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COMMON FAILURE FACTORS OF LEAN SIX SIGMA AND QUALITY 4.0, IN INDUSTRY 4.0 SERVICE SECTOR

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ABSTRACT

Purpose: *This research aims to identify and analyze the critical failure factors systematically that affect the implementation of Lean Six Sigma and Quality 4.0 initiatives*

Design/methodology/approach: *Descriptive Statistics is used for frequency of occurrence and cumulative frequency, while Pareto Analysis is used for quantitative prioritization of critical failure factors that impact the most and identify the vital few that contribute to over 80% of failures.*

Findings: *The findings show that 80% of the implementation issues are based on five critical failure factors, particularly leadership commitment and training.*

Practical implications: *By using the findings, the organizations may determine which critical failure has more impact on Quality 4.0 and Lean Six Sigma adoption and execution. Important steps include prioritizing high-impact initiatives, enhancing staff work by training, coordinating quality goals with strategy, and encouraging leadership support.*

Originality & Value: *This study exclusively contrasts Lean Six Sigma and Quality 4.0 by identifying and quantifying Critical Failure Factors by using Pareto Analysis. It introduces a novel viewpoint on the human and strategic gaps in digital quality transformation areas, which are previously unexplored in academic research.*

Keywords: *Quality 4.0, Lean Six Sigma, Industry 4.0, Pareto Analysis.*

INTRODUCTION

Over the previous year, the industry has been under constant progress. The quality concepts have gradually changed after this revolution. Such progress gives a revolution of high-level development (Popkova , Ragulina & Bogoviz, 2019), and digital transformation plays an important role in it.

In order to enhance agility, digital transformation has business models and a complete value chain at the organizational level. It has management aspects too, which introduce new strategic objectives (Cots, 2018). Here, for transformative initiatives, the quality acts as a strong base.

The other concept addressed in this paper is Lean Six Sigma, a comprehensive methodology that integrates principles of Lean with Six Sigma and enhances quality and efficiency. This approach is highly effective in identifying non-value-added activities and eliminating them, streamlining the process and hence enhancing customer satisfaction. Lean Six Sigma is also a merger of two techniques, Lean Management & six Sigma. Lean emphasizes speed and waste reduction, while Six Sigma focuses on quality and defect reduction (Rowland et al.,2003). The previous literature also highlighted that there is a significant gap in the Quality 4.0 sector. The literature also highlights the need to verify how the quality 4.0 components and dimensions interact and influence sustainable development and

enterprise and society levels (Nenadal et al., 2022). In order to achieve sustainable growth, organizations need to identify the critical failure factors to understand how quality standards align with their initiatives (Bhat et al.,2023; Sreedan et al., 2018). No doubt industry 4.0 technologies offer promising advancements in quality enhancement; however, the risk associated with implementing and adopting Quality 4.0 has not been explored yet.

This research aims to address the common critical failures of quality 4.0 and Lean Six Sigma. The previous researches focus on human dimensions to managing quality 4.0, such as adaptability, leadership, and workforce competence, which are not fully explored (Balouei Jamkhaneh et al., 2022). The basic objectives of this research are: To identify and analyze the critical failure factors after the adoption and implementation of Quality 4.0 and Lean Six Sigma. 2. To provide insight into how organizations address these critical factors and mitigate them, which enhances operational efficiency and quality.

The following two research questions have been addressed in this paper.

RQ1: What are the primary critical failure factors of Quality 4.0 and Lean Six Sigma?

RQ2: How do these factors impact the successful integration of Quality 4.0 and Lean Six Sigma?

While understanding these failure factors, it will be crucial for the organizations that are aiming to adopt Quality 4.0 and Lean Six Sigma, as it will lead to improving the operational performance and customer satisfaction. These insights also enable the practitioners to address key challenges strategically, therefore by fostering the mindset of ongoing improvement and driving innovation, give a response in shifting the industry expectations. (Antony et al., 2023)

Literature Review

Underpinning theory

Lean Six Sigma combines Lean principles, which focus on reducing waste and optimizing workflow, with Six Sigma's statistical tools and methodologies for improving process consistency and reducing defects. Here, the theory of constraint will be used. TOC identifies bottlenecks and constraints within a system and focuses on maximizing throughput by optimizing the constraint (Gupta et al.,2024).

