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Enhancing Inventory Performance in Manufacturing Supply Chains Through Lean Six Sigma: A Case Study

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Abstract

Effective inventory management is a critical determinant of operational efficiency, cost control, and service performance in increasingly volatile manufacturing environments. While Lean Six Sigma (LSS) is widely established as a methodology for waste reduction and process variability minimization, its structured application to inventory strategy and performance optimization remains comparatively underdeveloped in the literature. Existing inventory management practices are frequently constrained by fragmented decision-making, weak process integration, and limited responsiveness to demand uncertainty, leading to persistent inefficiencies such as excess stock, stockouts, and elevated holding costs. This study develops and empirically implements a Lean Six Sigma-based, DMAIC-driven framework for inventory optimization, integrating core tools including value stream mapping, root cause analysis, 5S, process mapping, and performance measurement systems. The framework operationalizes inventory management as a structured, data-driven process aligned with key performance indicators, enabling systematic identification of inefficiencies and targeted improvement interventions. The framework is applied in a medium-sized Egyptian electrical control panel manufacturer characterized by significant inventory inefficiencies, including high carrying costs, prolonged lead times, excess inventory, and recurring stockouts. The DMAIC implementation yields statistically and operationally meaningful improvements across multiple performance dimensions: inventory turnover increases by 20%, on-time order fulfillment improves by 15%, carrying costs decrease by 22%, lead times are reduced by 25%, stockout rates decline by 30%, and inventory accuracy improves by 15%. Overall, the findings demonstrate that Lean Six Sigma can effectively reconfigure inventory management from a reactive, fragmented system into a structured, performance-driven, and continuously improving operational capability. The proposed framework contributes both theoretically and practically by providing an empirically grounded, context-sensitive approach to inventory optimization in resource-constrained manufacturing environments.

Keywords: Lean Six Sigma; DMAIC; Inventory Optimization; Manufacturing Systems; Inventory Control; Supply Chain Performance; Operational Efficiency; Process Improvement

1. INTRODUCTION

Effective inventory management is critical for operational efficiency, cost control, and supply chain resilience in modern manufacturing. Organizations must balance material availability with financial efficiency to meet dynamic customer demand. Adequate inventory ensures uninterrupted production and service delivery, whereas excess stock ties up capital, increases storage and insurance costs, and risks obsolescence. Conversely, stockouts disrupt production, delay deliveries, and compromise customer satisfaction and organizational reputation. Increasingly complex multi-stage production, diverse product portfolios, and globally distributed suppliers underscore the need for structured, data-driven strategies that align operations with organizational objectives and foster continuous improvement throughout the supply chain [1-5].

1.1. Manufacturing Inventory Strategy

Inventories are essential assets that require careful management to prevent losses from both shortages and excess [6,7]. Inventory management involves planning, organizing, and controlling stock to balance supply and demand while minimizing investment, including procurement, storage, and accessibility [8,9].

A robust inventory strategy ensures materials and products are available at the right time, in the right quantity, and at minimal total cost [10-11]. Inefficient practices lead to production delays, lost sales, and reputational damage, whereas overstocking increases storage, insurance, and obsolescence costs. Core techniques include Economic Order Quantity (EOQ), which balances ordering and holding costs [9,12]; Just-In-Time (JIT), which synchronizes production with demand to reduce inventory and enhance responsiveness [13,14]; and ABC analysis, which prioritizes management attention on high-value stock [9,11,15]. Safety stock, reorder points, and Vendor-Managed Inventory (VMI) further mitigate demand and lead-time variability while strengthening supplier collaboration [15]. Integrated with analytics and performance measurement systems, these methods shift inventory management from reactive control to proactive, evidence-based decision-making, enhancing working capital efficiency and competitive advantage [16,17].

1.2. Lean Six Sigma in Inventory Management

Lean Six Sigma (LSS) combines Lean waste-elimination principles with Six Sigma's focus on reducing process variability, providing a structured methodology to improve efficiency, quality, and cost performance [18,19]. Traditional inventory models often assume stable demand and lead times, limiting applicability in complex, real-world operations. LSS addresses these limitations by embedding continuous improvement into inventory processes. The DMAIC framework—Define, Measure, Analyze, Improve, Control—systematically identifies inefficiencies, optimizes material flows, improves forecasting accuracy, and reduces replenishment cycles [20-22]. Complementary Lean tools, such as 5S and value stream mapping, enhance process standardization, visual management, and elimination of non-value-added activities [23].

Empirical evidence demonstrates that LSS adoption improves process quality, operational efficiency, and supply chain coordination, particularly when aligned with ISO 9001 standards [24,25]. Successful implementation requires attention to data integrity, organizational adoption, and cross-functional collaboration. Beyond operational improvements, LSS fosters a culture of continuous improvement, enabling organizations to adapt effectively to demand variability and operational complexity [4,26]. Most research is U.S.-focused, but organizational and cultural differences in Europe and Africa can significantly influence outcomes, emphasizing the need for context-sensitive studies and sector-specific performance metrics [26-28].

1.3. Study Objectives and Contributions

This study develops and validates an integrated LSS-based framework to optimize manufacturing inventory strategy, addressing limitations in conventional approaches that are fragmented, reactive, and slow to respond to demand fluctuations. The framework integrates process mapping, root cause analysis, value stream mapping, DMAIC, 5S, and performance measurement systems to enhance stock control, reduce lead times, improve order accuracy, and increase responsiveness.

Practical applicability is demonstrated through implementation at a medium-sized Egyptian electrical control panel manufacturer, generating measurable operational improvements and actionable insights for both researchers and practitioners [4]. The case study illustrates how LSS can be adapted to specific organizational contexts while delivering tangible benefits in efficiency, cost reduction, and supply chain responsiveness.

The paper is structured as follows: Section 2 reviews relevant literature; Section 3 identifies research gaps; Section 4 presents the LSS-based inventory optimization framework; Section 5 details the case study and results; and Section 6 discusses practical implications, limitations, and directions for future research.

