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Enhancing Product Development Excellence through Quality Management Tools: A Comprehensive Review and Integrated Conceptual Framework

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ABSTRACT: In today's rapidly evolving and highly competitive global markets, achieving product development excellence is critical for organizations striving for sustained growth and customer-centric innovation. This study highlights the integral role of key quality management tools in enhancing product development processes, reducing defects, and driving continuous improvement. It presents a robust methodology that strategically combines Quality Function Deployment (QFD), Failure Mode and Effects Analysis (FMEA), and the DMAIC (Define, Measure, Analyze, Improve, Control) framework to significantly improve the quality, reliability, and efficiency of product development efforts. Built on core principles of customer-centricity, innovation, cross-functional collaboration, continuous improvement, and risk-based thinking, the methodology emphasizes capturing the Voice of the Customer (VoC) and identifying Critical-to-Quality (CTQ) attributes to align product outcomes with customer expectations and business objectives. Utilizing the DMAIC framework, the organization systematically drives process optimization and innovation throughout the product lifecycle Key Performance Indicators (KPIs) are established to track efficiency, quality, customer satisfaction, and time-to-market, while Agile methodologies enhance flexibility, speed, and responsiveness. The study further identifies organizational, technical, cultural, and managerial barriers to product development excellence and proposes targeted strategies to address them and ensure sustainable success. This integrated framework fosters a culture of innovation and continuous learning, enabling organizations to anticipate challenges, manage risks, and consistently deliver superior product development outcomes. While currently conceptual, the framework is slated for empirical validation through case studies, pilot projects, and simulations to verify its practical applicability across diverse development contexts.

Keywords: Quality management; Product development; Total quality management (TQM); Lean six sigma (LSS); Design for reliability (DfR); Continuous improvement

1. Introduction

Achieving product development excellence is critical for organizations aiming to succeed in today's dynamic and competitive markets. Excellence in product development demands delivering high-quality, reliable products while continuously innovating to meet evolving customer needs, comply with regulations, and optimize operational efficiency. A strategic, integrated quality management approach is fundamental to driving superior performance throughout the product development lifecycle. Customer satisfaction lies at the heart of business sustainability, making robust product design and development processes critical for maintaining market leadership in manufacturing [1,2].

As illustrated in Figure 1, product development is a systematic and structured process designed to translate customer needs into high-quality, reliable products [3]. To elevate quality and operational efficiency, organizations increasingly integrate established quality methodologies, including Total Quality Management (TQM), Lean Six Sigma (LSS), and Design for Reliability (DfR). TQM fosters a culture of continuous improvement, LSS drives waste reduction and variability control, while DfR embeds reliability considerations from the earliest design stages. The convergence of these methodologies streamlines product development cycles, enhances regulatory compliance, and stimulates innovation, collectively reinforcing an organization's market position.

Further strengthening this approach, the Quality by Design (QbD) paradigm, introduced by Juran (1992), offers a systematic framework for aligning product features directly with customer expectations and quality attributes [4,5]. This paradigm facilitates proactive quality planning that permeates all stages of development, ensuring products meet or exceed performance criteria while effectively managing risk.

Beyond methodologies, cultivating a pervasive culture of quality excellence is indispensable for long-term success. Leadership commitment, cross-functional collaboration, and active workforce engagement transform quality from a mere compliance requirement into a powerful driver of innovation and customer satisfaction. Organizations that embed quality management principles throughout the product lifecycle are better positioned to enhance regulatory adherence, strengthen brand reputation, and build lasting customer loyalty. A holistic quality management framework—integrating proactive risk management, continuous improvement, and customer-centricity—empowers organizations to maximize efficiency, reduce time-to-market, and sustain growth in dynamic markets [6].

This paper explores the role of quality management tools and organizational enablers in advancing product development excellence. It focuses on methodologies, cultural factors, and performance optimization strategies that together form a comprehensive approach to superior product development. The paper is structured as follows: Section 2 reviews relevant literature, Section 3 identifies research gaps, Section 4 outlines the research methodology, and Section 5 discusses strategic insights, practical recommendations, and future research directions.

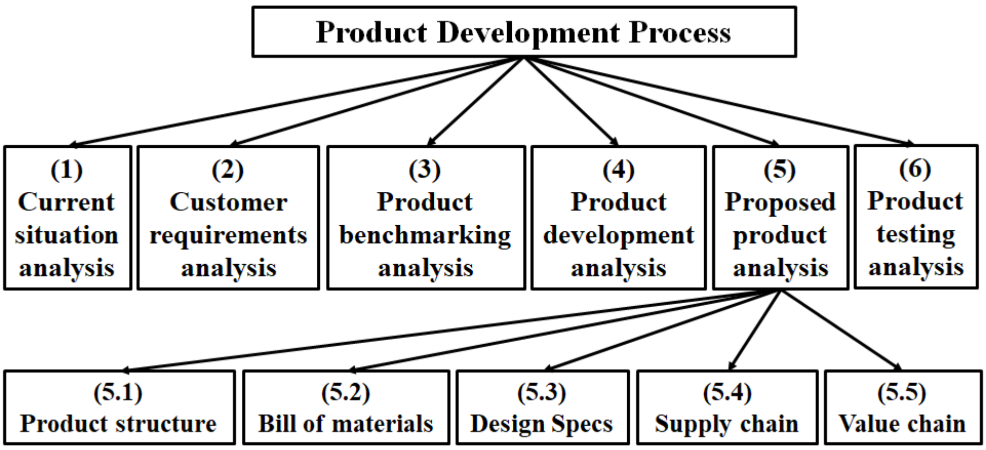

Figure 1. Product Development Process.

2. Literature Review

This section reviews key Quality management tools applied in product development, including the Quality Function Deployment (QFD), Failure Mode Effect Analysis (FMEA), Taguchi-based experimental design, Value Engineering (VE), Kano Model, and TRIZ. These tools are essential for optimizing design, improving efficiency, and driving innovation in product, service, and process development. Gomaa [3] explored the role of QM in research and development (R&D), emphasizing the importance of aligning product development with customer needs. While these tools have been widely studied individually, the literature lacks an integrated framework that systematically combines them to enhance product value, efficiency, and effectiveness. Additionally, successful implementation requires skilled development teams capable of managing these tools to drive continuous improvement and innovation.

2.1. A Comprehensive Review of the Quality Function Deployment (QFD) Approach

Quality Function Deployment (QFD), introduced by Akao in Japan (1966), is a structured methodology for optimizing product development and modification by systematically translating customer requirements (CRs) into design requirements (DRs) through the House of Quality (HOQ) [7,8]. As the foundation of QFD, HOQ provides a structured framework to align product design with customer expectations. It consists of key elements, including CRs, their relative importance, DRs, correlations among DRs, relationships between CRs and DRs, and the prioritization of DRs—a crucial outcome that directs product innovation and refinement. Table 1 presents an overview of QFD's core principles, challenges, process phases, enhancements, industry applications, key benefits, and future trends. A significant challenge in QFD implementation is the accurate assessment of CRs and their interdependencies with design factors. Traditional crisp values often fail to capture the uncertainty inherent in human judgment, making precise quantification difficult [9–11]. To address this, QFD employs a four-phase approach using structured matrices to streamline product and process development. Product Planning establishes relationships between CRs and engineering characteristics (ECs). Design Deployment maps ECs to critical part characteristics through the Part Deployment Matrix. Process Planning links part characteristics to production processes using the Process Planning Matrix. Production Planning defines quality control parameters and monitoring methods through the Process and Quality Control Matrix [12,13]. Due to its structured and systematic approach, QFD has been widely applied in new product development and the enhancement of existing products across diverse industries. Extensive research has explored its applications, as demonstrated by studies from [14–25].

Table 1. Summary of Quality Function Deployment (QFD).

Aspect	Key Details
Definition	A structured methodology translates customer requirements (CRs) into design requirements (DRs) via the House of Quality (HOQ) to enhance product and process development.
House of Quality (HOQ)	A core QFD tool that visually maps CRs to DRs, ensuring customer-driven prioritization and structured decision-making.
Challenges	Subjectivity in CR assessment, multi-criteria complexity, and scalability issues in large-scale applications.
Four-Phase Approach	1. Product Planning: CRs → Engineering Characteristics (ECs). 2. Design Deployment: ECs → Critical Part Characteristics. 3. Process Planning: Part Characteristics → Production Processes. 4. Production Planning: Defines quality control parameters.
Advanced Enhancements	- Fuzzy QFD: Addresses uncertainty in CR importance. - AHP/TOPSIS: Optimizes DR prioritization. - AI & IoT Integration: Enables predictive analytics and real-time decision-making.
Industry Applications	Automotive, Healthcare, Aerospace, Software, and Supply Chain, ensuring efficiency, quality, and innovation.
Key Benefits	- Customer-Centric Design for higher satisfaction. - Reduced Costs & Time-to-Market through efficient planning. - Improved Reliability & Competitive Advantage.
Future Trends	- AI-Driven QFD & Automation for intelligent design optimization. - Big Data for Real-Time CR Analysis. - Industry 4.0 Integration for Smart Manufacturing.

2.2. A Comprehensive Review of Failure Mode and Effects Analysis (FMEA)

Failure Mode and Effects Analysis (FMEA), developed by the U.S. military in the 1940s and refined by NASA in the 1960s, is a comprehensive and proactive risk assessment technique. It systematically identifies potential failure modes in products or processes, analyzes their root causes and potential impacts, and prioritizes mitigation efforts based on severity, likelihood, and detectability. By facilitating early identification and prevention of failures, FMEA plays a critical role in boosting product reliability, safety, and operational efficiency—key pillars of product development excellence [26–28]. Table 2 summarizes the key aspects of FMEA. FMEA is classified into two primary types: Design FMEA (DFMEA) and Process FMEA (PFMEA). DFMEA focuses on detecting and eliminating design-related failure modes, ensuring that products meet functional performance requirements at the system, subsystem, and component levels. In contrast, PFMEA addresses potential failures in manufacturing and assembly processes, identifying process deficiencies that may compromise quality. PFMEA is further divided into Manufacturing FMEA and Assembly FMEA, each targeting specific risks in production operations [29]. With its structured and preventive approach, FMEA is widely applied across industries to improve product and process reliability while reducing operational risks. Extensive research has explored its applications, including studies by [30–37].

Table 2. Overview of Failure Mode and Effects Analysis (FMEA).

Aspect	Description
Origin	Developed by NASA in the 1960s as a structured approach for system reliability assessment.
Purpose	A proactive risk management tool used to identify, analyze, and mitigate potential failure modes in products, processes, systems, and services.
Types of FMEA	- Design FMEA (DFMEA): Focuses on failure modes related to product design at the system, subsystem, and component levels. - Process FMEA (PFMEA): Addresses failure modes in manufacturing and assembly processes, further divided into: - Manufacturing FMEA: Focuses on failures in production operations. - Assembly FMEA: Identifies risks in product assembly stages.
Key Benefits	- Enhances system reliability and product quality. - Prevents defects and reduces risks. - Improves process efficiency and minimizes operational disruptions. - Facilitates continuous improvement in manufacturing and design processes.
Applications	Used across various industries to optimize product development, manufacturing, and quality assurance by proactively addressing risks.