On the other hand, Socio-technical system (STS) theory is used to build the Quality 4.0 model, which includes technology tools and social connections like quality and sustainability, corporations serving society, and environmental management system integration to motivate SE (Nguyen et al., 2023).

Quality 4.0

Dan Jacob was the first to define Quality 4.0 as the technology accompanying quality is a mass-produced technique that is directed to executives driving performance (Sony et al., 2020).

Sader et al., (2022) defined two approaches to produce a complete description of Quality 4.0. In the whole picture of Industrial Revolution 4.0 technologies, it entirely depends on updated technologies. Kupper et al. (2019) explained that Quality 4.0 is a technology-engrossed start rather than quality management. (Jacob, 2017a; Bowers and Pickerel, 2019) described Quality 4.0 as a digitalized kind of Quality Management, in which Industry 4.0 tools are used.

Quality 4.0 second approach is taken as an independent side, other than the evolution of Quality management iterations, which are Quality control, Total Quality Management, and Quality Assurance. ASQ also stated that the evolution of Quality 4.o also occurred simultaneously with the Industry 4.0 revolution.

Radziwill (2018) defined the necessity of understanding prior quality repetitions that lead to understanding Quality 4.0. Broday (2022) explained that there is not yet any universally accepted definition of Quality 4.0.

In service organizations, Quality 4.0 is described as the outcome of quality and organizational performance in terms of the 4th Industrial Revolution. Since the 21st Century, the 4th IR is occurring; it influences everything that people do, widens the digital impact of the 3rd IR, and summarizes it with the physical and natural world (Maganga and Taifa., 2023).

It connects machines, people, and data in innovative strategies, standardized technology available only for a few, and leads in

breakthrough capabilities like 3D printing and the science of things. These technologies are conducive for quality, enhancing partnership, culture, leadership, and transformation within service organizations and others.

Using Q4.0 features in a service organization, the entire change drastically by considering the dimensions of service like responsiveness, tangibility, empathy, reliability, and assurance, while delivering a service to customers

Luhanga (2019) concluded in his study that the Fourth Industrial Revolution affects the service organization in three ways: a shift from traditional factors to new ones, such as time capital and data, along with customization and personalization of service provided to customers, and the digitalization of service.

Furthermore, Q 4.0 properties such as AI usage and service availability benefit organizations in different ways, encompassing learn client needs and preferences, confirmations, proactive approach, real-time response, and better service availability to consumers in all (Laura et al., 2022).

Arsovski (2019) emphasized the importance of Q4.0 in improving decision-making, speed and quality, boosting human intelligence, ensuring transparency, auditability, and traceability, predicting changes, removing biases, and adjusting to new knowledge and situations, all of which are essential characteristics in delivering services to clients.Q4.0 likewise transforms relationships, organizational limitations, and the idea of trust to uncover prospects for ongoing enhancement and innovative operational frameworks. It focuses on acquiring study skills through the development of self-awareness abilities.

The integration of Quality4.0-related technologies would likewise influence the overall supply chain management (SCM) in various aspects. Rana & Daultani (2023) state that the use of Machine Learning and AI in Supply Chain Management reduces cost through the supply chain, provides outstanding customer service, and facilitates a smart supply chain in a digitized manner

Quality 4.0 integrates the technological advancement of Industry 4.0 with basic quality frameworks. Organizations use real-time data, and it is analyzed by using digital tools and sensor-based systems for proactive quality management.

Q4.0 connects the quality infrastructure to the I4.0 different time frames. Firms can utilize sensors and digital technologies to track and gather real-time information, enabling them to foresee and address quality concerns. Quality professionals can play essential roles in helping their organizations implement statistically validated quality methods for new, digital, and disruptive technologies.