2. Literature Review

This study conducts a systematic literature review (SLR) of peer-reviewed publications from 2010 to 2026, retrieved from Scopus, Web of Science, and Google Scholar, using targeted keywords such as “Lean Six Sigma AND inventory management,” “Lean Six Sigma AND supply chain efficiency,” and “Lean Six Sigma AND materials management.” The review focused on empirical studies examining the application of Lean Six Sigma in manufacturing and supply chain operations, while excluding non-English publications, purely theoretical research, and studies with limited methodological rigor. Articles were screened through titles and abstracts, followed by full-text evaluation, with data extracted on research objectives, industry context, methodologies, applied tools, performance outcomes, and research gaps. Findings were synthesized thematically to highlight trends in LSS adoption, its impact on inventory optimization, process improvement practices, and alignment with organizational objectives. This evidence-based review provides a comprehensive overview of current knowledge, identifies critical research gaps, and establishes a foundation for developing a structured, data-driven framework to improve inventory management, operational efficiency, service quality, and supply chain resilience.

2.1. Significance and Operational Challenges of Inventory Management

Inventory management is a cornerstone of operational efficiency, cost control, and supply chain resilience in modern manufacturing. Organizations must balance material availability with financial efficiency while responding to fluctuating customer demand. Adequate inventory ensures continuity in production and service delivery, whereas excess stock ties up capital, increases storage and insurance costs, and raises obsolescence risk. Conversely, stockouts disrupt production schedules, delay deliveries, and negatively impact customer satisfaction and organizational reputation. Multi-stage production, diverse product portfolios, and globally distributed supplier networks further complicate this balance, necessitating structured, data-driven strategies that align operational practices with organizational objectives and foster continuous supply chain improvement [1,3-5]. Inventories are strategic assets requiring careful planning, monitoring, and control to balance supply and demand while minimizing capital investment [7-9].

Inventories often constitute a substantial portion of current assets and possess intrinsic resale value, highlighting their importance for capital efficiency and profitability [29,30]. Ineffective practices—overstocking, inaccurate forecasting, or poor replenishment—increase operational inefficiencies, elevate holding costs, and negatively affect financial performance [31,32]. Stockouts may cause production delays, lost sales, and reputational harm, while excessive inventory increases storage, insurance, depreciation, and obsolescence costs [11,30,33]. Accurate tracking of available, ordered, and consumed inventory is essential for demand forecasting, production planning, and resource allocation. Real-time visibility enables organizations to respond flexibly to market fluctuations, prevent overstocking or shortages, and enhance customer satisfaction and brand loyalty [11,15].

The relationship between inventory management and financial performance is complex. Some studies report a positive correlation between inventory turnover and profitability [33,35-38], while others report weak or context-dependent effects [7,39-41]. Vertical integration improves raw material and finished goods turnover [42,43], and JIT adoption enhances returns on assets, shortens inventory holding periods, and increases turnover rates [44-47]. Sustainable practices, such as controlled greenhouse farming, demonstrate that profitability can coexist with environmentally responsible supply chain management [48].

2.2. Inventory Optimization Techniques

Manufacturers employ multiple techniques to optimize inventory. EOQ calculates the optimal order quantity to minimize total costs by balancing ordering and holding expenses [9,12]. JIT reduces inventory levels, lowers holding costs, and frees working capital, relying on accurate forecasting and reliable suppliers [13-15,49]. TPS operationalizes JIT principles, emphasizing lean operations, waste reduction, and continuous improvement [15]. ABC analysis classifies inventory by consumption value, prioritizing high-value Category A items while allocating fewer resources to lower-value categories based on the 80/20 principle [9,11]. Complementary strategies—safety stock, reorder points, and Vendor-Managed

Inventory—buffer against demand variability, ensure timely replenishment, and strengthen supplier collaboration [15].

Integration with data analytics and performance measurement systems enables proactive, evidence-based inventory management, enhancing capital efficiency, responsiveness, and competitiveness [16]. Materials management extends these practices to planning, procurement, storage, and utilization of resources, optimizing production efficiency, reducing costs, and maintaining supply chain competitiveness [50-52]. Advanced systems, including MRP I & II, DRP, and JIT, integrate forecasting, inventory control, and resource allocation, aligning production with demand while reducing costs [53,54].

2.3. Lean Six Sigma for Inventory and Supply Chain Optimization

Lean Six Sigma (LSS) combines Lean's waste-elimination principles with Six Sigma's statistical rigor to standardize operations, reduce variability, and optimize inventory and supply chain processes [55-57]. Applications include stock-level optimization, improved demand forecasting, reduced lead times, and enhanced operational efficiency [58]. Most research is US-centric, with limited studies exploring cultural and organizational variations in Europe, Africa, and emerging markets. Many industries lack standardized LSS measurement frameworks, limiting systematic adoption and benchmarking [26-28].

Inventory accuracy—alignment between recorded and actual stock—is critical for efficiency. Six Sigma methodologies, including DMAIC, identify root causes of overstocking or inefficient policies, improving consistency [59,60]. Puiu et al. [61] applied DMAIC in automotive manufacturing to reduce variability, eliminate non-value-added activities, and implement robust controls, improving inventory accuracy, responsiveness, and overall performance. DMAIC phases (Define, Measure, Analyze, Improve, Control) utilize metrics such as stock turnover, lead times, and defect rates, alongside interventions including safety stock optimization, demand-driven replenishment, and advanced forecasting, supported by SPC and FMEA [4,61].

Despite advances, the integrated use of DMAIC, RCA, and FMEA is limited. Most studies examine these tools independently, providing little guidance on simultaneous root-cause analysis, risk prioritization, and corrective action implementation. This research addresses the gap, combining DMAIC and RCA for systematic root-cause analysis with FMEA for risk prioritization, demonstrating how data-driven interventions improve inventory accuracy as a key performance metric and driver of operational excellence [61].

2.4. Strategic Integration and Outcomes

Lean Six Sigma integrates Lean's waste elimination and Six Sigma's analytical rigor to enhance efficiency, reduce defects, and improve process reliability [4,62-64]. Integration with ISO 9001 strengthens standardization, performance measurement, and alignment with strategic objectives [25,65,66].

Lean stabilizes workflows, standardizes processes, and eliminates waste, while Six Sigma provides statistical control and structured problem-solving to achieve near-zero defects and higher process capability [61-71]. Together, Lean and Six Sigma optimize material flow, reduce lead times, improve forecasting accuracy, and strengthen inventory and supply chain performance [72-75].

LSS also supports innovation and sustainability by enabling structured problem-solving, cross-functional collaboration, and environmentally responsible improvements [76-82]. Applications across manufacturing, healthcare, food processing, laboratories, and financial services demonstrate improvements in process stability, quality, and customer satisfaction [83-88]. Structured adoption, ISO alignment, and sustainability integration enhance competitiveness, resilience, and long-term value creation [4,25,80].