2.3. A Comprehensive Review of Taguchi-Based Lean Six Sigma

Manufacturing companies continuously strive to enhance competitiveness, process efficiency, and product quality through Lean Six Sigma (LSS)—a methodology that integrates Lean principles for waste reduction with Six Sigma tools for variability reduction [38]. Table 3 provides a summary of the key aspects of Taguchi-Based LSS. Several studies have highlighted the applications of LSS in manufacturing. Gomaa [39] proposed an LSS-DMAIC framework for the spare parts industry, utilizing tools such as brainstorming, process mapping, overall equipment effectiveness (OEE) analysis, seven QC tools, value stream mapping, the Taguchi method, ANOVA, the 7S framework, root-cause analysis, and the fishbone diagram. Similarly, Gomaa [40] developed an LSS approach to improve machining process efficiency. The Taguchi method, a robust design optimization technique, enhances LSS by minimizing process variability and improving quality. Chen et al. [41] combined DMAIC with the Taguchi method to optimize transistor gasket manufacturing, resulting in improved process quality and lower sigma levels. Muraleedharan et al. [42] applied Taguchi-based Six Sigma to galvanized iron processing, resulting in a significant increase in the material removal rate. Duc et al. [43] employed an LSS-Taguchi approach to determine optimal conditions for oil immersion tanks in molybdenum processing. The Taguchi method within LSS has been widely used across industries for process optimization and quality enhancement. Notable research contributions include Chen and Brahma [44–54].

Table 3. Overview of Taguchi-Based Lean Six Sigma (LSS).

Aspect	Description
Definition	A methodology integrating the Taguchi method with Lean Six Sigma (LSS) to optimize process parameters, minimize variability, and improve product quality and efficiency.
Key Objectives	- Reduce process variability and defects to enhance quality. - Optimize manufacturing parameters for improved performance. - Increase cost-effectiveness and operational efficiency.
Core Methodologies	- Lean Six Sigma (LSS): Merges Lean (waste elimination) and Six Sigma (variation control). - Taguchi Method: Uses Design of Experiments (DOE) to identify optimal process conditions and improve robustness.
Applications	- Spare Parts Industry: Developed an integrated LSS-DMAIC framework [39]. - Machining Processes: Improved efficiency and effectiveness [40]. - Transistor Gaskets: Optimized manufacturing parameters [41]. - Galvanized Iron Processing: Enhanced material removal rate [42]. - Oil Immersion Tanks: Determined optimal process conditions [43].
Key Benefits	- Enhanced product reliability through optimized design. - Systematic defect reduction leading to higher quality. - Improved manufacturing efficiency and cost savings. - Robust and repeatable process performance using DOE.

2.4. A Comprehensive Review of the Value Engineering (VE) Approach

Value Engineering (VE) was developed in the United States in 1947 after World War II by General Electric and was formally recognized in 1958. The establishment of the American Society of Value Engineers facilitated professional collaboration and knowledge exchange among practitioners in both the private and public sectors [55]. VE is a structured methodology aimed at achieving the required functionality at the lowest cost without compromising quality, reliability, service, or performance. By systematically evaluating functional requirements, VE ensures that essential functions are delivered most cost-effectively. Primarily applied in the pre-construction phase, it maximizes benefits by optimizing both function and cost. A core principle of VE is that fundamental functions must be preserved, ensuring that value improvements do not undermine performance. Table 4 provides an overview of the key aspects of VE, including its definition, objectives, benefits, and phases. The term "Value Management" is sometimes used interchangeably with "Value Engineering", as both focus on enhancing project planning and execution. However, VE differs from traditional cost-cutting methods by emphasizing functional optimization rather than simply reducing expenses [56,57]. It is a powerful tool for eliminating unnecessary costs arising from inefficiencies, limited information, or constrained resources. Poor value in projects often results from design inefficiencies or stakeholder limitations, which may stem from habitual practices, procedural obstacles, or organizational attitudes. VE systematically addresses these inefficiencies by analyzing and optimizing key project elements such as cost, maintenance, durability, and aesthetics. Importantly, improving project value through VE does not mean merely reducing costs but rather optimizing all contributing factors to enhance overall efficiency and effectiveness. VE has been widely applied across various industries as a structured approach to problem-solving, waste elimination, and function enhancement. Its implementation follows a structured job plan, which serves as a systematic framework for evaluating products or services and developing cost-effective alternatives. The success of a VE study largely depends on the effective application of this plan. The VE process consists of six key phases: the information phase, which defines the project scope and objectives; the function analysis phase, which identifies and categorizes essential functions; the creativity phase, which generates innovative alternatives; the evaluation phase, which assesses and refines proposed solutions; the development phase, which selects and optimizes the best alternative; and the presentation phase, which communicates final recommendations. VE has been extensively studied and successfully applied across various industries, demonstrating its effectiveness in improving project value, efficiency, and performance. Research has consistently validated its benefits, as highlighted in studies by [58–68].

Table 4. Overview of Value Engineering (VE) Approach.

Aspect	Details
Origin & Development	Developed by General Electric in 1947, post-World War II, and formally recognized in 1958. The American Society of Value Engineers was later established to advance the methodology and facilitate professional collaboration [55].
Definition	A structured, function-based methodology that maximizes value by achieving required functionality at the lowest cost without compromising quality, reliability, service, or performance.
Core Principle	Value is defined as the ratio of function to cost. VE enhances value by either improving functionality or reducing costs while maintaining essential performance standards.
Distinction from Cost Reduction	Unlike traditional cost-cutting methods, VE prioritizes functional optimization over mere cost reduction, ensuring efficiency improvements without sacrificing quality [56,57].
Causes of Poor Value	Design inefficiencies, stakeholder constraints, limited information, habitual practices, procedural barriers, and resistance to change.
VE Job Plan	A systematic approach is used to analyze and evaluate products, services, or projects, identifying cost-effective and functionally efficient alternatives.
VE Process Phases	1. Information Phase—Defines project scope, objectives, and constraints. 2. Function Analysis Phase—Identifies and categorizes essential functions. 3. Creativity Phase—Develops innovative solutions to enhance value. 4. Evaluation Phase—Assesses and refines alternatives based on feasibility and impact. 5. Development Phase—Selects and optimizes the best value-enhancing alternative. 6. Presentation Phase—Documents and communicates final recommendations for implementation [55,69].
Applications	Applied across industries such as construction, manufacturing, supply chain management, and service sectors to improve efficiency, eliminate waste, and optimize performance.
Key Benefits	Enhances project efficiency, optimizes resource utilization, reduces unnecessary costs, and improves overall quality and functionality.

2.5. A Comprehensive Review of the Kano Model

The Kano Model (KM), developed by Noriaki Kano in Japan in 1984, is a framework for assessing customer satisfaction based on product or service attributes. It helps organizations understand customer expectations and prioritize features that drive satisfaction. Widely applied across industries, KM is particularly valuable in new product development and service design, guiding businesses in enhancing quality and meeting customer needs [70]. Table 5 summarizes the key aspects of KM. Also known as the "Customer Delight *vs.* Implementation Investment" strategy, KM categorizes product and service attributes based on their impact on user satisfaction relative to implementation effort. It classifies attributes into five categories: (1) Must-Be Quality—essential features that customers expect; their absence causes dissatisfaction, but their presence is taken for granted. (2) Performance Quality—features that increase satisfaction proportionally to their level of fulfillment. (3) Excitement Quality—unexpected features that delight customers and create a competitive advantage. (4) Indifferent Quality—features that have little or no impact on satisfaction. (5) Reverse Quality—features that cause dissatisfaction for some customers when included. The Kano Model is often visualized through a Kano Diagram, helping businesses assess how different attributes influence overall satisfaction. This structured approach supports data-driven decision-making for feature prioritization and quality improvements. While originally designed for customer-product relationships, KM has also been applied to environmental quality and sustainability assessments [71]. KM has been widely adopted across industries for evaluating customer satisfaction and optimizing product and service offerings. Notable studies applying the Kano Model include [72–79].

Table 5. Summary of the Kano Model.

Aspect	Description
Origin & Development	Developed in 1984 by Noriaki Kano in Japan to assess customer satisfaction based on product attributes.
Purpose	Helps organizations understand and prioritize product or service attributes to enhance customer satisfaction and overall quality.
Alternative Name	"Customer Delight *vs.* Implementation Investment" strategy.
Key Classifications	(1) Must-Be Quality—Basic features customers expect; their absence causes dissatisfaction. (2) Performance Quality—Features that increase satisfaction proportionally when improved. (3) Excitement Quality—Unexpected features that delight customers and create a competitive advantage. (4) Indifferent Quality—Features with little to no impact on customer satisfaction. (5) Reverse Quality—Features that may cause dissatisfaction when included, depending on customer preferences.
Application Areas	New product development, service design, customer experience enhancement, quality management, and sustainability assessment.
Key Tool	Kano Diagram—A visual representation of how different product or service attributes impact customer satisfaction.
Recent Applications	Applied beyond product development to assess environmental quality, sustainability, and service innovation.

2.6. A Comprehensive Review of TRIZ

The Theory of Inventive Problem Solving (TRIZ) was developed by Genrich Altshuller in Russia in 1988. TRIZ, derived from the Russian, is a structured methodology designed to drive innovation and systematically resolve complex technical challenges. Altshuller's extensive analysis of patent data led him to classify inventive solutions into five levels, highlighting that true innovation arises from resolving contradictions rather than making compromises [80].

Table 6 presents an overview of the key components of TRIZ. The methodology provides a systematic framework for problem-solving by incorporating 39 engineering parameters, a contradiction matrix, and 40 inventive principles. These tools help engineers and designers eliminate trade-offs, address undesirable effects, and develop innovative solutions, making TRIZ particularly valuable in engineering, product development, and process optimization [81,82]. TRIZ is widely applied in the conceptual design phase, supporting structured and efficient idea generation. The effectiveness of TRIZ has been widely demonstrated across various industries, with researchers leveraging its principles to tackle complex design and development challenges. Notable studies applying TRIZ include [83–93].

Table 6. Summary of the TRIZ (Theory of Inventive Problem Solving).

Aspect	Details
Origin	Developed by Genrich Altshuller, Russia, 1988.
Definition	A systematic methodology for innovation and problem-solving by eliminating contradictions.
Core Principle	Innovation is driven by resolving contradictions rather than making trade-offs.
Key Components	39 engineering parameters, a contradiction matrix, and 40 inventive principles.
Applications	Engineering, product design, process optimization, and conceptual design.
Advantages	Enhances creativity, eliminates design trade-offs, improves efficiency, and fosters systematic innovation.

