priorities, and engaging stakeholders to ensure collaboration and support. Selecting appropriate Key Performance Indicators (KPIs) is critical for tracking progress and measuring success. Strategic planning in this phase ensures that the project is focused on high-impact areas that contribute directly to long-term business objectives.

(2) Measure: In the Measure phase, the aim is to assess current performance by collecting data on metrics such as lead times and inventory levels. Establishing baselines and identifying inefficiencies or performance gaps is a key activity. This data-driven approach provides clear insights into areas that need improvement. The phase sets the foundation for targeted actions aligned with business objectives, ensuring that performance gaps are addressed.

(3) Analyze: The Analyze phase identifies the root causes of inefficiencies. Tools like 5 Whys and Fishbone diagrams help uncover underlying issues. The impact of these inefficiencies on key business metrics—such as cost, quality, and customer satisfaction—is quantified to prioritize areas for improvement. By focusing on the most impactful issues, this phase ensures that efforts are aligned with strategic goals and will drive the greatest business impact.

(4) Improve: In the Improve phase, Lean and Six Sigma solutions are applied to eliminate waste, streamline processes, and enhance consistency. Techniques such as Just-In-Time (JIT), Kaizen, and Six Sigma tools like control charts are used to improve operational efficiency. Automation and predictive analytics may also be leveraged to optimize operations further. Strategic planning ensures that the

improvements align with business priorities, enhancing long-term competitiveness, quality, and operational efficiency.

(5) Control: The Control phase ensures that improvements are sustained over time. Key performance indicators (KPIs) are monitored to ensure that standards are maintained. Standard Operating Procedures (SOPs) are updated, and ongoing training is provided to sustain the changes. Regular audits help ensure continuous improvement. Strategic planning in this phase embeds continuous improvement into the company's culture, aligning operational practices with long-term business goals and supporting long-term resilience.

In summary, the LSS framework integrates strategic planning at each phase to ensure that operational improvements are both effective and aligned with long-term business objectives. This approach fosters data-driven decision-making, drives continuous improvement, and enables the organization to remain competitive and adaptable in a dynamic market.

6. Results and discussion

This section assesses the impact of Lean Six Sigma (LSS) on the supply chain operations of the case study organization, addressing challenges such as long lead times, inconsistent product quality, and the lack of standardized processes.