Though Q4.0 offers many advantages in service organizations, they still lack focused quality-driven strategies to facilitate digital transformation, highlighting the importance of concentrating on the integration of digital technologies within quality

Lean Management.

Origination of Lean Management is from Toyota Production System, and its knowledge is based on the contributions of well-renowned Quality experts Taiichi Ohno , Kaoru Ishikawa , and Shiego.

Dahlgaard & Dahlgaard-Park (2006); Hallavo et al., (2018); Muraliraj et al. (2018); Singh and Rathi (2019)all state that it gained recognition globally for its removal of non-value added tasks and is taken as the most efficient technique.

The term "Lean" signifies the elimination of various wastes, and retaining only what is essential and additionally displays key instruments employed for Lean management, along with the seven types of waste first identified in the Toyota Production System (Khalili et al., 2017; Raval et al., 2018).

Singh and Rathi (2019) describe two additional types of waste—wasted human talent (or training) and environmental waste.

Six Sigma

Six sigma refers to the application of various statistical data analysis tools to minimize and manage variation in a process, and enable it to reliably achieve its goals. Sigma (or standard deviation) indicates the variation of a trait (e.g., a process parameter, delivery time, response time, etc.) that needs management. Based on the characteristics of the Normal distribution, a six-sigma level process maintains its variation regulated within one-half of the permitted variation limits. Pital et al. (2017); Muraliraj et

al. (2018); Singh and Rathi (2019) state that when undesirable variation is eliminated and natural variation is foreseeable, the result can be planned with confidence. It aids in benefits, boosts savings, and improves stakeholder value.

Lean Six Sigma.

Lean Six Sigma is the combined application of Lean and Six Sigma. Outcomes attained through this approach surpass those obtained through their individual implementation (Sreedharan et al., 2018a). The methods and goals of Lean Management and Six Sigma are also similar. The elements contributing to the effective implementation of both methods are likewise. Consequently, professionals and organizations currently employ these ideas collectively as LSS.

Although LSS is straightforward, advantageous, and well-recognized, its implementation is challenging, and organizations frequently encounter obstacles.

Influence Of Quality 4.0 In Lean Six Sigma

When traditional Quality management practices are integrated with advanced technologies, the influence of Quality 4.0 on Lean Six Sigma is reflected. This integration increases efficiency, reduces defects, and adopts the culture of continuous improvement. The adoption of Quality 4.0 technologies with LSS not only prepares service organizations for future challenges but also improves competitiveness. The key influences are:

Integration of Technologies

Quality 4.0 enhances the usage of big data analytics and makes decision-making more effective during LSS cycles (Chawla, 2024). Also, the real-time data collection, which was previously tough to identify and address quality issues was facilitated by the usage of advanced technologies (Sharma et al., 2024)

Enhanced Decision Making

Quality 4.0 data-centric approach improves reliability and satisfaction through informed decision making (Chawla,2024). Reduction in lead time and enhancement of product quality are also achieved by integration of LSS and Quality 4.0 technologies. On the other hand, despite Quality 4.0's various benefits, barriers like technological complexity and change aversion may make it difficult to integrate with LSS. To effectively profit from this convergence, organizations need to overcome several barriers (Sharma et al., 2023).

Lean Six Sigma and Industry 4.0

Ibrahim & Kumar (2025) discuss the relationship between Lean Six Sigma, Industry 4.0, and sustainable manufacturing. This study suggests the DMAIC-DMADV-based framework, and also a phase-by-phase implementation path is proposed in order to integrate Lean Six Sigma and Industry 4,0 technologies to achieve sustainable manufacturing. This study also focuses on identifying and prioritizing the success factors in manufacturing; however, the critical failure factors are still unexplored in the service and manufacturing industries. This study uses the TOPSIS technique to identify and then rank the factors where input is taken from the experts of various manufacturing companies.