3. Research Gaps in Product Development Excellence

Effective quality management is crucial for achieving excellence in product development. However, several research gaps remain, limiting the full potential of Strategic Quality Management (SQM) in driving innovation, reliability, and efficiency. Table 7 categorizes research gaps in Strategic Quality Management (SQM) for product development into six key areas, each addressing critical challenges and outlining potential future research directions. Here's a breakdown of each category:

(1) Integration and Adaptability of SQM Frameworks: The lack of unified Strategic Quality Management (SQM) frameworks integrating Total Quality Management (TQM), Lean Six Sigma (LSS), and Design for Reliability (DfR) limits their overall effectiveness. Traditional SQM methodologies also struggle to align with Agile and Lean Product Development, making it difficult to maintain both structured quality assurance and the flexibility required for rapid iterations. Future research should focus on developing hybrid SQM frameworks that seamlessly integrate these methodologies while ensuring adaptability to evolving market demands.

(2) Organizational and Cultural Barriers to SQM Implementation: Cross-functional collaboration challenges hinder the effective application of SQM principles across departments. Additionally, embedding a quality-driven culture is difficult due to insufficient leadership commitment, lack of employee engagement, and limited training in advanced SQM tools. Rigid organizational structures further slow SQM adoption, reducing flexibility and innovation. Research should explore leadership-driven strategies, alternative organizational structures, and targeted workforce training programs to foster collaboration and instill a quality-centric mindset.

(3) Regulatory Compliance, Risk Management, and Cost Constraints: Organizations face challenges in adapting SQM frameworks to diverse global regulations and cultural differences, limiting seamless international implementation. The absence of structured risk management within SQM methodologies also makes it difficult to predict and mitigate quality-related risks effectively. High implementation costs for advanced SQM tools, combined with external factors such as economic shifts and supply chain disruptions, further restrict adoption. Future research should develop cost-efficient, region-specific SQM models that enhance resilience, regulatory compliance, and sustainable business practices.

(4) Customer-Centric Quality Management and Supplier Assurance: Rapidly evolving customer expectations challenge organizations to align product development with quality management strategies. Additionally, inconsistencies in supplier quality standards across global supply chains affect product reliability. Research should focus on best practices for real-time, customer-driven quality improvement and effective supplier quality monitoring to enhance consistency and standardization across international operations.

(5) Leveraging Digital and Emerging Technologies in SQM: The application of emerging technologies such as digital twins, artificial intelligence (AI), machine learning (ML), and blockchain in SQM remains underexplored. These technologies offer the potential for predictive quality assurance, real-time defect detection, and process optimization. AI-driven monitoring and predictive maintenance can significantly enhance proactive quality management, yet their integration into SQM frameworks is limited. Future studies should focus on incorporating digital transformation into quality management to improve defect prevention, real-time process control, and overall product reliability.

(6) Sustainability and Continuous Innovation in SQM: Current SQM frameworks lack sufficient integration of sustainability principles, including eco-design, circular economy strategies, and the use of sustainable materials. Additionally, organizations struggle to maintain continuous innovation while upholding stringent quality standards, creating a gap in methodologies that balance both. Future research should explore how SQM can incorporate sustainability-driven practices and innovation-friendly quality models, enabling businesses to achieve operational efficiency, environmental responsibility, and long-term competitiveness.

Addressing these research gaps will enable organizations to refine SQM practices, integrate emerging technologies, and foster continuous improvement in product development. By advancing these areas, businesses can achieve optimal performance, reliability, and innovation while maintaining a competitive edge in an evolving market.

Table 7. Research Gaps in Product Development Excellence.

Category	Research Gap	Challenges	Future Research Directions
1. SQM Frameworks & Integration	Unified SQM Models	Lack of integration between TQM, Lean Six Sigma, and digital tools.	Develop adaptable frameworks combining traditional and digital SQM.
	Agile SQM Integration	SQM lacks flexibility for Agile and Lean practices.	Explore hybrid models that incorporate Agile principles.
	Balancing Efficiency & Innovation	Trade-offs between process optimization and innovation.	Develop frameworks harmonizing quality, efficiency, and innovation.
2. Organizational Culture & Leadership	Cross-Functional Collaboration	Limited coordination across departments in SQM implementation.	Define best practices for improving synergy in quality management.
	Quality-Driven Culture	Embedding quality principles across diverse teams is a challenging task.	Identify leadership strategies to foster a quality-first mindset.
	Leadership & Employee Engagement	Insufficient leadership commitment and workforce motivation.	Assess leadership strategies for sustainable SQM adoption.
	SQM Training & Adoption	Lack of structured training on advanced SQM tools.	Evaluate the impact of targeted workforce development programs.
	Organizational Structure & SQM	Rigid hierarchies hinder SQM adaptability.	Investigate structural models that enhance SQM effectiveness.
3. Compliance & Global Adaptation	Global SQM Implementation	Regulatory and cultural variations impede standardization.	Develop flexible SQM models adaptable to different regions.
	SQM Risk Management	Inadequate risk assessment within SQM frameworks.	Design predictive risk management models leveraging AI and analytics.
	Cost-Efficiency of SQM	High investment costs for SQM adoption.	Identify cost-effective implementation strategies.
	External Disruptions in SQM	Economic and supply chain risks impact quality management.	Develop resilient SQM frameworks for uncertainty mitigation.
4. Customer & Supply Chain Management	Supplier & Outsourcing Quality	Variability in supplier standards across global networks.	Establish standardized supplier quality assurance practices.
	Customer-Centric SQM	Challenges in aligning quality management with evolving customer demands.	Strengthen SQM with real-time Voice of the Customer (VOC) insights.
5. Digital & Emerging Technologies	Digital Twin for SQM	Limited adoption in predictive quality assurance.	Investigate digital twin applications in quality optimization.
	AI & Data-Driven SQM	Underutilization of AI, ML, and blockchain in SQM.	Explore AI-driven quality assurance and process automation.
	Real-Time Monitoring & Predictive Maintenance	Insufficient use of real-time analytics for proactive quality control.	Develop AI-based monitoring and predictive maintenance solutions.
6. Sustainability & Continuous Innovation	Sustainable SQM Practices	Limited integration of sustainability with quality management.	Research circular economy and eco-design principles for SQM.
	Continuous Innovation in SQM	Difficulty maintaining long-term innovation without compromising quality.	Develop quality-driven innovation strategies for sustained growth.

4. Research Methodology for Product Development Excellence

A robust research methodology is vital for achieving product development excellence by ensuring compliance, market alignment, operational efficiency, and sustained innovation. This study integrates established quality management frameworks, core principles, and analytical tools to enhance product quality, reliability, and process effectiveness.

(1) Application of Key Quality Management Tools: Investigating the use of fundamental tools—Quality Function Deployment (QFD), Failure Mode and Effects Analysis (FMEA), and Statistical Process Control (SPC)—to improve process robustness and product reliability throughout development.
(2) Core Principles Guiding Product Development: Exploring essential principles such as customer focus, innovation, cross-functional collaboration, continuous improvement, and risk-based thinking as foundations for product development excellence.
(3) Voice of the Customer (VoC) Analysis: Capturing and translating customer needs and expectations into actionable design and process requirements to drive superior product outcomes.
(4) Critical-to-Quality (CTQ) Identification: Prioritizing key quality attributes critical to customer satisfaction and product performance, aligned with business and technical objectives.
(5) DMAIC Framework for Quality Enhancement: Employing the Define–Measure–Analyze–Improve–Control (DMAIC) methodology as a structured, data-driven approach to systematically elevate quality and innovation across the product development lifecycle.
(6) Key Performance Indicators (KPIs) Definition: Establishing and monitoring KPIs to assess process efficiency, product quality, customer satisfaction, time-to-market, and alignment with strategic goals.
(7) Integration of Agile Practices: Incorporating Agile methodologies—iterative development, adaptive planning, and rapid feedback loops—to increase flexibility, speed, and customer responsiveness.
(8) Identification of Critical Failure Factors: Analyzing organizational, technical, cultural, and managerial obstacles that may hinder product development excellence and recommending mitigation strategies.

In conclusion, this research methodology provides a comprehensive and integrated framework to achieve product development excellence. Through the strategic application of quality management tools, customer-focused principles, agile practices, and performance metrics, organizations can consistently deliver innovative, reliable products. By proactively identifying and mitigating potential failure factors, this approach supports continuous improvement, operational resilience, and sustained competitive advantage in dynamic markets.

4.1. Key Quality Management Tools for Product Development Excellence

Achieving excellence in product development requires a structured quality management approach that ensures products meet customer expectations while maintaining efficiency, reliability, and cost-effectiveness. By leveraging proven quality management tools, organizations can minimize defects, optimize processes, and enhance overall performance. Table 8 categorizes 20 essential quality management tools into six key areas, outlining their purpose and benefits in product development.

(1) Customer-Centric Design and Requirements: Understanding and integrating customer needs into product development is critical for quality management. Voice of the Customer (VoC) gathers user insights to align products with market demands, while Critical to Quality (CTQ) defines key product attributes that influence satisfaction. Quality Function Deployment (QFD) translates customer needs into technical specifications, with the House of Quality (HoQ) ensuring strong alignment between expectations and design. These tools enhance customer satisfaction, reduce redesign efforts, and improve market success.
(2) Risk Management and Reliability Engineering: Ensuring product reliability and mitigating risks are essential for long-term quality and customer trust. Failure Mode and Effects Analysis (FMEA) proactively identifies potential failures and their impact, enabling early risk mitigation. Design for Reliability (DfR) ensures product durability, reducing failures over time. Fault Tree Analysis (FTA) pinpoints failure pathways for improved system safety, while Root Cause Analysis (RCA) identifies the underlying causes of defects to prevent recurrence. These tools enhance reliability, minimize defects, and ensure consistent product performance.
(3) Process Optimization and Robust Design: Optimizing development processes improves efficiency and reduces defects. Design for Six Sigma (DFSS) integrates Six Sigma principles early in development to ensure defect-free products. Design of Experiments (DOE) facilitates controlled testing for performance optimization, while the Taguchi Method strengthens robustness against variations in manufacturing and usage. Statistical Process Control (SPC) continuously monitors production to detect variations and maintain stability. These tools streamline operations, accelerate time-to-market, and enhance manufacturing precision.
(4) Cost and Competitive Analysis: Balancing cost efficiency with quality is vital for sustainable product development. Cost of Quality (CoQ) Analysis assesses the financial impact of quality-related activities, helping organizations optimize resources and implement cost-effective defect prevention strategies. Benchmarking allows companies to

compare their performance with industry leaders, identify best practices, and enhance competitiveness. These tools support strategic decision-making, reduce waste, and drive cost-efficient quality improvements.

(5) Continuous Improvement and Lean Practices: A culture of continuous improvement fosters innovation and operational excellence. The Ishikawa (Fishbone) Diagram systematically identifies the root causes of quality issues for more effective problem-solving. Kaizen promotes incremental improvements to enhance efficiency at every stage of the development process. Poka-Yoke (Error Proofing) integrates fail-safe mechanisms to prevent defects, while Jidoka (Autonomation) combines automation with real-time quality control for instant defect detection and correction. These tools eliminate inefficiencies, enhance responsiveness, and sustain long-term quality improvements.