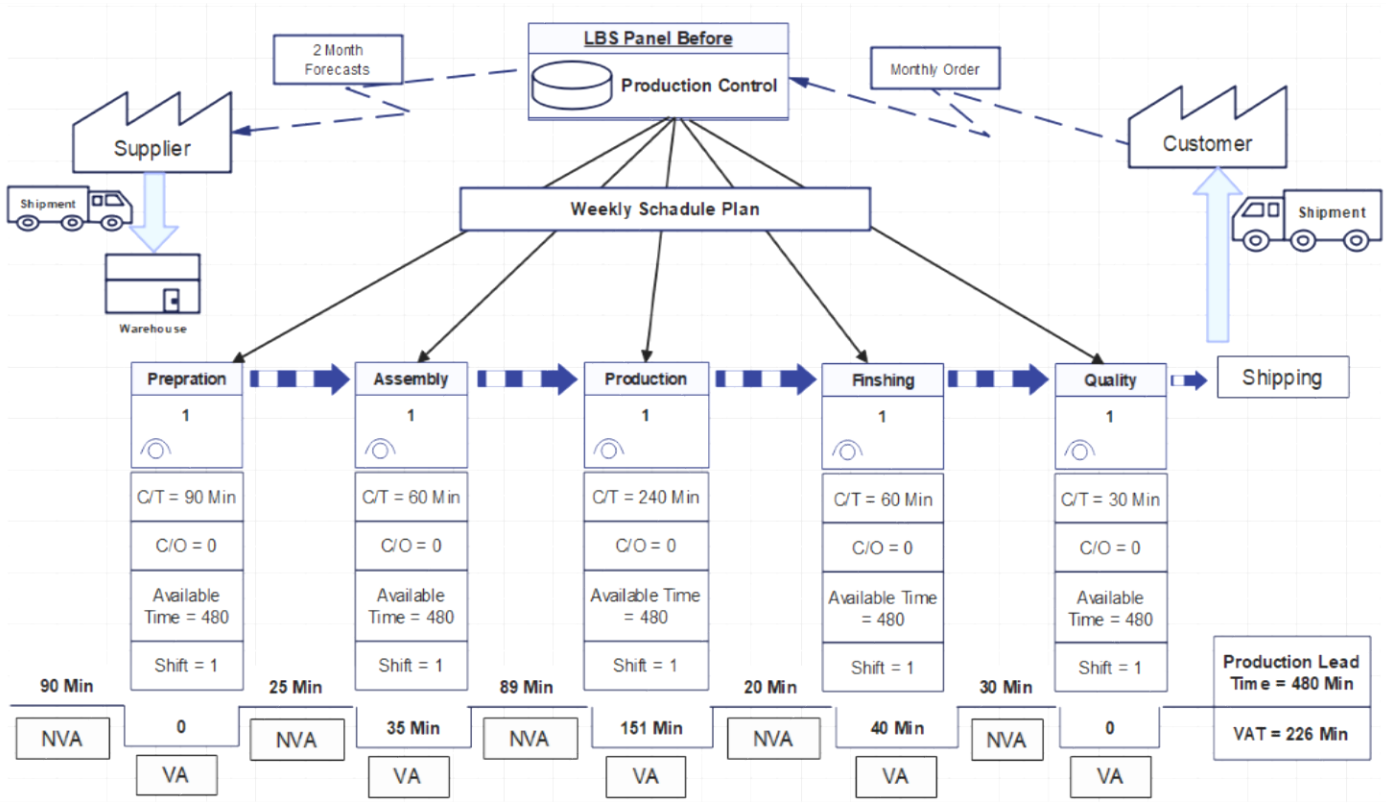

Figure 1. Value stream mapping (before improvement).

1) Pre-implementation challenges: Before LSS, the organization struggled with inefficiencies including prolonged production lead times, fluctuating product quality, and no standardized processes. As shown in **Figure 1**, the typical production time for

a panel was 480 min, but only 226 min were value-added, resulting in a Value-Added Process Efficiency (VAPE) of 47.1%. This indicated that over half of production time was consumed by non-value-adding activities such as idle time, excessive movement, and rework. Key contributing factors included poor workflow management, inadequate communication, and a lack of process standardization.

2) Root cause analysis: A value stream mapping (VSM) exercise identified critical bottlenecks and excessive WIP inventory. **Figure 2**, using an Ishikawa diagram, revealed root causes such as:

- Poor-quality raw materials, leading to increased defects.
- Inconsistent machine maintenance, causing downtime.
- Lack of training, resulting in operator errors.
- Process variability, due to non-standardized procedures.

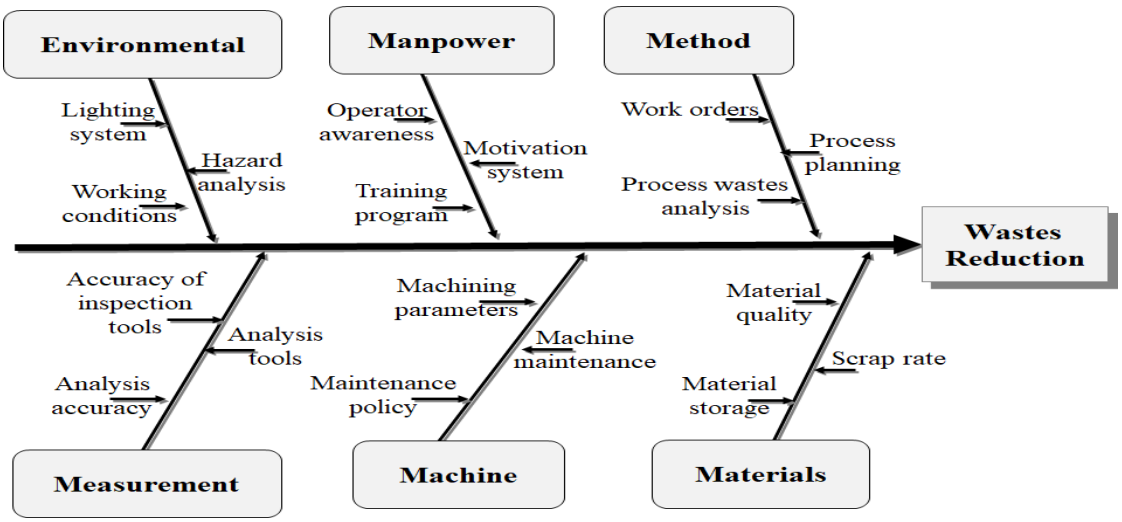

Figure 2. C&E diagram for non-value-added reduction.