Gomaa,. (2025). Discussed that combining Industry 4.0 technologies, including Artificial Intelligence (AI), the Internet of Things (IoT), Digital Twins, and Big Data Analytics, to improve smart manufacturing excellence, Lean Six Sigma 4.0 (LSS 4.0) is an evolution. The DMAIC methodology, when incorporated with IoT-driven Process monitoring, AI predictive-driven analytics, and digital twin simulation, enables the manufacturing process to achieve autonomous optimization from reactive control. These changes improve productivity, resource efficiency, and sustainability by reducing the variability, defects, and waste**.** It enables **data-driven decision-making, intelligent automation, and predictive maintenance** to enhance **process reliability and operational performance**

This transformation **reduces variability, defects, and waste,** while **improving productivity, resource efficiency, and sustainability.** It enables **data-driven decision-making, intelligent automation, and predictive maintenance** to enhance **process reliability and operational performance.** Technological complexity, workforce up-skilling, and organizational resistance are challenges that need to be addressed. Block chain for safe supply chain traceability,

augmented reality (AR) for human–machine communication, and edge computing for decentralized intelligence are important enablers. Alignment of the digital transformation initiative with Lean principles promotes innovation

Adoption Of Quality 4.0

Adoption of Q4.0 also frequently calls for significant adjustments to organizational structures, workflows, and processes. For these transitions to be successful, both individuals and teams need to be capable of managing change (Chiarini, 2020). Adoption of Q4.0, in particular, necessitates outstanding departmental and team collaboration and communication. People need to collaborate well with others and communicate with stakeholders at all organizational levels (Antony et al., 2022b). Lastly, teams and individuals need to be technically capable of implementing Q4.0 solutions successfully. Cybersecurity, data analytics, and computer programming are all included (Antony et al., 2022c; Sony et al., 2020).

It is widely acknowledged that the implementation of Quality 4.0 in the service sector is also essential for the improvement of operational effectiveness and service quality. In order to maximize service delivery and customer satisfaction, this shift involves the integration of IoT and big data analytics. The following benefits will be achieved if the service industry adopts 4.0

- **Enhanced Customer Experience**: Customer Satisfaction can be increased through data analytics, which is facilitated by Q4.0(Antony et al., n.d)
- **Operational Efficiency**: Automation and digitization streamline processes, which in result reduce cost and increase productivity (Swarnakar et al., 2023)
- **Sustainability**: While maintaining service quality, the integration of sustainable practices within Q4.0 framework reduces environmental impacts (Rafiq, 2024)

Along with benefits, the following challenges will be faced by the service industry when adopting Q4.0 technology.

Resource Limitations: In the adoption of Quality 4.0, many firms face initial investment costs and a lack of trained staff (Antony et al.,n,d.; Nzumile,n.d).

- **Cultural Resistance**: Current quality control plans could cause doubt on the necessity of Q4.0, especially in companies with ingrained policies (Antony et al., n.d.).
- **Infrastructure problems**: Effective implementation is much hampered by inadequate technological infrastructure, including slow internet speeds (Nzumile, n.d.).

Some organizational readiness factors also affect the adoption of Quality 4.0 technologies.

- **Leadership Commitment**: Strong top management support and a change-embracing culture are essential for the successful implementation of Q4.0 (Antony et al., n.d.) (Swarnakar et al., 2023).
- • **Training and Development:** To acquire the skills required to utilize Q4.0 technologies, employees must receive ongoing training (Swarnakar et al., 2023).

Although implementing Quality 4.0 has many advantages, organizations still face many obstacles, especially when it comes to allocating resources and adjusting to a new culture. For service organizations, striking a balance between utilizing new technologies and upholding current quality standards is still crucial.

Quality 4.0 Critical Failure Factors

Less cyber internet linkage; insufficient leadership assistance; and employee hurdle to change (Antony et al., 2022c). Additionally, Zonnenshain and Kenett (2020) looked into a shortage of evidence for a better staging technique and the structure to get Q 4.0. Before base Q4.0, the quest must hence call these CFFs and make criteria to capture; shortage of Q4.0 capability, boring and knowledge; irregularly confirm their victory. Might be achieved by insecure in map, send training and literacy to staff, launch a data management system, and integrate an organizational culture of substitute and repair (Antony et al., 2022c; Sony et al., 2020).