(6) Lean Six Sigma and Structured Problem-Solving: Integrating Lean and Six Sigma methodologies enables organizations to optimize processes and reduce defects using a structured, data-driven approach. Lean Six Sigma (LSS) combines Lean principles for waste reduction with Six Sigma techniques to enhance process stability and quality. The DMAIC (Define, Measure, Analyze, Improve, Control) framework improves existing processes, while DMADV (Define, Measure, Analyze, Design, Verify) ensures quality is embedded from the start in new product development. These structured approaches drive continuous innovation, maintain consistency, and achieve excellence in product development.

In conclusion, the strategic application of quality management tools enhances customer satisfaction, product reliability, cost optimization, and continuous innovation. A well-structured quality framework helps organizations remain agile, competitive, and aligned with evolving market demands. By integrating these methodologies, businesses can proactively mitigate risks, optimize processes, and drive sustained excellence, ensuring long-term success and superior customer value.

Table 8. Key Quality Management Tools for Product Development Excellence.

Category	#	Tool	Purpose	Key Benefits
(1) Customer-Centric Design & Requirements	1	Voice of the Customer (VoC)	Captures and prioritizes customer needs	Improves market alignment and user satisfaction
	2	Critical to Quality (CTQ)	Defines essential product attributes	Ensures focus on key quality drivers
	3	Quality Function Deployment (QFD)	Converts customer needs into design specifications	Reduces redesigns and enhances product-market fit
	4	House of Quality (HoQ)	Links customer expectations to design elements	Strengthens cross-functional collaboration
(2) Risk Management & Reliability Engineering	5	Failure Mode and Effects Analysis (FMEA)	Identifies and mitigates potential failure risks	Enhances reliability and defect prevention
	6	Design for Reliability (DfR)	Ensures durability and long-term performance	Reduces failures and builds customer trust
	7	Fault Tree Analysis (FTA)	Evaluates failure pathways and system vulnerabilities	Improves risk prediction and safety assurance
	8	Root Cause Analysis (RCA)	Identifies underlying causes of defects	Prevents recurrence and strengthens process improvement
(3) Process Optimization & Robust Design	9	Design for Six Sigma (DFSS)	Embeds Six Sigma principles in early design	Minimizes variability and ensures defect-free launches
	10	Design of Experiments (DOE)	Optimizes design through controlled testing	Reduces development time and cost
	11	Taguchi Method	Enhances robustness against external variations	Improves consistency and performance reliability
	12	Statistical Process Control (SPC)	Monitors and controls process variations	Ensures stability, reduces defects, and improves quality
(4) Cost & Competitive Analysis	13	Cost of Quality (CoQ) Analysis	Evaluates quality-related costs	Optimizes resource allocation and cost efficiency
	14	Benchmarking	Compares performance against industry best practices	Identifies improvement opportunities and enhances competitiveness
(5) Continuous Improvement & Lean Practices	15	Ishikawa (Fishbone) Diagram	Analyzes root causes of quality issues	Strengthens problem-solving and defect prevention
	16	Kaizen (Continuous Improvement)	Drives incremental improvements	Boosts efficiency, innovation, and process excellence
	17	Poka-Yoke (Error Proofing)	Prevents defects through design mechanisms	Reduces human errors and enhances reliability

	18	Jidoka (Autonomation)	Integrates automation with built-in quality control	Enables real-time defect detection and corrective action
(6) Lean Six Sigma & Structured Problem-Solving	19	Lean Six Sigma (LSS)	Combines Lean and Six Sigma for waste reduction	Enhances efficiency, quality, and process effectiveness
	20	DMAIC	Structured Six Sigma approach for process improvement	Reduces defects and optimizes operational efficiency
	21	DMADV	Six Sigma framework for new product and process design	Ensures high-quality, defect-free product development

4.2. Core Principles of Quality Management for Product Development Excellence

Strategic Quality Management (SQM) in product development ensures that organizations consistently deliver high-quality, reliable, and competitive products. By integrating structured methodologies, risk mitigation strategies, and emerging technologies, businesses can achieve excellence in product quality, efficiency, and innovation. Table 9 outlines a comprehensive SQM framework.

(1) The Customer-Driven Quality category emphasizes aligning product quality with customer expectations to enhance satisfaction and market success. This is achieved through methodologies like Voice of the Customer (VoC), Quality Function Deployment (QFD), and Critical to Quality (CTQ), ensuring that customer requirements are translated into measurable product attributes. By prioritizing the customer experience, organizations can reduce redesign efforts and improve market alignment.

(2) Process and Risk Optimization focuses on minimizing defects and ensuring product reliability. Process Optimization & Defect Prevention applies Lean, Six Sigma, and Total Quality Management (TQM) to streamline workflows and eliminate inefficiencies. Proactive Risk & Reliability Management ensures product durability and safety by identifying and mitigating potential failure points through Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and predictive failure analysis. These approaches help organizations enhance consistency, reduce costs, and maintain high-quality standards.

(3) A Culture of Continuous Improvement & Innovation is critical for maintaining long-term product excellence. The Continuous Improvement & Innovation principle encourages ongoing process refinements using Kaizen, DMAIC (Define-Measure-Analyze-Improve-Control), and Design of Experiments (DOE). Additionally, Data-Driven Quality Management leverages advanced analytics, Artificial Intelligence (AI), Big Data, and Statistical Process Control (SPC) to enable real-time monitoring, fault detection, and data-informed decision-making.

(4) The Agility and Market Responsiveness category ensures that businesses can quickly adapt to market changes while maintaining rigorous quality standards. Agile & Adaptive Quality Strategies incorporate Lean Startup, rapid prototyping, and scalable quality systems, allowing for flexibility and responsiveness in dynamic environments. This approach accelerates product development cycles while maintaining quality excellence.

(5) Sustainability and Ethical Quality Practices integrate environmental and ethical considerations into quality management. By adopting eco-design, circular economy models, and green manufacturing, companies can minimize waste, optimize resource use, and ensure regulatory compliance. Ethical quality practices also enhance brand reputation and contribute to long-term business sustainability.

(6) Leadership and Collaboration play a pivotal role in driving quality excellence. Cross-functional collaboration & Leadership Commitment fosters teamwork across departments and engages leadership in quality-driven initiatives. Interdisciplinary teams, employee training, and a strong quality-driven culture ensure that SQM principles are effectively implemented across all business functions.

(7) Ensuring supplier quality is equally important. Supplier Quality & Global Supply Chain Assurance focuses on maintaining consistency across supply chains through Supplier Quality Management (SQM), compliance monitoring, and supplier audits. Strong supplier relationships and stringent quality controls help minimize variability and uphold product integrity.

(8) Finally, Smart Manufacturing & Industry 4.0 Integration leverages emerging technologies to enhance precision and efficiency in quality management. The integration of IoT-enabled quality monitoring, blockchain for traceability, and AI-driven automated inspections ensures real-time process optimization, reduces defects and improves overall manufacturing quality. These advancements position organizations for competitive advantage in the era of digital transformation.

In conclusion, these core SQM principles provide a comprehensive framework for achieving product reliability, operational efficiency, risk minimization, and continuous innovation. By adopting a strategic approach to quality management, businesses can remain agile, competitive, and well-positioned for long-term success in an evolving market.

Table 9. Core Principles of Strategic Quality Management (SQM) for Product Development.

Category	#	Core Principle	Description	Key Focus Areas
(1) Customer-Driven Quality	1	Customer-Centric Quality Excellence	Aligning product quality with customer needs for market success.	VoC, QFD, CTQ, CX Optimization
(2) Process & Risk Optimization	2	Process Optimization & Defect Prevention	Ensuring efficient, defect-free processes to enhance quality.	Lean, Six Sigma, TQM, Standardization
	3	Proactive Risk & Reliability Management	Identifying and mitigating risks to improve reliability.	FMEA, FTA, Risk-Based Thinking, Predictive Analysis
(3) Continuous Improvement & Innovation	4	Continuous Improvement & Innovation	Driving systematic enhancements and innovation in quality.	Kaizen, DMAIC, DOE, Robust Design
	5	Data-Driven Quality Management	Leveraging AI and analytics for real-time quality control.	AI, Big Data, SPC, Predictive Quality Models
(4) Agility & Market Responsiveness	6	Agile & Adaptive Quality Strategies	Implementing flexible quality approaches for fast-changing markets.	Agile QM, Lean Startup, Rapid Prototyping, Scalable Systems
(5) Sustainability & Ethics	7	Sustainable & Ethical Quality Practices	Integrating sustainability and ethics into quality management.	Eco-Design, Circular Economy, Green Manufacturing, CSR, Compliance
(6) Leadership & Collaboration	8	Cross-Functional Collaboration & Leadership	Enhancing teamwork and leadership commitment to quality culture.	Interdisciplinary Teams, Leadership, Training, Quality Mindset
(7) Supplier & Supply Chain Excellence	9	Supplier Quality & Global Supply Assurance	Strengthening supplier quality and global supply chain consistency.	SQM, Audits, Compliance, Supplier Performance Metrics
(8) Smart Manufacturing & Industry 4.0	10	Smart Manufacturing & Industry 4.0	Using digital technologies to optimize quality and efficiency.	IoT, Blockchain, AI-Driven Inspections, Smart Manufacturing

4.3. Voice of Customer (VOC) Analysis in Product Development Excellence

Voice of Customer (VOC) analysis is a structured approach to capturing and utilizing customer insights to drive product development. It ensures products align with market needs, enhance user satisfaction, and maintain a competitive edge. Table 10 outlines the key aspects of VOC analysis:

(1) Core Components: VOC involves systematically collecting, analyzing, and integrating customer feedback throughout the product lifecycle. A continuous feedback loop enhances product relevance, minimizes redesign efforts, and improves market fit.
(2) Data Collection Methods: Various techniques—such as surveys, interviews, focus groups, social media listening, Net Promoter Score (NPS), and market research—help capture customer needs, preferences, and pain points, providing actionable insights for product refinement.
(3) Integration in Product Development: Embedding VOC insights across all development stages—from concept ideation and prototyping to testing, production, and post-launch refinement—reduces risks, enhances usability, and boosts product adoption rates.
(4) Strategic Impact: VOC-driven development fosters innovation, accelerates time-to-market, minimizes defects, and strengthens brand loyalty. By continuously aligning products with customer expectations, businesses improve market positioning and ensure long-term growth.

Implementing a robust VOC strategy enables organizations to create high-quality, customer-centric products, ensuring sustained success in competitive markets.

Table 10. Voice of Customer (VOC) Analysis in Product Development.

#	Category	Key Elements	Description	Benefits
1	Core Components	Insight Collection, Data Analysis, Feedback Loop	Capturing and utilizing customer feedback systematically.	Enhances product relevance and market success.
2	Data Collection Methods	Surveys, Interviews, Focus Groups, Social Media, NPS	Gathering customer expectations, pain points, and preferences.	Provides insights for product innovation.
3	Integration in Development	Ideation, Prototyping, Testing, Production, Refinement	Embedding customer insights throughout the product lifecycle.	Reduces risks, accelerates adoption, and minimizes redesigns.