3) Improvement plan: The improvement plan, based on Lean principles and the 7S methodology (Sort, Set in Order, Shine, Standardize, Sustain, Safety, Sustainability), focused on:

- Factory layout redesign: Transitioning to a U-shaped layout to optimize material flow and reduce unnecessary movement.
- Standardization: Establishing SOPs to eliminate variability and improve consistency.
- Employee training: Improving skills to reduce errors and enhance productivity.
- Maintenance: Introducing preventive measures to minimize downtime.

4) Results: The following improvements were realized:

- Production lead time: Reduced by 35%, from 480 min to 310 min (**Figure 3**).
- Value-added process efficiency (VAPE): Increased from 47.1% to 66.1%.

As illustrated in **Table 9**, substantial improvements were recorded across all key performance indicators:

- First-pass product quality increased from 80.6% to 90.1%, signifying a notable reduction in initial defects.
- Product quality after rework improved significantly from 85.7% to 99.0%, indicating near-optimal quality levels.

- Sigma level (first-pass) rose from 2.4 to 2.8, reflecting enhanced process capability and consistency.
- Sigma level (post-rework) increased from 2.6 to 2.8, demonstrating reduced process variability.
- Process lead time was reduced to 310 minutes, exceeding expectations by outperforming the 400-minute target.
- Process efficiency improved considerably, rising from 47.1% to 74.1%, indicating more effective resource utilization.
- Value-added ratio increased from 50.0% to 66.1%, highlighting a greater proportion of value-generating activities.
- Customer satisfaction rose from 83.0% to 93.0%, reflecting a significant enhancement in product and service quality.