In conclusion, Lean Six Sigma is a comprehensive methodology that integrates efficiency, quality, innovation, and sustainability. By combining Lean's waste-elimination strategies with Six Sigma's statistical rigor, LSS enables measurable improvements in operational performance, financial outcomes, customer satisfaction, and environmental stewardship, fostering continuous improvement and long-term competitive advantage [4,25,80].

3. Challenges and Research Gaps Analysis

Despite extensive research on inventory management and Lean Six Sigma (LSS) applications, manufacturing organizations continue to face persistent operational and strategic challenges, revealing critical research gaps. A primary challenge is balancing inventory efficiency with financial performance. Organizations must prevent stockouts, which disrupt production, delay deliveries, and compromise customer satisfaction, while avoiding overstocking, which ties up capital, increases storage and insurance costs, and accelerates obsolescence [11,29,30,33]. This balancing act is particularly difficult in multi-stage production systems and globally distributed supply chains, where variability in demand and supply, extended lead times, and logistical constraints increase operational uncertainty [1,3-5].

A related challenge is the fragmented and inconsistent application of inventory management practices. Tools such as EOQ, JIT, ABC analysis, safety stock, and Vendor-Managed Inventory (VMI) are often applied in isolation or reactively, reducing overall effectiveness. For instance, JIT reduces inventory levels and frees working capital but relies on accurate demand forecasting, reliable suppliers, and real-time monitoring—resources that many organizations lack [13-15,49]. Similarly, ABC analysis and safety stock methods are frequently applied without dynamic adjustment to demand or risk exposure, limiting their ability to prevent stockouts or excess inventory [9,11,15].

Integration with materials and production management presents further complexities. Effective inventory control must align with procurement, maintenance, repair, and operations (MRO), and production planning to optimize costs and ensure operational continuity [50,51,54]. However, these functions are often implemented independently, resulting in inefficiencies, unplanned downtime, and overstocking [42]. Advanced systems such as MRP I & II, DRP, and JIT can integrate forecasting, inventory control, and resource allocation, but their effectiveness depends on accurate data, skilled personnel, and organizational alignment [53,54].

Lean Six Sigma has proven effective in optimizing inventory and supply chain processes through standardization, waste reduction, and variability minimization [55-58]. Nonetheless, context-specific adoption challenges remain. Most studies focus on the United States, with limited attention to Europe, Africa, and emerging markets, where organizational culture, supplier networks, and workforce competencies affect outcomes [26-28]. Many industries also lack standardized LSS measurement frameworks, limiting benchmarking, scalability, and consistent evaluation.

Inventory accuracy remains a significant concern. Misalignment between recorded and actual stock undermines forecasting, production planning, and operational responsiveness [59,60]. Although DMAIC, SPC, and FMEA improve accuracy [4,60], most studies treat these tools separately, providing limited guidance on integrated application. Organizations often struggle to simultaneously identify root causes, prioritize risks, and implement sustainable corrective actions.

The integration of real-time data and analytics represents both a challenge and an opportunity. Timely visibility into inventory, production, and supply chain conditions is critical for proactive decision-making, yet many organizations rely on outdated or fragmented systems, limiting dynamic optimization and increasing vulnerability to inefficiencies [15,16]. Combining LSS with advanced analytics can enhance forecasting, risk management, and operational agility, though empirical research remains limited.

Finally, a significant gap exists in holistic, integrated frameworks that combine traditional inventory methods, Lean Six Sigma principles, and advanced analytics. Most studies focus on isolated techniques or metrics, limiting applicability in complex, multi-echelon manufacturing systems [7,40,41,61]. Without integrated, evidence-based frameworks, organizations cannot systematically reduce costs, improve service levels, or achieve sustainable operational excellence.

In summary, the key challenges and research gaps include balancing operational efficiency and financial performance under volatile demand and supply conditions, fragmented inventory practices, limited context-specific LSS adoption with insufficient measurement frameworks, persistent inventory inaccuracies, underutilization of real-time analytics, and the absence of holistic frameworks linking traditional practices, LSS, and analytics to operational and financial performance. Addressing these gaps requires research that integrates process optimization, risk prioritization, and data-driven decision-making to provide actionable strategies for improving inventory management, operational efficiency, and responsiveness in complex manufacturing environments. To provide structured guidance, Table 1 summarizes these challenges, their implications, and strategic recommendations.

Table 1. Challenges, Implications, and Strategic Recommendations

#	Challenge	Implications	Strategic Recommendations
1	Balancing inventory and financial performance	Stockouts disrupt operations; overstocking ties up capital and increases costs.	Adopt integrated EOQ, JIT, and safety stock strategies; apply demand forecasting and scenario planning.
2	Fragmented inventory practices	Isolated methods reduce efficiency and responsiveness.	Standardize policies; integrate multiple techniques; monitor inventory dynamically using data analytics.
3	Limited integration with materials and production	Misalignment causes inefficiencies, downtime, and excess inventory.	Foster cross-functional coordination; implement MRP/DRP systems and dashboards.
4	Context-specific LSS adoption challenges	Cultural and organizational differences hinder implementation; metrics are inconsistent.	Customize LSS training; adapt methods to local context; establish consistent performance metrics.
5	Inventory inaccuracies	Inaccurate records compromise forecasting and disrupt planning.	Apply DMAIC, RCA, and FMEA to identify root causes and maintain ongoing control.
6	Underutilization of real-time data	Limited visibility reduces agility and proactive decision-making.	Deploy IoT, ERP, and analytics platforms for real-time monitoring and dynamic adjustments.
7	Absence of holistic frameworks	Isolated approaches hinder multi-echelon optimization.	Develop integrated frameworks combining inventory models, LSS tools, and analytics for sustainable improvement.

4. Research Methodology for Optimizing Manufacturing Inventory Strategy

Effective inventory management is a key driver of operational efficiency, financial performance, and customer satisfaction in manufacturing organizations. Proper inventory control ensures that materials and products are available to meet production schedules and customer demand, while minimizing unnecessary costs. Conversely, poorly managed inventories can result in high holding costs, stockouts, delayed deliveries, and lost sales, reducing competitiveness and profitability. Despite its strategic importance, inventory management in many organizations remains reactive, fragmented, and dependent on manual processes, ad-hoc decisions, and limited analytical support.