Unhealed by critical management is the basic CFFs of the Q4.0 process. Unaccompanied senior leadership help, achieving the main basics, and determining stakeholders might be

taught (Antony et al., 2022b). Fewer keywords and techniques are more designed. Organizations must have a clear vision, action, infrastructure, and concise strategy for practical work (Maganga and Taifa., 2023).

As per reports, Q4.0 is mostly due to a shortage of funds. Rollout of Q4.0 requires adequate supplies, including economic, trained staff, and a technological road map. Organizations should ensure enough resources to assist actions (Antony et al., 2022c; Sureshchandar, 2022). A basic human factor in all significant efforts, including the implementation of Q4.0, is a hurdle to overcome. Change opposition should be energetically called by organizations, and main stakeholders must participate in the implementation (Antony et al. 2022b; Sony et al. 2020). The Q4.0 utilization is hindered by a shortage of strong and reliable data. Impactful data management, Reliable techniques, and technology road maps are therefore needed (Maganga and Taifa, 202 3; Ranjith Kumar et al., 2022).

Updated systems and techniques are embedded into Q4.0; cybersecurity threats could materialize. Data breaches and other sides of cybercrime might stay far from companies that have a strong cybersecurity plan. Lack of data analysis, programming, and quality management capabilities broke the Q4.0 start. Organizations must have nice individuals to assist in working (Escobar et al., 2021; Ranjith Kumar et al., 2022).

Several projects do not work successfully because Q4.0 needs to be notably united into a living company process. Organizations make sure to use Q4.0 gradually with their business tricks and connections with other critical business works (Antony et al., 2022b). Research on the CFFs of Q4.0 is the main thing since it may help organizations in identifying the critical issues and hindrances that may arise while the working of Q4.0 projects is in process (Antony et al., 2022c; Chiarini, 2020).

Moreover, relevant to CFFs may help assure the generation of effective risk management strategies to control the impact of these variables on Q4.0 approval (Suresh chandar, 2022). Moreover, research on CFFs helps in learning from the errors made by other organizations that act upon Q4.0 programs and refrain from repeating the same mistakes (Antony et al., 2023). Hence, studying CFFs is key to the even operation of Q4.0 programs.

Lean Six Sigma Critical Failure Factors

Lean Six Sigma (LSS) can be hampered by different analytic failure factors, which change over different construction sites and circumstances. These strands can fully affect the victory of LSS projects, leading to inabilities and defeats. The following segments figure the reproving failure aspects recognized in different studies, giving a brief sketch of the challenges faced in LSS execution.

Leadership and Management Issues

- **Failure of Leadership to Inspire and Motivate**: A shortfall of impactful leadership can dispirit teams and inhibit LSS start-up's (Kumar et al., 2024).
- **Lack of Top Management Commitment and Involvement**: Unsupported by top management, LSS projects often lack assumptions and resources (Patel & Patel, 2022; Albliwi et al., 2014).
- **Lack of Visionary Leadership**: Transformational leadership is decisive for situate LSS with enduring business targets (Patel & Patel, 2022).

Strategic and Resource Alignment

- **Lack of Synergy with Business Strategy**: Twisted between LSS enterprise and all business strategy can direct to unprofitable execution (Patel & Patel, 2022).
- **High Implementation Cost and Poor Estimation of Cost**: Economics hindrances and inexact cost guesses can derail LSS projects (Kumar et al., 2024).
- **Lack of Financial Resources**: Inadequate sponsorship can limit the extent and potency of the LSS enterprise (Patel & Patel, 2022).

Cultural and Educational Barriers

- **Resistance Related to Culture Change**: Organizational culture impenetrable to change can retard LSS adoption (Patel & Patel, 2022).
- **Lack of Training and Education**: Insufficient training can result in poor mastery and impact of LSS rules (Patel & Patel, 2022; Albliwi et al., 2014).