4	Strategic Impact	Innovation, Faster Time-to-Market, Competitive Edge	Using VOC for customer-driven product excellence.	Boosts brand loyalty and market positioning.

4.4. Critical to Quality (CTQ) Analysis in Product Development Excellence

CTQ analysis ensures product quality aligns with customer expectations by identifying and integrating key attributes throughout development. As outlined in Table 11, this structured approach enhances consistency, reduces defects, and improves customer satisfaction.

(1) Customer Needs Identification captures the Voice of Customer (VOC) through surveys, focus groups, and market research. This ensures product design reflects real customer expectations, minimizing misalignment and costly redesigns.
(2) CTQ Attribute Definition translates customer insights into measurable quality factors using CTQ trees. Prioritizing critical attributes helps organizations focus on factors that directly impact performance and user satisfaction.
(3) Quality Metrics Development establishes clear performance benchmarks, such as defect rates, durability, and usability. These Key Performance Indicators (KPIs) provide objective criteria for assessing and maintaining product quality.
(4) Process Integration embeds CTQ factors into design, manufacturing, and testing, ensuring a proactive approach to quality. This minimizes defects, enhances reliability, and streamlines production.
(5) Continuous Monitoring and Improvement tracks CTQ performance, analyzes trends, and drives corrective actions. This ongoing evaluation sustains product excellence, optimizes efficiency, and reinforces customer trust.

In conclusion, by systematically defining and integrating CTQ attributes, organizations can improve efficiency, reduce risks, and maintain a competitive edge while delivering high-quality, customer-focused products.

Table 11. Critical to Quality (CTQ) Analysis in Product Development Excellence.

#	CTQ Component	Objective	Key Activities	Benefits
1	Customer Needs Identification	Capture customer expectations	Surveys, focus groups, market research	Aligns product design with needs
2	CTQ Attribute Definition	Define key quality factors	Translate VOC into measurable attributes	Focuses on critical product aspects
3	Quality Metrics Development	Set performance standards	Establish KPIs (defects, durability, usability)	Provides clear quality benchmarks
4	Process Integration	Embed CTQ in workflows	Apply CTQ to design, manufacturing, testing	Ensures consistency, reduces defects
5	Continuous Improvement	Sustain and optimize quality	Monitor trends, refine processes, and corrective actions	Drives long-term excellence

4.5. DMAIC Framework for Product Development Excellence

The DMAIC (Define, Measure, Analyze, Improve, Control) framework is a structured, data-driven approach that enhances product quality, minimizes defects, and optimizes processes within Strategic Quality Management (SQM). As outlined in Table 12, DMAIC ensures alignment with customer expectations and business objectives while fostering continuous improvement and innovation. Each phase plays a critical role in delivering high-quality, reliable, and cost-effective products that meet industry standards and regulatory requirements.

(1) Define—Setting Quality Objectives and Customer Expectations: The Define phase establishes a strong foundation by identifying customer needs, business goals, and key product attributes. Tools such as Voice of the Customer (VoC) capture market insights while Critical to Quality (CTQ) metrics ensure alignment with essential design and performance requirements. Quality Function Deployment (QFD) translates customer expectations into engineering specifications, fostering collaboration and minimizing costly redesigns.
(2) Measure—Evaluating Performance and Identifying Variability: This phase focuses on establishing performance baselines, detecting inefficiencies, and quantifying process variations. Techniques such as Failure Mode and Effects Analysis (FMEA) assess risks, while Statistical Process Control (SPC) ensures process stability. Cost of Quality (CoQ) analysis helps balance investment in quality improvements with cost efficiency. By leveraging data-driven insights, organizations can identify deviations early and establish benchmarks for continuous enhancement.
(3) Analyze—Diagnosing Root Causes of Defects and Inefficiencies: The Analyze phase identifies the root causes of defects and process inefficiencies using structured problem-solving tools. Methods such as Root Cause Analysis (RCA), Ishikawa (Fishbone) Diagrams, and Fault Tree Analysis (FTA) trace failure pathways, while statistical

techniques like Regression Analysis and Hypothesis Testing validate findings. By addressing these underlying issues, organizations can implement targeted improvements that enhance reliability and mitigate risks.

(4) Improve—Enhancing Product Quality and Process Efficiency: The improvement phase focuses on optimizing product performance and minimizing defects. Lean Six Sigma (LSS) principles eliminate waste, while Design of Experiments (DOE) determines optimal design configurations through controlled testing. Poka-Yoke (Error Proofing) prevents defects at the source, and Design for Reliability (DfR) enhances product durability. These strategies accelerate time-to-market, reduce production costs, and ensure consistent product quality.

(5) Control—Sustaining Quality Excellence and Driving Continuous Improvement: The Control phase ensures that process improvements are sustained and quality standards remain consistently high. Predictive Maintenance and Digital Twin Technology enable real-time tracking, while SPC ensures long-term process stability. Organizations cultivate a Kaizen (Continuous Improvement) culture, driving sustained enhancements and reinforcing a proactive quality management approach. Standardized control plans safeguard improvements and prevent recurring defects.

By integrating DMAIC within SQM, organizations can systematically enhance product development outcomes, reduce defects, improve efficiency, and foster innovation. This structured, data-driven methodology strengthens market positioning, drives sustainable success, and ensures the consistent delivery of high-quality, customer-centric products.

Table 12. DMAIC Framework for Strategic Product Development Excellence.

Phase	Objective	Key Activities	Benefits
Define	Set clear quality goals based on customer needs.	- Capture Voice of the Customer (VoC) - Identify Critical to Quality (CTQ) attributes - Use Quality Function Deployment (QFD) - Develop a project charter	- Aligns development with customer needs - Minimizes redesign efforts - Enhances market fit
Measure	Assess performance and identify improvement areas.	- Conduct Failure Mode and Effects Analysis (FMEA) - Apply Statistical Process Control (SPC) - Perform Cost of Quality (CoQ) analysis	- Detects inefficiencies early - Enables data-driven decisions - Improves process control
Analyze	Identify root causes of defects and inefficiencies.	- Perform Root Cause Analysis (RCA) and Fishbone Diagrams - Use Fault Tree Analysis (FTA) - Apply Regression Analysis & Hypothesis Testing	- Prevents recurring defects - Strengthens risk management - Improves process stability
Improve	Optimize product quality and process efficiency.	- Implement Lean Six Sigma (LSS) - Use Design of Experiments (DOE) - Apply Poka-Yoke (Error Proofing) - Strengthen reliability with Design for Reliability (DfR)	- Reduces defects and costs - Speeds up time-to-market - Enhances product performance
Control	Sustain improvements and ensure long-term quality.	- Use Predictive Maintenance & Digital Twin Technology - Apply Statistical Process Control (SPC) - Foster a Kaizen culture	- Maintains consistent quality - Prevents defect recurrence - Enhances adaptability and competitiveness

4.6. KPIs for Product Development Excellence

To achieve excellence in product development, organizations must establish well-defined and measurable Key Performance Indicators (KPIs) within Strategic Quality Management (SQM). Table 13 outlines the Main Key Performance Indicators (KPIs) for Strategic Quality Management (SQM) in product development, which is essential for ensuring product quality, process efficiency, continuous improvement, customer satisfaction, and digital transformation.

(1) Product Quality & Reliability: These KPIs are focused on minimizing defects and ensuring the overall reliability of the product. Defect Density measures the number of defects per unit or batch, helping identify quality weaknesses early and improve product reliability. First-Pass Yield (FPY) assesses the efficiency of the production process by tracking the percentage of products that pass quality checks without rework. It ensures cost-effective production by minimizing rework costs and improving throughput. Warranty Claim Rate tracks the percentage of products returned under warranty due to defects, which helps identify areas for improvement and reduce after-sales costs. Mean Time Between Failures (MTBF) measures the average time before a product fails, which reflects its durability and helps in building customer trust.

(2) Process Efficiency and Cost: This category focuses on optimizing production efficiency while reducing costs. Cost of Poor Quality (CoPQ) represents the financial impact of defects, rework, and warranty claims, helping optimize resource allocation and reduce waste. Cycle Time measures the time taken from product concept to market launch, directly impacting competitiveness and time-to-market. Rework Percentage indicates the proportion of products requiring rework, which helps minimize inefficiencies, reduce waste, and lower production costs.

(3) Continuous Improvement and Innovation: Continuous improvement is essential for long-term product quality. The Defect Reduction Rate tracks the year-over-year reduction in defects, demonstrating an ongoing commitment to quality enhancement. Corrective Action Closure Rate measures how quickly quality issues are addressed, ensuring timely resolutions. Process Capability Index (Cpk) assesses the consistency and stability of production processes, ensuring product reliability and reducing variations.

(4) Customer Satisfaction and Market Performance: Customer-centric KPIs assess how well products meet customer expectations. Net Promoter Score (NPS) measures customer loyalty and the likelihood of recommending the product, contributing to improved brand reputation. Customer Satisfaction Score (CSAT) gauges customer satisfaction, offering insights into product performance. Customer Retention Rate tracks the percentage of repeat customers, indicating long-term customer loyalty and overall product success in the market.

(5) Digitalization & Smart Quality Management: As digital technologies are increasingly integrated into product development, these KPIs measure the effectiveness of advanced tools. Predictive Maintenance Accuracy uses predictive analytics to prevent equipment failures, thereby reducing downtime and improving asset reliability. AI-Driven Quality Control enhances defect detection through artificial intelligence, improving inspection accuracy and efficiency, ultimately optimizing quality management processes.

These KPIs provide a comprehensive framework for evaluating product development, emphasizing quality, process efficiency, continuous improvement, customer satisfaction, and digital innovation. Each category is designed to drive superior product outcomes, reduce costs, and ensure long-term customer satisfaction.

Table 13. Main KPIs for Product Development Excellence.

Category	#	KPI	Objective	Benefits
(1) Product Quality & Reliability	1	Defect Density	Minimize defects	Enhances reliability and reduces product failures
	2	First-Pass Yield (FPY)	Improve production efficiency	Reduces rework costs, improves throughput
	3	Warranty Claim Rate	Reduce post-sales quality issues	Identifies weaknesses, lowers warranty costs
	4	Mean Time Between Failures (MTBF)	Increase product lifespan	Improves durability, strengthens customer trust
(2) Process Efficiency & Cost	5	Cost of Poor Quality (CoPQ)	Reduce the financial impact of defects	Optimizes resource allocation and cost efficiency
	6	Cycle Time	Accelerate product development	Reduces time-to-market, improves competitiveness
	7	Rework Percentage	Minimize inefficiencies	Lowers production costs and waste
(3) Continuous Improvement & Innovation	8	Defect Reduction Rate	Improve quality over time	Demonstrates ongoing quality improvement
	9	Corrective Action Closure Rate	Strengthen issue resolution	Ensures timely resolution of quality issues
	10	Process Capability Index (Cpk)	Ensure process stability	Enhances consistency and production reliability
(4) Customer Satisfaction & Market Performance	11	Net Promoter Score (NPS)	Measure customer loyalty	Boosts brand reputation and customer retention
	12	Customer Satisfaction Score (CSAT)	Measure customer experience	Provides insight into product satisfaction
	13	Customer Retention Rate	Increase repeat customers	Indicates brand loyalty and long-term satisfaction
(5) Digitalization & Smart Quality Management	14	Predictive Maintenance Accuracy	Prevent failures proactively	Reduces downtime, improves asset reliability
	15	AI-Driven Quality Control	Enhance defect detection	Increases inspection efficiency and accuracy

4.7. Integrating Agile Methodologies into Product Development Excellence

Agile methodologies have transformed product development by promoting flexibility, collaboration, and customer-centric innovation. By adopting Agile principles, organizations can accelerate development cycles, enhance product quality, and quickly adapt to market changes. Table 14 outlines the key aspects of Agile integration in product development, detailing the categories, practices, and benefits. Here is a concise breakdown:

(1) Agile Frameworks: Agile frameworks like Scrum, Kanban, SAFe, and Lean Startup enable iterative development, quick feedback, and rapid decision-making. These frameworks ensure faster time-to-market and better alignment with customer needs by promoting flexibility in the development process.