Lean Six Sigma (LSS) provides a structured methodology to systematically improve inventory performance by combining Lean principles, which eliminate waste and improve process flow, with Six Sigma techniques, which reduce process variation and improve accuracy. However, LSS is often underutilized in manufacturing inventory systems, resulting in suboptimal performance. To address this gap, this study develops a comprehensive LSS DMAIC (Define, Measure, Analyze, Improve, Control) framework to systematically identify inefficiencies, implement targeted improvements, and sustain operational gains.

The DMAIC framework aligns inventory management processes with organizational objectives. Traditional approaches often suffer from misalignment with strategic goals, inconsistent KPI monitoring, insufficient root cause analysis, and limited continuous improvement. DMAIC addresses these challenges through five structured phases:

- 1) **Define Phase:** Establishes project scope, objectives, and Critical-to-Quality (CTQ) requirements, such as service levels, cost efficiency, and data reliability. Activities include SIPOC mapping of inventory and order-fulfillment processes, and stakeholder workshops to align priorities. This ensures improvement initiatives are focused on high-impact areas.

- 2) **Measure Phase:** Quantifies baseline performance for KPIs, including inventory turnover, operational cost per unit, lead time, stockout rate, order fulfillment accuracy, and inventory data accuracy.

Workflow mapping identifies bottlenecks and non-value-added activities, while data validation ensures reliable measurement. This phase establishes a factual basis for performance assessment.

3) Analyze Phase: Determines root causes of inefficiencies using tools such as Root Cause Analysis (RCA), Fishbone diagrams, Pareto analysis, and Value Stream Mapping (VSM). Typical challenges include inaccurate demand forecasting, fragmented workflows, unstructured inventory classification, and limited real-time visibility. Identifying these causes guides the design of targeted improvements.

4) Improve Phase: Implements corrective actions to address inefficiencies. Strategies include ABC/XYZ classification, demand-driven replenishment, workflow standardization, safety stock policies, error-proofing (Poka-Yoke), and barcode/RFID tracking to enhance data accuracy and responsiveness. Improvements are monitored and refined to ensure measurable performance gains.

5) Control Phase: Ensures sustainability of improvements through dashboards, control charts, SOPs, staff training, and audits. Continuous monitoring maintains KPI performance, prevents regression, and fosters a culture of operational excellence.

Table 2 summarizes the DMAIC framework, outlining objectives, key activities, tools, and outcomes for each phase. By integrating Lean and Six Sigma, organizations can address both efficiency (Lean) and accuracy/effectiveness (Six Sigma), ensuring improvements are systematic, measurable, and sustainable.

To align inventory management with organizational goals, the framework defines strategic objectives supported by actionable strategies and measurable KPIs. Table 4 presents these objectives, linking operational efficiency, service quality, and data accuracy to specific improvement actions and expected outcomes. Key objectives include maximizing inventory utilization, enhancing customer service, reducing operational costs, shortening lead times, minimizing stockouts, improving order accuracy, and ensuring inventory accuracy. Strategies include ABC/XYZ classification, demand-driven replenishment, workflow standardization, staff training, and error-proofing, while KPIs such as Inventory Turnover, Days of Inventory on Hand (DOH), On-Time In-Full (OTIF), and Stockout Rate allow precise performance monitoring. Expected outcomes include lower costs, improved cash flow, faster replenishment, higher product availability, fewer errors, and more reliable inventory data.

1) Optimize Inventory Utilization: Maximizes inventory efficiency by reducing excess and obsolete stock while maintaining adequate availability. Strategies include ABC/XYZ classification, managing slow-moving items, and implementing demand-driven replenishment. KPIs such as Inventory Turnover and DOH monitor performance, reducing holding costs and enhancing utilization.

2) Improve Customer Service: Enhances the reliability and responsiveness of order fulfillment. Strategies include streamlining order processing, strengthening supplier coordination, and implementing real-time tracking. OTIF and Order Cycle Time measure performance, resulting in more reliable deliveries, higher customer satisfaction, and competitive advantage.

3) Reduce Operational Costs: Lowers production and inventory-related expenses while improving process efficiency. Strategies include eliminating non-value-added activities, optimizing batch sizes, and applying Kaizen initiatives. KPIs such as Cost per Unit and Inventory Carrying Cost (%) track progress, producing lower costs and better resource utilization.

4) Shorten Lead Time: Reduces procurement and replenishment times to improve responsiveness. Strategies include standardizing procurement, monitoring suppliers, and streamlining workflows. Lead Time and Supplier On-Time Delivery (%) measure improvements, enabling faster, more predictable replenishment cycles.

5) Minimize Stockouts: Ensures supply continuity and prevents production or service disruptions. Strategies include setting optimal safety stock, automating replenishment, and improving forecasting accuracy. KPIs such as Stockout Rate and Fill Rate (%) track effectiveness, increasing availability and stabilizing production planning.

6) Improve Order Accuracy: Minimizes errors in order fulfillment to enhance service quality. Strategies include standardizing procedures, staff training, and implementing Poka-Yoke techniques. KPIs such as Order Accuracy (%) and Return Rate (%) monitor performance, reducing errors and rework, and increasing customer satisfaction.

7) Ensure Inventory Accuracy: Maintains reliable inventory data for informed planning and decision-making. Strategies include cycle counting, periodic reconciliations, and deploying

barcode/RFID systems. KPIs such as Inventory Accuracy (%) and Inventory Variance (%) track progress, ensuring dependable data and stronger inventory control.

By linking Tables 2 and 3, the DMAIC framework demonstrates a systematic, data-driven approach to inventory management, transforming it from a reactive process into a proactive, continuously improving system. This methodology delivers measurable benefits in operational efficiency, cost reduction, service reliability, and decision support.

Figure 1 illustrates the DMAIC framework as a continuous improvement cycle. The five phases—Define, Measure, Analyze, Improve, and Control—are centered on core objectives: inventory efficiency, customer service, cost reduction, and data accuracy. Key strategies, including ABC/XYZ classification, demand-driven replenishment, Poka-Yoke, and RFID/barcode tracking, support these objectives. Each phase details critical activities and tools, emphasizing alignment between operational actions, KPIs, and strategic goals for a structured, data-driven approach to inventory management.