Communication and Framework Deficiencies

- **Lack of Well-Defined Framework for Executing Initiatives**: A visionary framework is

necessary for leading LSS targets (Kumar et al., 2024).

- **Lack of Communication**: Lack of clarity can lead to misconstruction and conflict within teams (Albliwi et al., 2014).

While these points emphasize the hurdles in the LSS process, it is key to note that successful LSS projects can lead to significant improvements in running regulations and customer content. Labelling these defeat factors through tactical planning, leadership headway, and staff granting can increase the fears of successful LSS deployment.

Despite the above-mentioned critical failure factor (Albiwi et al., 2014), they also highlight the 34 critical failure factors. These factors are

Factors	References
14. Lack of employee engagement and participation/lack of team autonomy	Burcher *et al.* (2010), Jeyaraman and Teo (2010), McAdam and Lafferty (2004), Scherrer-Rathje *et al.* (2009)
15. Lack of process thinking and process ownership	Aboelmaged (2011), Antony *et al.* (2012a), Bhasin (2012a, b), Hilton and Sohal (2012)
16. Poor organisation capabilities	Chakravorty (2009), Kumar *et al.* (2009b), Shah *et al.* (2008), Zhang *et al.* (2012)
17. High implementation cost	Bhasin (2012a, b), Chakravorty (2009), Panizzolo *et al.* (2012), Percin and Kahraman (2010)
18. Lack of experience in Lean/ Six Sigma project implementation	Gurumurthy and Kodali (2011), Jeyaraman and Teo (2010), Panizzolo *et al.* (2012), Pedersen and Huniche (2011)
19. Lack of awareness of the need for Lean/Six Sigma	Antony *et al.* (2012a, b), Gurumurthy and Kodali (2011), Pamfilie *et al.* (2012), Psychogios *et al.* (2012)
20. Ineffective project management	Jeyaraman and Teo (2010), Kwak and Anbari (2006), McAdam and Lafferty (2004)
21. Poor selection of candidates for belts training	Hilton and Sohal (2012), Kumar *et al.* (2009b), Snee (2010)
22. Lack of clear vision and a future plan	Bhasin (2012a, b), Jeyaraman and Teo (2010), Kwak and Anbari (2006)
23. Lack of an effective model or roadmap to guide the implementation	Chakravorty (2009), Kumar *et al.* (2011), Pepper and Spedding (2010)
24. Poor execution	Chakravorty (2009), Nwabueze (2012), Pinto *et al.* (2008)
25. Threat of redundancy	Bamber and Dale (2000), Gurumurthy and Kodali (2011), Martinez-Jurado and Moyano-Fuentes (2012)
26. Time consuming	Panizzolo *et al.* (2012), Percin and Kahraman (2010)
27. Lack of estimation of implementation cost	Aboelmaged (2011), Kumar *et al.* (2008b)
28. Weak infrastructure	Arumugam *et al.* (2013), Snee (2010)
29. Replicating another organisation's Lean/Six Sigma strategy	Al Amin and Karim (2013), Antony *et al.* (2012a), Bhasin (2012a, b)
30. Lack of a performance measurement system	Karim and Arif-Uz-Zaman (2013), Kumar *et al.* (2007)
31. Lack of understanding of how to get started	Kumar *et al.* (2009a, 2011)
32. Lack of application of statistical theory	Thomas *et al.* (2009)
33. Weak linking to suppliers	Bamber and Dale (2000)
34. Misalignment between the project aim, the main goals of the company and the customer demand	Ho *et al.* (2008)

Figure 1: Shows the highlighted critical failure factors

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Methodology

Firstly, we explore the literature through which we identify the failure factors of Lean Six Sigma and quality 4 implementation. Secondly, to rank the common failure factors of quality 4.0 and lean six sigma by using Pareto analysis.