(2) Agile Mindset & Culture: Agile is not just a process but a cultural shift. It emphasizes self-organizing teams, cross-functional collaboration, adaptive leadership, and continuous learning. Organizations that adopt this mindset foster innovation, transparency, and quick adaptation to change, improving efficiency and responsiveness.

(3) Agile & Digital Transformation: Integrating Agile with digital technologies such as AI, IoT, Digital Twins, DevOps, and cloud development enhances automation, real-time decision-making, and predictive analytics. This synergy optimizes resources, boosts product quality, and streamlines the development lifecycle.

(4) Agile in Hardware and Software Development: While Agile is widely used in software, it's increasingly applied in hardware development. Hybrid Agile models, modular design, and concurrent engineering enable hardware teams to iterate quickly while ensuring compliance and maintaining quality standards.

(5) Agile Metrics and Performance Measurement: Agile metrics like Sprint Velocity, Cycle Time, Defect Density, and Customer Satisfaction Scores (NPS, CSAT) help monitor progress and identify areas for improvement. These data-driven insights allow teams to refine processes and enhance efficiency, quality, and user satisfaction.

(6) Challenges and Solutions in Agile Adoption: Challenges such as resistance to change, regulatory constraints, and team dependencies can hinder Agile adoption. These challenges can be overcome with Agile training, hybrid models, and scalable frameworks that strike a balance between flexibility and compliance, ensuring both quality and adaptability.

(7) Future Trends in Agile Product Development: The future of Agile product development includes advancements such as AI-driven automation, blockchain for enhanced transparency, and human-centric practices. These trends will further improve decision-making, streamline workflows, and increase productivity, ensuring long-term success in an evolving market.

In summary, integrating Agile methodologies into product development drives efficiency, innovation, and a customer-focused approach. By aligning Agile principles with digital transformation, organizations can accelerate innovation, optimize processes, and maintain a competitive edge in a fast-paced market.

Table 14. Integrating Agile Methodologies with Product Development Excellence.

#	Category	Key Aspects	Benefits
1	Agile Frameworks	Scrum, Kanban, SAFe, Lean Startup	Shortens development cycles, boosts flexibility, and aligns closely with customer needs.
2	Agile Mindset & Culture	Self-organizing teams, adaptive leadership, collaboration, continuous learning	Promotes innovation, transparency, and fast adaptation to market changes.
3	Agile & Digital Transformation	AI, IoT, Digital Twins, DevOps, Cloud-based development	Enhances real-time analytics, predictive insights, and process automation.
4	Agile for Hardware & Software	Hybrid Agile, modular design, concurrent engineering	Integrates Agile for hardware development, ensuring compliance and faster iterations.
5	Agile Metrics & Performance	Sprint velocity, cycle time, defect density, NPS, CSAT	Provides actionable insights to drive quality, speed, and customer satisfaction.
6	Challenges & Solutions	Resistance to change, regulatory constraints, cross-functional dependencies	Overcomes challenges with training, hybrid approaches, and scalable frameworks.
7	Future Trends in Agile	AI automation, blockchain, human-centered Agile	Improves decision-making, data security, and productivity in Agile development.

4.8. Critical Failure Factors in Achieving Product Development Excellence

Critical Failure Factors (CFFs) are the primary challenges that prevent organizations from creating high-quality, innovative products that meet customer expectations and comply with regulatory standards. These challenges can arise at various stages of the product development process, leading to inefficiencies, increased costs, and reduced competitiveness. Identifying and addressing these CFFs is essential for organizations striving for excellence in product development. Table 15 outlines these critical failure factors and suggests solutions for overcoming them, categorized into eight strategic areas that are crucial for achieving product development excellence.

(1) Leadership and Culture: Strong leadership and a clear organizational culture are pivotal to successful product development. Without a well-defined vision and clear goals, teams may lose alignment and direction. To address this, companies should set measurable goals and engage leadership actively. By fostering a culture of continuous improvement and promoting employee engagement, organizations can reduce inefficiencies and boost morale, ensuring a quality-driven culture.
(2) Innovation and R&D: Sustaining innovation through investment in R&D is vital for maintaining competitiveness. A lack of focus or insufficient investment in R&D can lead to stagnation and a loss of market relevance. Organizations should prioritize R&D funding, encouraging a culture of creativity and innovation to drive product advancement and retain a competitive edge.
(3) Customer and Market Orientation: Aligning product development with customer needs is fundamental for success. Misunderstanding customer requirements can result in market misalignment and customer dissatisfaction. Methods like Voice of the Customer (VOC) and Critical to Quality (CTQ) can help organizations align their designs with customer expectations. Additionally, simplifying designs to address core needs can reduce costs, increase efficiency, and improve overall customer satisfaction.
(4) Quality and Risk Management: Ensuring high product quality and proactively managing risks is critical to avoiding defects, delays, and cost overruns. Implementing frameworks like Total Quality Management (TQM) and Six Sigma standardizes quality processes, ensuring consistency. A comprehensive risk management strategy helps identify potential risks early, allowing for better mitigation and smoother development cycles.
(5) Project and Resource Management: Effective project and resource management are essential to meeting deadlines and minimizing inefficiencies. Poor resource allocation and skills mismatches can lead to delays and increased costs. Aligning resources with project needs and skills, along with using structured project management methodologies, helps prevent scope creep and ensures projects remain on schedule and within budget.
(6) Compliance and Technology Integration: Compliance with regulations and the integration of modern technologies are essential for maintaining product quality and avoiding legal challenges. Keeping up to date with regulatory requirements and incorporating compliance checks into processes helps mitigate legal risks. Embracing emerging technologies like AI, IoT, and automation ensures products remain competitive and up-to-date, avoiding obsolescence.
(7) Performance Monitoring and Decision-Making: Monitoring product performance post-launch and making data-driven decisions are key to continuous improvement. Ignoring feedback or failing to track product performance can lead to missed opportunities. Implementing feedback loops and adopting data-driven decision-making frameworks enable organizations to make timely, informed decisions and identify areas for product enhancement.
(8) Supply Chain and Lifecycle Management: Efficient supply chain management and effective lifecycle management are crucial for timely delivery and long-term product success. Poor supplier relationships and disruptions can lead to delays and increased costs. Strengthening supplier relationships, improving supply chain visibility, and managing the entire product lifecycle help mitigate risks and ensure products evolve with changing customer needs, preventing obsolescence.

In conclusion, addressing these Critical Failure Factors underscores the importance of Strategic Quality Management (SQM) in overcoming barriers to successful product development. By aligning leadership, fostering collaboration, focusing on customer needs, and implementing quality management practices, organizations can develop high-performing, innovative products. These solutions not only help avoid common pitfalls but also strengthen the overall product development process, ensuring long-term competitiveness and sustainable growth.

Table 15. Critical Failure Factors and Solutions for Achieving Product Development Excellence.

#	Strategic Area	Perspective	Critical Failure Factor (CFF)	Solution
1	Leadership & Culture	Leadership	Unclear vision and goals	Define clear, measurable goals; align leadership
		Organizational Culture	Low engagement, lack of quality focus	Foster a culture of continuous improvement; engage leadership
2	Innovation & R&D	Innovation	Insufficient R&D investment	Increase R&D funding; cultivate a culture of innovation
		R&D	Lack of R&D focus or investment	Boost R&D investments; prioritize innovation
3	Customer & Market Orientation	Customer Orientation	Misunderstanding customer needs	Use VOC/CTQ methods to align with customer expectations
		Product Design	Overcomplicated or irrelevant designs	Simplify designs; focus on core customer needs
4	Quality & Risk Management	Quality Management	Inconsistent quality control	Standardize processes using TQM and Six Sigma
		Risk Management	Failure to manage risks	Apply risk management frameworks; continuously monitor risks
5	Project & Resource Management	Resource Management	Poor resource allocation, skills mismatch	Align resources to project needs and skills
		Project Management	Poor planning, scope creep	Apply structured project management methodologies
6	Compliance & Technology	Compliance	Non-compliance with regulations	Stay updated on regulations; integrate compliance checks
		Technology Integration	Resistance to new technologies or outdated systems	Embrace emerging technologies (AI, IoT, automation)
7	Performance Monitoring & Decision-Making	Post-Launch Monitoring	Ignoring feedback, inadequate monitoring	Implement feedback loops; track performance continuously
		Decision-Making	Delayed decisions, lack of accurate data	Implement data-driven decision-making frameworks
8	Supply Chain & Lifecycle	Supply Chain	Poor supplier relationships, disruptions	Strengthen supplier relationships; improve visibility
		Lifecycle Management	Ignoring lifecycle stages, lack of post-launch support	Integrate lifecycle management from planning to post-launch

5. Conclusions and Future Work

This study presents a comprehensive methodology for achieving product development excellence by strategically applying key quality management tools and frameworks. It explores the use of essential tools—such as Quality Function Deployment (QFD), Failure Mode and Effects Analysis (FMEA), and Statistical Process Control (SPC)—to improve product quality, reliability, and process efficiency. The approach emphasizes core principles, including customer-centricity, innovation, cross-functional collaboration, continuous improvement, and risk-based thinking to align development with market needs.

Central to the methodology is capturing the Voice of the Customer (VoC) and identifying Critical-to-Quality (CTQ) factors to ensure products meet customer expectations and business goals. The DMAIC framework guides systematic process optimization and innovation throughout the product lifecycle. Strategic Key Performance Indicators (KPIs) track efficiency, quality, customer satisfaction, and time-to-market. Agile methods enhance flexibility, iterative development, and responsiveness.

The study also identifies organizational, technical, cultural, and managerial barriers to achieving product development excellence and proposes targeted strategies to overcome them, thereby promoting sustainable success and a competitive advantage.

Future research should focus on validating this methodology across diverse industries and organizational settings to robustly evaluate its effectiveness in achieving product development excellence. Additionally, exploring the integration of advanced digital technologies—such as Artificial Intelligence, Internet of Things (IoT), and Digital Twins—within the quality management framework could further elevate the precision, agility, and overall quality of product development processes. Longitudinal studies examining the sustained impact of this integrated approach on innovation performance and market competitiveness will be essential to understanding its long-term contribution to product development excellence.