Table 2. DMAIC Framework Implementation for Inventory Optimization

Phase	Objective	Key Activities	LSS Tools	Outcomes
Define	Set project scope and strategic goals	Identify operational challenges, define CTQs, map processes	SIPOC, Project Charter	Clear scope, aligned stakeholders, well-defined KPIs
Measure	Quantify current performance	Collect KPI data, map workflows, and validate inventory	Process Mapping, KPI Measurement, Data Validation	Accurate baseline metrics, performance gaps identified
Analyze	Determine root causes	RCA, Fishbone diagrams, Pareto analysis, VSM	RCA, Fishbone, Pareto, VSM	Key issues identified: poor forecasting, fragmented processes, limited visibility
Improve	Implement targeted solutions	ABC/XYZ classification, standardize workflows, optimize costs, safety stock, error-proofing, RFID/barcode systems	DMAIC, Kaizen, 5S, Standard Work, Poka-Yoke	KPI improvements: higher turnover, shorter lead times, lower costs, improved service, fewer stockouts, better data accuracy
Control	Sustain improvements	Dashboards, control charts, SOPs, training, audits	Control Charts, SOPs, Dashboards, Training	Sustained KPI performance, stable processes, culture of continuous improvement



Figure 1. DMAIC Framework for Optimizing Manufacturing Inventory Strategy.

Table 3. Strategic Objectives, Strategies, KPIs, and Expected Outcomes

#	Objective	Key Strategies	KPIs	Expected Outcomes
1	Optimize Inventory Utilization	ABC/XYZ classification; reduce excess/obsolete inventory; demand-driven replenishment	Inventory Turnover; DOH	Reduced holding costs; improved cash flow; enhanced utilization
2	Improve Customer Service	Streamline order processing; strengthen supplier coordination; real-time tracking	OTIF (%); Order Cycle Time	Improved delivery reliability; increased customer satisfaction
3	Reduce Operational Costs	Eliminate non-value-added activities; optimize batch sizes; Kaizen initiatives	Cost per Unit; Inventory Carrying Cost (%)	Lower costs; improved resource efficiency
4	Shorten Lead Time	Standardize procurement; monitor supplier performance; streamline workflows	Lead Time; Supplier On-Time Delivery (%)	Faster replenishment; improved responsiveness
5	Minimize Stockouts	Set safety stock; automate replenishment; improve forecasting	Stockout Rate (%); Fill Rate (%)	Increased availability; reduced disruptions
6	Improve Order Accuracy	Standardize procedures; staff training; error-proofing (Poka-Yoke)	Order Accuracy (%); Return Rate (%)	Reduced errors; minimized rework; improved service quality
7	Ensure Inventory Accuracy	Cycle counting; reconciliation; barcode/RFID systems	Inventory Accuracy (%); Inventory Variance (%)	Reliable data; improved planning and decision-making

5. Case Study and Results: Implementation of the Lean Six Sigma Framework

The Lean Six Sigma (LSS) framework was implemented in a medium-sized Egyptian electrical control panel manufacturer, operating in a complex production environment with diverse inventory and supply chain challenges. Despite having standard inventory procedures, the company experienced persistent operational inefficiencies, including stockouts, excess and stagnant inventory, delayed deliveries, and high operational costs. These inefficiencies highlighted a gap between daily operations and strategic objectives, emphasizing the need for a structured, data-driven methodology capable of systematically identifying inefficiencies, implementing corrective actions, and sustaining operational improvements. By integrating Lean tools for efficiency and Six Sigma analytics for precision, the LSS framework provided a comprehensive approach to optimize inventory strategy, enhance performance metrics, and foster continuous improvement.

5.1. Operational Challenges and Problems

The company faced multiple interrelated challenges: excess inventory tying up working capital, inefficient coordination causing delayed deliveries, non-value-added activities increasing operational costs, long lead times limiting responsiveness, frequent stockouts disrupting production, errors in order fulfillment leading to rework, and inaccurate inventory records hindering planning and forecasting. These challenges revealed a misalignment between operational practices and strategic objectives, necessitating a structured framework linking operational improvements to measurable outcomes.

Table 4 summarizes the alignment between operational challenges, strategic objectives, and corresponding KPIs. Excess inventory and low turnover are linked to optimizing inventory utilization measured through Inventory Turnover. Delayed deliveries correspond to improving customer service measured by On-Time Order Fulfillment (OTIF). High operational costs are monitored through Inventory Carrying Cost, while long lead times are addressed via Lead Time KPI. Frequent stockouts, order errors, and inaccurate records are associated with minimizing stockouts, maximizing order fulfillment accuracy, and ensuring inventory accuracy, respectively. This table provides a clear roadmap for connecting daily operational issues with strategic priorities, enabling targeted performance monitoring.

Table 5 details the KPIs, including units, calculation equations, and required data, providing a standardized approach for monitoring performance. For example, Inventory Turnover and Days of Inventory on Hand (DOH) measure inventory efficiency, OTIF and Stockout Rate track delivery reliability and supply continuity, and Inventory Accuracy ensures the integrity of inventory records for forecasting and planning. Lead Time and Inventory Carrying Cost provide insight into operational responsiveness and cost efficiency. Standardizing KPIs ensures consistent, accurate, and data-driven monitoring, forming the foundation for informed decision-making and continuous improvement.

5.2. Corrective Actions and Lean Six Sigma Tools

Table 6 links KPIs to baseline performance, corrective actions, and Lean Six Sigma tools used for improvement. For instance, Inventory Turnover was improved through ABC/XYZ classification, reducing obsolete stock, and demand forecasting, supported by VSM, 5S, and Kanban. On-Time Order Fulfillment was enhanced by streamlining order processing, improving supplier communication, and implementing real-time tracking using SIPOC and process mapping. Inventory Accuracy was strengthened via cycle counts, reconciliations, and barcode/RFID systems with PDCA cycles and control charts. Lead Time, stockout rates, and order fulfillment accuracy were addressed through standardized workflows, safety stock policies, and Poka-Yoke techniques. This table demonstrates the structured application of LSS tools to achieve measurable, sustainable operational improvements.

The implementation of the LSS framework transformed inventory management from a reactive, fragmented process into a proactive, continuously improving system. By linking operational problems to strategic objectives, defining measurable KPIs, and applying corrective actions through Lean Six Sigma tools, the company achieved enhanced inventory efficiency, reduced operational costs, improved service reliability, and more accurate inventory data. Tables 4–6 collectively illustrate how operational challenges are translated into actionable strategies, monitored through KPIs, and improved using structured LSS methodologies, bridging the gap between daily operations and organizational goals.