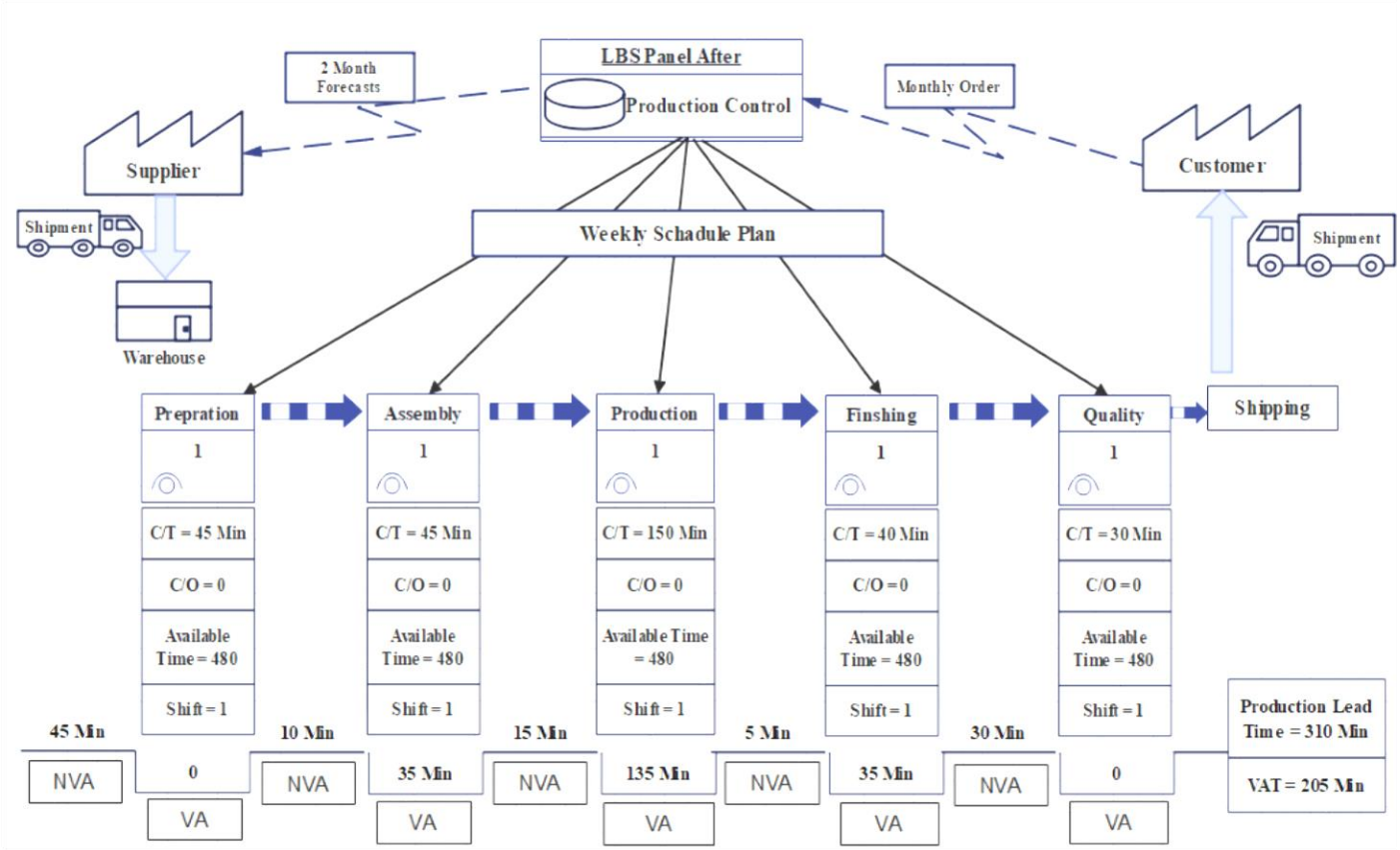

Figure 3. Value stream mapping (After improvement).

5) Impact and sustainability: Digital tools enabled real-time monitoring and data-driven decisions, ensuring that improvements were sustained over time. The use of digital dashboards improved visibility into key performance indicators (KPIs), helping the team identify issues early and address them proactively.

Standardized processes and improved communication further streamlined workflows, minimizing inefficiencies and allowing the company to scale operations effectively.

In conclusion, Lean Six Sigma led to notable gains in operational efficiency, product quality, and customer satisfaction, strengthening the organization's

competitive position. These improvements set a foundation for further growth, as the ongoing application of Lean Six Sigma principles will continue to drive long-term operational excellence.

Table 9. A summary of process performance indicators (Before and after improvement).

#	Indicator	Unit	Target	Before	After
1	Product quality (first time)	%	≥ 90	80.6	90.1
2	Product quality (after rework)	%	≥ 95	85.7	99.0
3	Sigma level (first time)	#	≥ 2.8	2.4	2.8
4	Sigma level (after rework)	#	≥ 3.1	2.6	3.8
5	Process lead time	Min./panel	≤ 400	480	310
6	Process efficiency	%	≥ 60	47.1	74.1
7	Value added	%	≥ 55	50.0	66.1
8	Customer satisfaction	%	≥ 92	83.0	93.0

7. Conclusion and future work

This study examines the strategic integration of Lean Six Sigma (LSS) to enhance manufacturing supply chain performance. By addressing inefficiencies, reducing waste, and resolving issues such as delays and process variability, the research applies the DMAIC (Define, Measure, Analyze, Improve, Control) methodology and key performance indicators (KPIs) to demonstrate LSS's effectiveness in optimizing operations. The study also considers challenges unique to developing countries, such as limited resources, infrastructure gaps, and market instability, emphasizing the need for adaptable and resilient strategies. A conceptual framework is proposed to align LSS initiatives with long-term strategic goals, fostering sustainable supply chain excellence.

A case study of an Egyptian electrical control panel manufacturer highlights the practical impact of this approach. Results include a 10% improvement in product quality, a 35% reduction in lead time, and significant enhancements in equipment efficiency, customer satisfaction, and value-added activities. These outcomes underscore the value of LSS tools—such as value stream mapping, root cause analysis, and standardization—in eliminating waste and improving performance across the supply chain.

Future research should explore strategies to sustain these improvements and extend LSS applications across industries. Integrating advanced technologies—such as artificial intelligence, data analytics, and automation—can further enhance supply chain agility, enabling predictive insights, real-time monitoring, and data-driven decision-making. For developing economies, such technologies can bridge operational gaps and support global competitiveness.

Furthermore, successful LSS adoption depends on leadership commitment, a culture of continuous improvement, and workforce engagement. Investigating these enablers will be crucial for understanding how to embed LSS practices for long-term success, especially in resource-constrained environments.

In conclusion, the integration of Lean Six Sigma with strategic planning enhances

manufacturing supply chain performance by improving efficiency, quality, and adaptability. As organizations respond to digital transformation and global challenges, LSS offers a robust, scalable framework for achieving sustained operational excellence.

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Abbreviations

5S	A Visual control approach and a workplace organization method
AI	Artificial intelligence
DMAIC	A data-driven problem-solving methodology (Define, measure, analyze, improve, and control)
IoT	Internet of things
JIT	Just-In-Time
KPIs	Key performance indicators
LSS	Lean Six Sigma
SCM	Supply Chain Management
SPC	Statistical Process Control
SRM	Supplier relationship management
SWOT	Strengths, weaknesses, opportunities, and threats
TWOS	Threats, weaknesses, opportunities, and strengths
VSM	Value stream mapping

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