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References

1. Chiang RY, Wei CC, Cheng YC, Wei CS. Attractiveness Maximisation Model for Designing Product Complexity. *Total Qual. Manag. Bus. Excell.* **2020**, *31*, 1829–1840.
2. Gijo EV, Bhat S, Antony J, Park SH. Ten Commandments for Successful Implementation of Design for Six Sigma. *TQM J.* **2021**, *33*, 1666–1682.
3. Gomaa AH. Enhancing Product Development Using Lean Six Sigma Approach: From Continuous Improvement to Continuous Innovation. *IUP J. Oper. Manag.* **2024**, *23*, 5–26.
4. Singh B, Beg S, Sharma G, Jain A, Negi P. Holistic Application of Quality by Design (QbD) for Pharma Product Development Excellence and Regulatory Compliance. *Nirma Univ. J. Pharm. Sci.* **2014**, *1*, 19–35.
5. Khan A, Naquvi KJ, Haider MF, Khan MA. Quality by Design- Newer Technique for Pharmaceutical Product Development. *Intell. Pharm.* **2024**, *2*, 122–129.
6. Gomaa AH. Leading with excellence: Critical leadership dimensions in Lean Six Sigma for business excellence. *Hum. Resour. Manag. Serv.* **2025**, *7*, 4399–4399.
7. Chen W, Yang B, Liu Y. An Integrated QFD and FMEA Approach to Identify Risky Components of Products. *Adv. Eng. Inform.* **2022**, *54*, 101808.
8. Gai T, Wu J, Liang C, Cao M, Zhang Z. A Quality Function Deployment Model by Social Network and Group Decision Making: Application to Product Design of e-Commerce Platforms. *Eng. Appl. Artif. Intell.* **2024**, *133*, 108509.
9. Huang J, You XY, Liu HC, Si SL. New Approach for Quality Function Deployment Based on Proportional Hesitant Fuzzy Linguistic Term Sets and Prospect Theory. *Int. J. Prod. Res.* **2019**, *57*, 1283–1299.
10. Liu HC, Chen XQ, Duan CY, Wang YM. Failure Mode and Effect Analysis Using Multi-Criteria Decision Making Methods: A Systematic Literature Review. *Comput. Ind. Eng.* **2019**, *135*, 881–897.
11. Haron NA, Ales AH, Hua LT. Developing a New Model to Control Risk and Improve Quality in the Construction Industry by Integrating Risk Management and Quality Function Deployment. *Period. Eng. Nat. Sci.* **2024**, *12*, 101–122.
12. Fiorenzo F, Maurizio G, Domenico M, Luca M. Engineering Characteristic Prioritization in QFD Using Ordinal Scales: A Robustness Analysis. *Eur. J. Ind. Eng.* **2018**, *12*, 151–174.
13. Henshaw MJDC, Everitt MJ, Dwyer VM, Lemon J, Jones SC. The Challenges for Systems Engineers of Non-Classical Quantum Technologies. *Eng. Phys. Comput. Sci.* **2017**, *1*, 1–17.
14. Escayola J, Tricás J. Service Quality Study in the Property and Casualty Insurance Market Using the Quality Function Deployment Methodology. *Eur. Account. Manag. Rev.* **2016**, *3*, 72–92.
15. Khorshidi HA, Nikfalazar S, Gunawan I. Statistical Process Control Application on Service Quality Using SERVQUAL and QFD with a Case Study in Trains' Services. *TQM J.* **2016**, *28*, 195–215.
16. Kassela K, Papalexi M, Bamford D. Applying Quality Function Deployment to Social Housing? *TQM J.* **2017**, *29*, 422–437.
17. Alsaadi MR, Ahmad SZ, Hussain M. A Quality Function Deployment Strategy for Improving Mobile-Government Service Quality in the Gulf Cooperation Council Countries. *Benchmarking Int. J.* **2018**, *25*, 3276–3295.
18. Erdil NO, Arani OM. Quality Function Deployment: More than a Design Tool. *Int. J. Qual. Serv. Sci.* **2019**, *11*, 142–166.

19. Kaya SK, Erginel N. Futuristic Airport: A Sustainable Airport Design by Integrating Hesitant Fuzzy SWARA and Hesitant Fuzzy Sustainable Quality Function Deployment. *J. Clean. Prod.* **2020**, *275*, 123880.
20. Ginting R, Ishak A, Pitaloka D. Application of Quality Function Deployment (QFD) Method in Meeting Customer Satisfaction in the Bookshelf Industry. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *1003*, 012005.
21. Erdil A. Development Supply Chain Management. in Terms of Quality Function: An Application in the Manufacturing Industry. *Avrupa Bilim ve Teknoloji Dergisi* **2021**, *1*, 456–465.
22. Sharma J. Quality Function Deployment: Exploiting Interrelationships for Progressive Prioritization. *TQM J.* **2021**, *33*, 681–705.
23. Singh P, Agrawal G. Mapping the Customer Centric Weather Index Insurance Service Design Using Quality Function Deployment. *TQM J.* **2022**, *34*, 1800–1822.
24. Yulius H, Dewata I, Heldi, Putra A. Designing Eco-Friendly Kambuik Shopping Bags: A Quality Function Deployment Approach. *Int. J. Des. Nat. Ecodyn.* **2023**, *18*, 1469–1474.
25. Amalia F, Cahya HN, Waluyo DE, Zakaria F. Efforts to Improve Service Quality at Skenario Kopi Cafe Based on Consumer Needs Using Quality Function Deployment. *J. Indones. Sos. Sains* **2024**, *5*, 1425–1438.
26. Huang J, Li ZS, Liu HC. New Approach for Failure Mode and Effect Analysis Using Linguistic Distribution Assessments and TODIM Method. *Reliab. Eng. Syst. Saf.* **2017**, *167*, 302–309.
27. Sunday A, Enesi S, Kehinde O, Samuel A, Ikechi I, Remilekun E. Failure Mode and Effect Analysis a Tool for Reliability Evaluation. *Eur. J. Eng. Res. Sci.* **2018**, *3*, 65–68.
28. Gomaa AH. Improving Shutdown Maintenance Management Performance Using Lean Six Sigma Approach: A Case Study. *Int. J. Appl. Phys. Sci.* **2024**, *10*, 1–14.
29. Sharma KD, Srivastava S. Failure Mode and Effect Analysis (FMEA) Implementation: A Literature Review. *J. Adv. Res. Aeronaut. Space Sci.* **2018**, *5*, 1–17.
30. Banduka N, Veza I, Biliæ B. An Integrated Lean Approach to Process Failure Mode and Effect Analysis (PFMEA): A Case Study from Automotive Industry. *Adv. Prod. Eng. Manag.* **2016**, *11*, 355–365.
31. Adar E, Ince M, Karatop B, Bilgili MS. The Risk Analysis by Failure Mode and Effect Analysis (FMEA) and Fuzzy-FMEA of Supercritical Water Gasification System Used in the Sewage Sludge Treatment. *J. Environ. Chem. Eng.* **2017**, *5*, 1261–1268.
32. Peeters JFW, Basten RJ, Tinga T. Improving Failure Analysis Efficiency by Combining FTA and FMEA in a Recursive Manner. *Reliab. Eng. Syst. Saf.* **2018**, *172*, 36–44.
33. Colli M, Sala R, Pirola F, Pinto R, Cavalieri S, Wæhrens BV. Implementing a Dynamic FMECA in the Digital Transformation Era. *IFAC-Pap.* **2019**, *52*, 755–760.
34. Li Z, Chen L. A Novel Evidential FMEA Method by Integrating Fuzzy Belief Structure and Grey Relational Projection Method. *Eng. Appl. Artif. Intell.* **2019**, *77*, 136–147.
35. Panteliæ MP, Bošnjak SM, Misita MZ, Gnjatović NB, Stefanović AZ. Service FMECA of a Bucket Wheel Excavator. *Eng. Fail. Anal.* **2020**, *108*, 104289.
36. Baghele P, Londhe N, Rode B, Bharsakade R, Kuber S, Kotwal G. Failure Modes and Effects Analysis (FMEA) for Litter Picking Machine. In Proceedings of the 2020 International Conference on Industry 4.0 Technology (I4Tech), Pune, India, 13–15 February 2020; pp. 55–60.
37. Bharsakade R, Badgujar P, Malani K, Rithe S, Salunke P. Quality and Efficiency Improvement Through Process FMEA—A Case Study. In *Advances in Modelling and Optimization of Manufacturing and Industrial Systems: Select Proceedings of CIMS 2021*; Springer Nature: Singapore, 2023; pp. 375–391.
38. Gomaa AH. Maintenance Process Improvement Framework Using Lean Six Sigma: A Case Study. *Int. J. Bus. Adm. Stud.* **2023**, *9*, 139–148.
39. Gomaa AH. Improving Productivity and Quality of a Machining Process by Using Lean Six Sigma Approach: A Case Study. *Eng. Res. J.* **2024**, *53*, 1–16.
40. Gomaa AH. Optimizing Machining Quality and Production Efficiency Through a Taguchi-Based Six Sigma Framework. *Int. J. Darshan Inst. Eng. Res. Emerg. Technol.* **2024**, *13*, 34–46.
41. Chen KS, Ye GP, Yu CM, Yu CH. Construct the Optimum Process Model for Transistor Gaskets with Six-Sigma DMAIC. *Appl. Sci.* **2023**, *13*, 6895.
42. Muraleedharan P, Muruganantham VR, Karthikeyan AG, Muruganandhan P, Mani M, Hussain BI. Parametric Optimization in Turning Process of Galvanized Iron Metal Using Taguchi Based Six Sigma. *J. Mines Met. Fuels* **2023**, *71*, 2616–2623.
43. Duc ML, Hlavaty L, Bilik P, Martinek R. Enhancing Manufacturing Excellence with Lean Six Sigma and Zero Defects Based on Industry 4.0. *Adv. Prod. Eng. Manag.* **2023**, *18*, 32–48.
44. Chen JC, Buddaram Brahma AR. Taguchi-Based Six Sigma Defect Reduction of Green Sand Casting Process: An Industrial Case Study. *J. Enterp. Transform.* **2014**, *4*, 172–188.
45. Lin EW, Wong M. Improving the Efficiency of Taguchi with Six Sigma- A Case Study of Hand Tool Drilling Process Production. In Proceedings of the 2014 IEEE International Conference on Management of Innovation and Technology, Singapore, 23–25 September 2014; pp. 549–554.