Table 4. Operational Problems, Strategic Objectives, and KPIs

#	Operational Problem	Strategic Objective	KPI
1	Excess inventory and low turnover	Optimize Inventory Utilization	Inventory Turnover
2	Delayed deliveries	Improve Customer Service	On-Time Order Fulfillment
3	High operational costs	Reduce Operational Costs	Inventory Carrying Cost
4	Long lead times	Shorten Lead Time	Lead Time
5	Frequent stockouts	Minimize Stockouts	Stockout Rate
6	Errors in order fulfillment	Maximize Order Fulfillment Accuracy	Order Fulfillment Rate
7	Inaccurate inventory records	Ensure Inventory Accuracy	Inventory Accuracy

Table 5. KPIs, Units, Calculation Equations, and Required Information

#	KPI	Unit	Calculation Equation	Required Information
1	Inventory Turnover	Times	$\text{COGS} \div \text{Average Inventory}$	COGS; Beginning and Ending Inventory
2	Days of Inventory on Hand (DOH)	Days	$(\text{Average Inventory} \div \text{COGS}) \times 365$	Average Inventory; COGS
3	On-Time Order Fulfillment (OTIF)	%	$(\text{Orders Delivered On-Time} \div \text{Total Orders}) \times 100$	Orders delivered on time; Total orders
4	Stockout Rate	%	$(\text{Number of Stockouts} \div \text{Total Demand Instances}) \times 100$	Number of stockouts; Total demand instances
5	Order Fulfillment Accuracy	%	$(\text{Correctly Fulfilled Orders} \div \text{Total Orders}) \times 100$	Correctly fulfilled orders; Total orders
6	Lead Time	Days	Delivery Date – Order Date	Order placement date; Delivery date
7	Inventory Accuracy	%	$[(\text{Recorded Inventory} - \text{Physical Count Variance}) \div \text{Recorded Inventory}] \times 100$	Recorded inventory; Physical count; Discrepancy
8	Inventory Carrying Cost	%	$(\text{Total Holding Costs} \div \text{Average Inventory Value}) \times 100$	Holding costs (storage, insurance, depreciation); Average inventory value
9	Fill Rate	%	$(\text{Quantity Shipped} \div \text{Quantity Ordered}) \times 100$	Quantity shipped; Quantity ordered
10	Cost per Unit	Currency	$\text{Total Production/Procurement Cost} \div \text{Total Units Produced/Procured}$	Production/procurement cost; Total units produced or procured

Table 6. KPIs, Baseline, Corrective Actions, and Lean Six Sigma Tools.

#	KPI	Unit	Baseline	Corrective Actions	LSS Tools
1	Inventory Turnover	Times	5.0	ABC/XYZ classification; reduce excess/obsolete stock; improve demand forecasting	VSM, 5S, Kanban
2	On-Time Order Fulfillment	%	80	Streamline order processing; enhance supplier communication; real-time order tracking	SIPOC, Process Mapping
3	Inventory Carrying Cost	%	18	Eliminate non-value-added activities; optimize batch sizes; Kaizen initiatives	VSM, Process Mapping, Control Charts
4	Lead Time	Days	20	Standardize procurement; monitor suppliers; minimize workflow delays	VSM, Process Mapping, Control Charts
5	Stockout Rate	%	20	Set optimal safety stock; improve forecasting; automate replenishment alerts	5S, Kanban, Forecasting Tools
6	Order Fulfillment Rate	%	85	Standardize work instructions; train staff; implement Poka-Yoke and double checks	Standard Work, FMEA
7	Inventory Accuracy	%	75	Conduct cycle counts; reconcile discrepancies; implement barcode/RFID systems	5S, PDCA, Control Charts

5.3. Practical Implementation of DMAIC

The Lean Six Sigma (LSS) framework was implemented using the DMAIC methodology, offering a structured approach to optimize inventory management. DMAIC combines Lean principles for operational efficiency with Six Sigma tools for data-driven decision-making. Table 8 summarizes the practical implementation, linking each phase to objectives, key activities, tools, and measurable outcomes.

1) Define Phase: The project scope, strategic objectives, and Critical-to-Quality (CTQ) requirements—such as service levels, responsiveness, cost efficiency, and data accuracy—were established. A SIPOC model mapped the end-to-end inventory and order fulfillment processes, defining inputs, outputs, stakeholders, and process boundaries. Cross-functional workshops aligned teams across production, procurement, and logistics, ensuring shared understanding of priorities and measurable goals. As shown in Table 8, this phase resulted in a clearly defined scope, aligned stakeholders, and well-established KPIs.

2) Measure Phase: Baseline performance data for key KPIs—Inventory Turnover, Days of Inventory on Hand (DOH), Lead Time, Operational Costs, Stockout Rate, and Order Fulfillment Accuracy—was collected and validated. Detailed process mapping identified bottlenecks, redundancies, and non-value-added activities. This phase provided a reliable understanding of current performance and highlighted areas requiring improvement, as reflected in Table 8.

3) Analyze Phase: Root causes of inefficiencies were identified using Root Cause Analysis (RCA), Fishbone diagrams, Pareto analysis, and Value Stream Mapping (VSM). Key challenges included poor demand forecasting, fragmented workflows, unstructured inventory classification, and limited real-time visibility. Table 8 shows that this phase enabled prioritization of corrective actions based on data-driven insights.

4) Improve Phase: Targeted solutions were implemented to address identified gaps. Inventory optimization included ABC/XYZ classification and demand-driven replenishment. Workflow efficiency was enhanced through standardization, supplier coordination, and real-time tracking. Operational costs were reduced by eliminating non-value-added activities, optimizing batch sizes, and applying Kaizen principles. Lead times were shortened, stockouts reduced via safety stock policies and automated alerts, and order accuracy improved through staff training and Poka-Yoke error-proofing. Inventory data reliability was strengthened via cycle counts, reconciliation, and RFID/barcode systems. **Table 7** highlights that these actions led to measurable KPI improvements, including higher turnover, faster replenishment, lower costs, fewer stockouts, and enhanced service quality.

5) Control Phase: Sustainability was ensured through dashboards for real-time KPI monitoring, control charts for process stability, SOPs, staff training, and audits. Table 8 indicates that this phase resulted in stable processes, sustained KPI performance, and a culture of continuous improvement.

Overall Impact: The application of DMAIC transformed inventory management from a reactive and fragmented process into a proactive, structured, and continuously improving system. Linking operational activities to KPIs ensured alignment with strategic objectives, delivering measurable improvements in efficiency, cost reduction, service reliability, and decision-making accuracy. This structured approach demonstrates how targeted, data-driven interventions create sustainable operational and competitive advantages.