According to Tranfield et al. (2003), the research methodology is based on planning, performance, data analysis, and reporting. To initiate the study, SCOPUS was selected. According to Gupta et al. (2020), Scopus is the largest electronic database of research articles, and it was also used for screening purposes.

for screening, as it is the largest electronic repository of articles. The literature was searched with the key words "Lean Six Sigma, "failure factors", "barriers," and " hurdles either found in the title or abstract of the article.

Another separate search was conducted with the keywords Quality 4.0, "failure factors," "barriers," either in the title or the abstract of the article. The published articles were taken from the period 2015-2025.

Inclusion and exclusion criteria were applied during the screening phase, and also peer-reviewed articles that are published in reputable journals and written in English, as it is taken as the global language of instruction.

Pareto Analysis

Pareto analysis serves as a valuable decision-making tool among the seven recognized tools of quality. It helps in pinpointing the critical failure factors that highly impact the data. The concept is widely used in the "80-20 " rule or vital few. The concept originates from the work of Vilfredo Pareto, an Italian economist. It is necessary to document the frequency of every critical factor and its cumulative frequency to highlight their significance.

Common Failure of Quality 4.0 And Lean Six Sigma

After studying the 52 papers, this study highlights the critical failure factors of Quality 4.0 and Lean Six Sigma that need to be addressed. After the implementation of Lean Six Sigma and advanced Quality 4.0 technologies, many projects still failed. The

comparative table shows the main critical failure factor that occurs in every paper

Table 1.1 shows the critical factors along with the author name who high light the factors first.

Critical Failure Factor	Domain	Author(s)	Year
Lack of top management commitment	Lean Six Sigma	Albliwi et al.	2014
Poor project selection and prioritization	Lean Six Sigma	Antony et al.	2019
Resistance to cultural change	Lean Six Sigma	Singh et al.	2019
Inadequate training and education	Lean Six Sigma	Sreedharan et al.	2018
Lack of strategic alignment	Lean Six Sigma	Singh & Rathi	2019
Weak supplier linkage	Lean Six Sigma	Singh et al.	2019
Lack of continuous improvement culture	Lean Six Sigma	Parmar & Desai	2021
Lack of digital infrastructure	Quality 4.0	Yadav et al.	2021
Poor data governance and integration	Quality 4.0	Antony et al.	2023
Resistance to adopting emerging technologies	Quality 4.0	Mohd Aripin et al.	2024
Lack of skilled workforce for digital transformation	Quality 4.0	Saha et al.	2025
Absence of leadership vision for digital quality initiatives	Quality 4.0	Abu-Salim et al.	2023
Misalignment between Quality 4.0 strategy and business goals	Quality 4.0	Francescatto et al.	2023

Table 1.2 shows the approx. occurrence of the critical failure factors

Critical Failure Factor	Domain	Approx. Occurrence Count	Source(s)
ack of top management commitment	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
oor project selection and ioritization	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
esistance to cultural change	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
adequate training and education	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
ack of strategic alignment	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
eak supplier linkage	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
ack of continuous improvement lture	ean Six Sigma	out of 56 papers	lbiwi et al.,(2014)
ack of digital infrastructure	uality 4.0	out of 15 interviews	ntony et al., (2023)
oor data governance and integration	uality 4.0	out of 15 interviews	ntony et al., (2023)
esistance to adopting emerging chnologies	uality 4.0	out of 15 interviews	ntony et al., (2023)
ack of skilled workforce for digital ansformation	uality 4.0	out of 15 interviews	ntony et al., (2023)
bsence of leadership vision for gital quality initiatives	uality 4.0	out of 15 interviews	ntony et al., (2023)

isalignment between Quality 4.0 rategy and business goals	uality 4.0	out of 15 interviews	ntony et al., (2023)