46. Kaushik V, Dhindsa G, Kumar R. Utilization of Six Sigma Method to Reduce Defects in Green Sand Casting Process and Improve the Productivity. *Int. J. Eng. Manag. Res. (IJEMR)* **2016**, *6*, 167–172.
47. Chou S, Chen JC. Taguchi-Based Six Sigma Approach to Optimize Surface Roughness for Milling Processes. *Int. J. Ind. Manuf. Eng.* **2017**, *11*, 1653–1658.
48. Ganganallimath MM, Patil SD, Gijo EV, Math RB, Hiremath V. Application of Taguchi- Based Six Sigma Method to Reduce Defects in Green Sand Casting Process: A Case Study. *Int. J. Bus. Syst. Res.* **2019**, *13*, 226–246.
49. Ibrahim MS, Hanif A, Ahsan A. Identifying Control Factors for Business Process Improvement in Telecom Sector Using Taguchi Approach. *IEEE Access* **2019**, *7*, 129164–129173.
50. Yusof N, Lee KL. Improve Product Quality and Production Process with Integration of Six Sigma and Quality Management System ISO 9001: A Case Study of Bakery Shop in France. *Int. J. Ind. Manag.* **2022**, *14*, 557–579.
51. Erlangga RB, Wahyuni HC. Application of Quality Control Using Six Sigma and Taguchi Method on UMKM Kerupuk Tahu Bangil in Pandemic Period (Case Study: UD. Sanusi). *Procedia Eng. Life Sci.* **2022**, *3*, 1–7.
52. Gerger A, Firuzan AR. Taguchi Based Case Study in the Automotive Industry: Nonconformity Decreasing with Use of Six Sigma Methodology. *J. Appl. Stat.* **2021**, *48*, 2889–2905.
53. Omprakas MA, Muthukumar M, Saran SP, Ranjithkumar D, Venkatesh ST, Sengottuvelan M. Analysis of Shrinkage Defect in Sand Casting by Using Six Sigma Method with Taguchi Technique. *IOP Conf. Ser. Mater. Sci. Eng.* **2021**, *1059*, 012047.
54. Ketabforoush M, Abdul Aziz N. The Effect of Taguchi-Based Six Sigma Method on Variation Reduction in a Green Construction Material Production Process. *Iran. J. Sci. Technol. Trans. Civ. Eng.* **2021**, *45*, 879–889.
55. Alhumaid AM, Bin Mahmoud AA, Almohsen AS. Value Engineering Adoption's Barriers and Solutions: The Case of Saudi Arabia's Construction Industry. *Buildings* **2024**, *14*, 1017.
56. Selim AM, Meetkees OA, Hagag MR. Value Engineering (VE) Application in Infrastructure Projects by Public-Private Partnership (PPPs). *Int. J. Appl. Eng. Res.* **2017**, *12*, 10367–10375.
57. Mehta CS, Mehta EP, Pitroda J. Application of Value Engineering in Construction Projects. *Int. Res. J. Eng. Technol*. **2020**, *7*, 433–437.
58. Abdelghany M, Rachwan R, Abotaleb I, Albughdadi A. Value Engineering Applications to Improve Value in Residential Projects. In Proceedings of the Annual Conference–Canadian Society for Civil Engineering, Regina, SK, Canada, 27–30 May 2015; pp. 27–30.
59. Abd-Karim SB. The Application of Value Management on Private Projects. *QS Link* **2016**, *2*, 33–36.
60. Rane NL, Attarde PM. Application of Value Engineering in Construction Projects. *Int. J. Eng. Manag. Res. (IJEMR)* **2016**, *6*, 25–29.
61. Parakhiya D, Patel J. Application of Value Engineering in Construction Project: Case Study on Residential Project in Ahmedabad. *Int. J. Sci. Res. Dev.* **2017**, *5*, 1890–1894.
62. Perpetua NN. The Application of Value Engineering on Construction Projects in Abia State. *Niger. Iconic Res. Eng. J.* **2019**, *3*, 40–55.
63. Mahinkanda MMMP, Sandanayake YG, Ekanayake BJ. Bridging the Theory-Practice Gap in Value Management in Sri Lankan Construction Industry. In Proceedings of the 8th World Construction Symposium, Colombo, Sri Lanka, 8–10 November 2019, pp. 147–157.
64. Othman I, Kineber AF, Oke AE, Zayed T, Buniya M. Barriers of Value Management Implementation for Building Projects in Egyptian Construction Industry. *Ain Shams Eng. J.* **2021**, *12*, 21–30.
65. Almansour M, Krarti M. Value Engineering Optimal Design Approach of High-Performance Residential Buildings: Case Study of Kuwait. *Energy Build.* **2022**, *258*, 111833.
66. Elsayed A, Abdelalim AM, Elhakeem A, Said SO. A Proposed Framework for The Integration of Value Engineering and Building Information Modeling. *Eng. Res. J.* **2024**, *182*, 322–340.
67. Al-Salmawi MAK, Al-Eqabi MAR. Integration Between Value Engineering Technology and Activity-Based Costing and their Impact on Reducing Costs: Applied Research in Baghdad Soft Drinks Company/Private Shareholding. *Eur. J. Bus. Manag. Res.* **2024**, *9*, 94–105.
68. Husal HR, Ginting R, Anizar A. Integrated Value Engineering with QFD and DFA as Product Design and Development Techniques: Literature Review. *J. Sist. Tek. Ind.* **2024**, *26*, 22–34.
69. Abdelrahman SA, Nassar AH. Integrating Theory and Practice in Value Engineering Within Egypt's Construction Industry. *J. Eng. Appl. Sci.* **2024**, *71*, 188.
70. Tandiono Y, Rau H. An Enhanced Model Using the Kano Model, QFDE, and TRIZ with a Component-Based Approach for Sustainable and Innovative Product Design. *Sustainability* **2023**, *15*, 527.
71. Dace E, Stibe A, Timma L. A Holistic Approach to Manage Environmental Quality by Using the Kano Model and Social Cognitive Theory. *Corp. Soc. Responsib. Environ. Manag.* **2020**, *27*, 430–443.
72. Sohn JI, Woo SH, Kim TW. Assessment of Logistics Service Quality Using the Kano Model in a Logistics-Triadic Relationship. *Int. J. Logist. Manag.* **2017**, *28*, 680–698.

73. Velikova N, Slevitch L, Mathe-Soulek K. Application of Kano Model to Identification of Wine Festival Satisfaction Drivers. *Int. J. Contemp. Hosp. Manag.* **2017**, *29*, 2708–2726.
74. Chen YH, Chou YL, Tsai CL, Chang HC. Evaluating Car Centre Service Quality with Modified Kano Model Based on the First-Time Buyer's Age. *Cogent Bus. Manag.* **2018**, *5*, 1441593.
75. Sugarindra M, Pratama RN. Kano Model for Identification Car Modification Features of Mobile Application. *MATEC Web Conf.* **2018**, *221*, 03003.
76. Asian S, Pool JK, Nazarpour A, Tabaeeian RA. On the Importance of Service Performance and Customer Satisfaction in Third-Party Logistics Selection: An Application of Kano Model. *Benchmarking Int. J.* **2019**, *26*, 1550–1564.
77. Djekic I, Ilic J, Guiné RP, Tomasevic I. Can We Understand Food Oral Processing Using Kano Model? Case Study with Confectionery Products. *J. Texture Stud.* **2020**, *51*, 861–869.
78. Kohli A, Singh R. An Assessment of Customers' Satisfaction for Emerging Technologies in Passenger Cars Using Kano Model. *Vilakshan-XIMB J. Manag.* **2021**, *18*, 76–88.
79. Hariri A, Domingues JPT, Sampaio P. Applying Refined Kano Model to Classify and Rank Customer Requirements, Case Study: Automotive Industry in Portugal. In Proceedings of the 2022 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), Kuala Lumpur, Malaysia, 7–10 December 2022, pp. 0257–0264.
80. Belski I, Belski I. Application of TRIZ in Improving the Creativity of Engineering Experts. *Procedia Eng.* **2015**, *131*, 792–797.
81. Rantanen K, Conley DW, Domb ER. *Simplified TRIZ: New Problem Solving Applications for Technical and Business Professionals*; Taylor & Francis: Abingdon, UK, 2017.
82. Hatipoðlu A, Subran M, Korkmaz FF. Verification of Patent Solution Proposed for Munition Release Systems Using TRIZ-Based Root Conflict Analysis (RCA+) Approach. *Acad. Perspect. Procedia* **2020**, *3*, 115–126.
83. Abramov O, Kogan S, Mitnik-Gankin L, Sigalovsky I, Smirnov A. TRIZ-Based Approach for Accelerating Innovation in Chemical Engineering. *Chem. Eng. Res. Des.* **2015**, *103*, 25–31.
84. Al-Betar MA, Alomari OA, Abu-Romman SM. A TRIZ-Inspired Bat Algorithm for Gene Selection in Cancer Classification. *Genomics* **2020**, *112*, 114–126.
85. Alomari OA, Makhadmeh SN, Al-Betar MA, Alyasseri ZAA, Doush IA, Abasi AK, et al. Gene Selection for Microarray Data Classification Based on Gray Wolf Optimizer Enhanced with TRIZ-Inspired Operators. *Knowl. -Based Syst.* **2021**, *223*, 107034.
86. Baharoma MZ, Delbressine F, Toeters M, Feijs L. The Identification of Contradictions in Cliff: An Automatized Zipper Prototype Using the TRIZ Method with Root Conflict Analysis (RCA+). In Proceedings of the 13th International MATRIZ Conference TRIZfest, Krakow, Poland, 14–16 September 2017; pp. 407–418.
87. Casner D, Livotov P, da Silva PK. TRIZ-Based Approach for Process Intensification and Problem Solving in Process Engineering: Concepts and Research Agenda. In *Advances and Impacts of the Theory of Inventive Problem Solving: The TRIZ Methodology, Tools and Case Studies*; Springer: Cham, Switzerland, 2018; pp. 217–229. doi:10.1007/978-3-319-96532-1_20.
88. Elyoussoufi S, Mazouzi M, Cherrafi A. TRIZ and LSS Integrated Models Assessment: A Holistic Model Development for Organizations' Excellence. In Proceedings of the 2nd Indian International Conference on Industrial Engineering and Operations Management Warangal, Telangana, India, 16–18 August 2022.
89. Kamarudin KM, Ridgway K, Hassan MR. Modelling the conceptual design process with hybridization of TRIZ methodology and systematic design approach. *Procedia Eng.* **2015**, *131*, 1064–1072.
90. Lin SY, Wu CT. Application of TRIZ Inventive Principles to Innovate Recycling Machine. *Adv. Mech. Eng*. **2016**, *8*, 1–8.
91. Madara DS, Tuigong D, Sitati S, Namango S, Ataro E. Potential of Theory of Innovative Problem Solution (TRIZ) in Engineering Curricula. *IJISET—Int. J. Innov. Sci. Eng. Technol.* **2015**, *2*, 984–994.
92. Rahim ZA, Sheng ILS, Nooh AB. TRIZ Methodology for Applied Chemical Engineering: A Case Study of New Product Development. *Chem. Eng. Res. Des.* **2015**, *103*, 11–24.
93. Zhao D, Chen W. Design and Research of Smart Neck Helmets Based on the KANOQFD Model and TRIZ Theory. *Secur. Commun. Netw.* **2021**, *2021*, 4693719.