Table 7. Practical Implementation of DMAIC

Phase	Objective	Key Activities	Tools	Outcomes
Define	Set project scope and strategic goals	Identify operational challenges, define CTQs, map end-to-end processes	SIPOC, Project Charter	Clear scope, aligned stakeholders, well-defined KPIs
Measure	Quantify current performance	Collect KPI data, map workflows, and validate inventory	Process Mapping, KPI Measurement, Data Validation	Accurate baseline metrics, performance gaps identified
Analyze	Determine root causes	RCA, Fishbone diagrams, Pareto analysis, VSM	RCA, Fishbone, Pareto, VSM	Key issues identified: poor forecasting, fragmented processes, limited visibility
Improve	Implement solutions	ABC/XYZ classification, standardize workflows, optimize costs, safety stock, error-proofing, RFID/barcode systems	DMAIC, Kaizen, 5S, Standard Work, Poka-Yoke	KPI improvements: higher turnover, shorter lead times, lower costs, improved service, fewer stockouts, better data accuracy
Control	Sustain improvements	Dashboards, control charts, SOPs, training, audits	Control Charts, SOPs, Dashboards, Training	Sustained KPI performance, stable processes, culture of continuous improvement

5.4. Results and KPI Analysis

The implementation of the Lean Six Sigma (LSS) DMAIC framework produced substantial, measurable improvements across all key performance indicators (KPIs), demonstrating enhanced operational efficiency, cost management, service quality, and inventory accuracy. By applying a structured, data-driven approach, the company systematically identified inefficiencies, implemented targeted corrective actions, and aligned inventory operations with strategic objectives, transforming inventory management from reactive and fragmented to proactive, optimized, and measurable.

Table 8 presents the impact of the DMAIC framework on inventory management performance. Each KPI shows clear improvement, reflecting the effectiveness of Lean Six Sigma interventions in achieving operational and strategic goals. The results also highlight interdependencies across processes, where gains in one area—such as inventory accuracy—directly benefit stock availability, turnover, and order fulfillment.

1) **Inventory Turnover:** Increased from 5.0 to 6.0 times (+20%), achieving the target of 6.0. Improvements reflect efficient inventory utilization, reduced excess and obsolete stock, and better cash flow. Key interventions included ABC/XYZ classification, demand-driven replenishment, and workflow standardization.

2) **On-Time Order Fulfillment (OTIF):** Rose from 80% to 92% (+15%), surpassing the 90% target. Streamlined order processing, enhanced supplier coordination, and real-time tracking enabled faster, more reliable deliveries, improving customer satisfaction.

3) **Inventory Carrying Cost:** Declined from 18% to 14% (−22%), approaching the 15% target. Savings were achieved through elimination of obsolete stock, better inventory classification, and demand-driven replenishment, optimizing resource utilization and profitability.

4) **Lead Time:** Shortened from 20 to 15 days (−25%), outperforming the 16-day target. Standardized procurement, improved internal workflows, and supplier performance monitoring enabled faster replenishment, minimizing production delays.

5) **Stockout Rate:** Reduced from 20% to 14% (−30%), exceeding the 15% target. Safety stock policies, improved forecasting, and automated replenishment alerts ensured product availability and minimized production disruptions.

6) **Order Fulfillment Rate:** Increased from 85% to 94% (+10%), surpassing the 92% target. Standardized procedures, staff training, and Poka-Yoke error-proofing improved order accuracy, reduced rework, and enhanced service quality.

7) **Inventory Accuracy:** Improved from 75% to 86% (+15%), exceeding the 85% target. Cycle counts, reconciliations, and RFID/barcode tracking ensured reliable inventory data, supporting accurate planning, forecasting, and decision-making while indirectly improving stockout rates and fulfillment performance.

The improvements reveal system-wide interdependencies: higher inventory accuracy enabled more precise replenishment; shorter lead times facilitated faster product availability; and increased turnover optimized working capital. Lean Six Sigma interventions—including ABC/XYZ classification, demand-driven replenishment, standardized workflows, Kaizen initiatives, Poka-Yoke, and RFID/barcode systems—not only enhanced individual KPIs but also strengthened overall operational performance.

Figure 2 presents a clear visual summary of the effects of Lean Six Sigma (LSS) interventions on key inventory management KPIs, displaying baseline, target, and post-implementation values. It demonstrates how structured, data-driven strategies—such as ABC/XYZ classification, demand-driven replenishment, standardized workflows, Poka-Yoke error-proofing, Kaizen continuous improvement, and RFID/barcode tracking—enhanced operational efficiency, reduced costs, improved service quality, and strengthened data accuracy. The figure highlights the transformation of inventory management from a reactive, fragmented process into a proactive, strategically aligned system. Additionally, it emphasizes the interconnections among KPIs, showing how gains in inventory accuracy, lead time, and turnover collectively optimize working capital, minimize stockouts, accelerate replenishment, and improve overall supply chain performance.

In conclusion, the results confirm that the DMAIC framework is scalable, repeatable, and highly effective. It delivers measurable improvements in efficiency, cost control, service quality, and data reliability, while embedding a culture of continuous improvement. The framework ensures long-term

supply chain resilience, operational excellence, and alignment between inventory operations and strategic organizational objectives.

Table 8. KPI Performance Before and After Lean Six Sigma Implementation

#	KPI	Unit	Target	Before	After	Improvement
1	Inventory Turnover	Times	6.0	5.0	6.0	+20%
2	On-Time Order Fulfillment	%	90	80	92	+15%
3	Inventory Carrying Cost	%	15	18	14	-22%
4	Lead Time	Days	16	20	15	-25%
5	Stockout Rate	%	15	20	14	-30%
6	Order Fulfillment Rate	%	92	85	94	+10%
7	Inventory Accuracy	%	85	75	86	+15%