Table 1.3 shows the total number of . occurrence of the critical failure factors

Critical Failure Factor	Lean Six Sigma	Quality 4.0	Total Mentions	Sources
Lack of top management commitment	42	10	52	Albliwi et al., (2014), Antony et al., (2023)
Inadequate training and education	35	8	43	Albliwi et al., (2014), Antony et al., (2023)
Resistance to cultural/technological change	30		39	Albliwi et al., (2014), Antony et al., (2023)
Lack of strategic alignment	26	5	31	Albliwi et al., (2014), Antony et al., (2023)
Poor project selection and prioritization	28	–	28	Albiwi et al.,(2014)
Weak supplier linkage	18	–	18	Albiwi et al.,(2014)
Lack of continuous improvement culture	22	–	22	Albiwi et al.,(2014)
Lack of digital infrastructure	–	7	7	Antony et al., (2023)
Poor data governance and integration	–	6	6	Antony et al., (2023)
Misalignment with business goals	–	5	5	Antony et al., (2023)

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Table 1.4 shows the cumulative frequencies and cumulative percentages of the following critical failure factors.

Critical Failure Factor	Lean Six Sigma	Quality 4.0	Total Mentions	Sources	cumulative frequency	cumulative percentage
Lack of top management commitment	42	10	52	Albliwi et al., (2014), Antony et al., (2023)	52	20.72%
Inadequate training and education	35	8	43	Albliwi et al., (2014), Antony et al., (2023)	95	37.85%

Resistance to cultural/technological change	30	9	39	Albliwi et al., (2014), Antony et al., (2023)	134	53.39%
Lack of strategic alignment	26	5	31	Albliwi et al., (2014), Antony et al., (2023)	165	65.74%
Poor project selection and prioritization	28	–	28	Albiwi et al.,(2014)	193	76.89%
Weak supplier linkage	18	–	18	Albiwi et al.,(2014)	211	84.06%
Lack of continuous improvement culture	22	–	22	Albiwi et al.,(2014)	233	92.83%
Lack of digital infrastructure	–	7	7	Antony et al., (2023)	240	95.62%
Poor data governance and integration	–	6	6	Antony et al., (2023)	246	98.01%
Misalignment with business goals	–	5	5	Antony et al., (2023)	251	100.00%



Figure 2: Pareto Analysis of Quality 4.0 and Lean Six Sigma Critical Failure Factors

The Pareto analysis discloses that a few critical failure components unequally participate to overall execution of setbacks in Lean Six Sigma and Quality 4.0 strategies. In particular:

- The top **five factors**—including **lack of top management commitment**, **inadequate training and education**, **resistance to change**, **lack of strategic alignment**, and **poor project prioritization**—together constitute **over 80% of reported issues**.
- These "vital few" show immense areas that should be ranked by organizations intending to better high efficiency and digital quality evolutions.
- Resolving these underlying causes can promote more effective leadership involvement, increase workforce ability and enhance strategic alignment ultimately facilitating faster continuous improvement and sustainable innovation throughout the enterprise.

Conclusion

The research highlights that a focused group of root failure causes leadership commitment, training inadequacies, culture and technology resistance, strategic misalignment, and project management inadequacies—are the root causes of most implementation failures in Lean Six Sigma and Quality 4.0 projects. By methodically mapping out and sequencing these "vital few," organizations can dramatically improve the success rate of their quality transformations. This amplifies the strategic significance of aligning leadership, competencies, and

processes to assure continuous betterment and innovation.

To meet the changing demands of digital-era quality management, future studies must emphasize:

- **Quantitative Validation**: Building empirical models to measure the effect of CFFs on project performance, especially in hybrid systems combining Lean Six Sigma with Quality 4.0 tools.
- **Human-centric Factors**: Examining the influence of workforce flexibility, leadership vision, and digital literacy on Q4.0 readiness.
- **Sector-Specific Insights**: Performing comparative studies by industry (e.g., healthcare, manufacturing, public services) in order to customize mitigation approaches.
- **Capability Gaps**: Investigating how technical, social, and methodological capability gaps among quality professionals hinder digital transformation.
- **Integrated Frameworks**: Developing comprehensive assessment tools that integrate quality standards, CFFs, and organizational effectiveness with Industry 4.0.

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