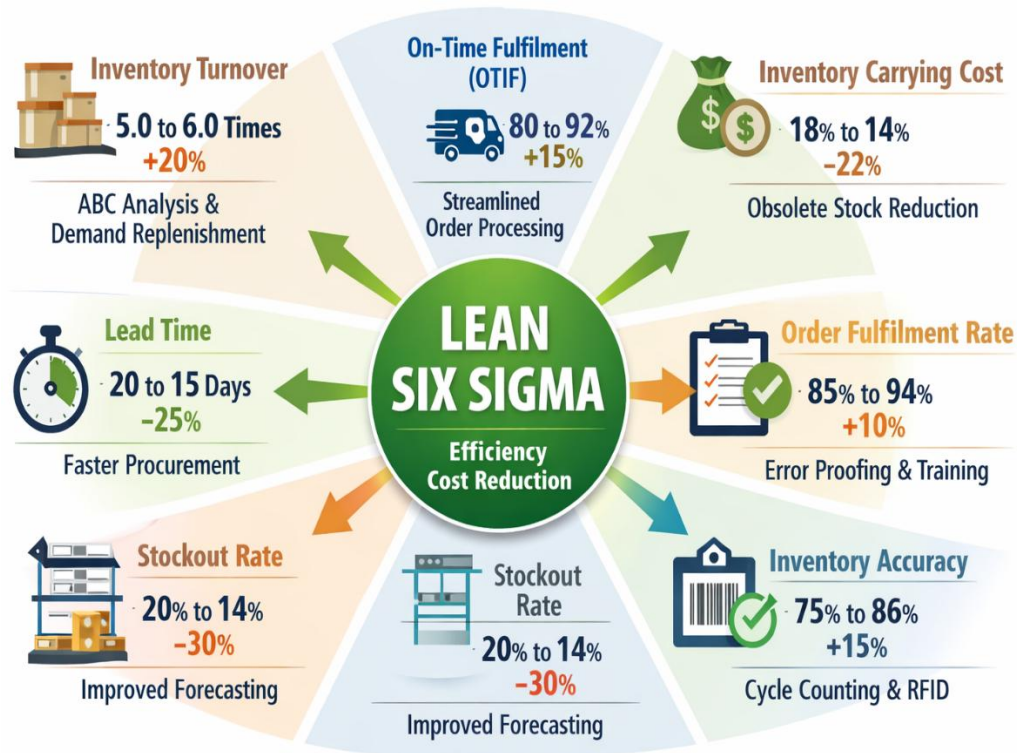


Figure 2. KPI Improvements Following Lean Six Sigma Implementation.

6. Conclusion and Future Work

This study developed and empirically implemented a case-specific Lean Six Sigma (LSS)–DMAIC framework for enhancing inventory performance in a medium-sized Egyptian electrical control panel manufacturer. The framework integrates established LSS instruments—including value stream mapping, root cause analysis, 5S, and process mapping—within a structured DMAIC cycle to address firm-level inventory inefficiencies. In contrast to generic LSS configurations, the proposed model is explicitly contextualized to SME manufacturing constraints, particularly limited digitalization, material variability, and constrained operational resources.

The empirical application demonstrates measurable improvements in key inventory performance indicators. Inventory turnover increased by 20%, on-time order fulfillment improved by 15%, inventory carrying costs decreased by 22%, lead times were reduced by 25%, stockout rates declined by 30%, order fulfillment accuracy improved by 10%, and inventory accuracy increased by 15%. Collectively, these outcomes indicate enhanced process stability, improved flow efficiency, reduced non-value-added activities, and stronger alignment between inventory operations and demand requirements.

Theoretical Implications: This study contributes to operations and supply chain theory by advancing a contextualized implementation perspective of Lean Six Sigma in inventory systems. Specifically, it extends prior research by demonstrating how LSS tools can be operationalized as an integrated, KPI-driven improvement architecture tailored to SME manufacturing environments. The findings reinforce the role of Lean Six Sigma as a dynamic capability mechanism for translating process improvement practices into measurable inventory performance gains under real industrial constraints.

Practical Implications

Managerial perspective: The proposed framework offers a structured and replicable approach for diagnosing inventory inefficiencies, prioritizing improvement actions, and institutionalizing KPI-based performance monitoring. It enables decision-makers to systematically reduce inventory-related waste, improve service levels, and enhance operational responsiveness in resource-constrained manufacturing settings. Managers can utilize the DMAIC-based structure to align inventory control practices with strategic operational objectives, strengthen process discipline, and embed continuous improvement routines into daily operations. The framework also supports more evidence-based decision-making through the integration of measurable performance indicators across inventory processes.

Study Limitations: Despite the observed performance improvements, the study is constrained by its single-case research design, which limits external validity and generalizability. Furthermore, the absence of a control group restricts causal attribution, as observed improvements may partially reflect exogenous factors such as demand seasonality, managerial interventions, and concurrent operational adjustments. Accordingly, the findings should be interpreted as context-specific evidence of implementation effectiveness rather than broadly generalizable causal effects.

Future Research: Future research should advance this work along several interrelated dimensions to strengthen methodological rigor and broaden theoretical applicability. First, multi-case and cross-industry empirical studies are required to assess the robustness and transferability of the proposed framework across heterogeneous manufacturing environments, including both SMEs and large-scale enterprises. Such studies would enable the identification of contextual contingencies that condition Lean Six Sigma effectiveness in inventory systems.

Second, future research should adopt more rigorous causal inference designs, including quasi-experimental approaches, matched control-group comparisons, and difference-in-differences methodologies, to better isolate the net effect of Lean Six Sigma interventions on inventory performance and mitigate confounding influences.

Third, longitudinal investigations are essential to evaluate the persistence of performance gains over time and to determine whether improvements are sustained, decay, or further enhanced as Lean Six Sigma practices become embedded within organizational routines and learning systems.

Fourth, future studies should examine the integration of Industry 4.0 enabling technologies, such as IoT-based real-time inventory visibility, artificial intelligence-driven demand forecasting, advanced analytics, and digital twin simulation. These technologies have the potential to significantly enhance the responsiveness, predictive accuracy, and decision-support capability of Lean Six Sigma-enabled inventory systems.

Finally, future research should incorporate socio-technical and behavioral dimensions, including leadership commitment, employee engagement, organizational readiness, and change management capabilities, as critical moderating factors influencing implementation success and sustainability. This would support a more comprehensive understanding of Lean Six Sigma as both a technical and organizational transformation mechanism in inventory management contexts.

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Abbreviations:

Abbreviation	Full Term	Short Definition
LSS	Lean Six Sigma	A combination of Lean and Six Sigma for efficiency and quality.
DMAIC	Define–Measure–Analyze–Improve–Control	Structured problem-solving cycle for process improvement
KPI	Key Performance Indicator	Measurable metric to assess operational performance
OTD	Order-to-Delivery	Time taken from order placement to fulfillment.
OTIF	On-Time In-Full	Percentage of orders delivered on time and complete
ABC/XYZ	ABC/XYZ Classification	Inventory categorization by value and demand variability
DOH	Days of Inventory on Hand	Average number of days inventory is held
SOP	Standard Operating Procedure	Documented instructions for consistent standardized operations

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