

Strategic Advantages Of Industry 4.0 And Lean Six Sigma In Sustainable Manufacturing

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Abstract

This article evaluates the combination of Lean Six Sigma (LSS) methodologies and Industry 4.0 technologies on organizational performance. It has been proven that mixing these sophisticated technological tools with quality improvement strategies yields results in various aspects of performance including but not limited to finance, operations, environment, human resources, and innovation measures. Real-time data analytics, automation and interconnected systems can be used by organizations to gain higher efficiency levels, reduce costs, improve product quality and stimulate innovation. The studies conducted shows how such integration streamlines processes and promotes sustainable operational patterns as well as decision-making abilities through improved productivity. In addition, review of recent studies provides insights into how Industry 4.0 can be employed together with Lean Six Sigma in order to enhance sustainability and create excellent organizational practices. This article therefore contributes to the understanding of where future investigations should focus both for researchers and practitioners in the field.

Keywords- Lean Six Sigma, Industry 4.0, Synergy, Organizational Performance, Financial performance, Operational Performance, Employee Performance, Environment Performance, Innovation Performance

Introduction

In the present day, the industrial landscape is rapidly changing. In this scenario, the integration of the industry 4.0 concepts and the Lean Six Sigma Methodologies are emerging as a critical strategy for achieving the much sought after operational excellence and business sustainability as a competitive advantage. The much-discussed Lean Six Sigma is a comprehensive methodology that combines the waste-reduction principles of Lean methodology and defect-reduction concepts of Six Sigma (Sony & Naik, 2019). This concept has been prime mover among the contemporary improvement methodologies applied in Industries for last three decades. However, with the introduction of the Industry 4.0 elements in last decade, concepts of achieving improvements and sustaining those in the industry have graduated to next level of perfection. The elements of Industry 4.0, such as Internet of things (IoT), Big data Analysis, Artificial Intelligence (AI), and Cyber-Physical Systems (CPS), offer unrepresented newer opportunities and related challenges that provide organizations opportunities for performance optimization and every level of operations.

The so-called fourth industrial revolution, the industry 4.0 in popular jargon, offers a north-south paradigm shift that help organizations adopt smart manufacturing and digital transformations. With support of interconnected systems, intelligent automation, along with real-time data, the industrial processes become more flexible, fast responsive and efficient. When the elements of Industry 4.0 are integrated with lean Six Sigma methodologies, together they can enhance the traditional effectiveness of the organizational improvement initiatives, which may lead to substantial gains in productivity, product quality and overall organizational performance.

Though this integrated approach offers host of benefits, this is still an emerging field. There has been limited research exploring the impact of this concept on organizational performance. The objective of this review is to explore ideas and opinions on the many ways how organizational performance KPIs, such as financial, employee, operational, environmental and innovation performances are impacted.

Objectives of this Review

While providing a simple in-depth review of the state-of-the-art in this field, this article tries to contribute on how practicing organizations can effectively implement this combined methodology and achieve a sustainable operations excellence and competitive advantage in smart and sustainable industrial era. This review also tries to dive deep into ascertaining the various ways on how the implementation of the LSSI approach brings in benefits in different key performance indicators of different functions of the organization.

Research methodology

To further strengthen the ideas propagated, only a focussed study can yield the desired results. The current work is principally conducted by exploring numerous leading journals. Various research databases like Scopus, Web of Science, Science Direct were explored.

In our literature survey, we searched for articles, book chapters, and books on issues relevant to the implementation of Lean, Six Sigma, and Industry 4.0 and their implications in research Scopus and Web of Science Data Bases were explored using the keywords, inter alia <Lean>, <Six Sigma>, <Lean Six Sigma> and <Industry 4.0>, and a combination thereof taking any two and all three keywords at a time (Fig.1). The search was not restricted to any specific industry. The research methodology is detailed in Figure 1. A systematic prior art review can help identify, select, analyze, and evaluate the literature in a particular area of research. Furthermore, the available databases were used extensively to ensure that all relevant documents are considered.

The initial search resulted in a list of 352 publications in various fields in the manufacturing and service industry. The principal objective of using different databases was to gather a high level of search clarity and select the relevant papers to be included in the subsequent analysis as we wanted to gain a broad overview of the published works of literature. However, after analysing the initial search outcomes, further shortlisting was done to accommodate only the publications that are directly dealing with the referred subject and not just make a passing comment. After this, the more relevant and recent time frame was employed. The list was restricted to publications after the year 2005 and only to all the publications that discuss and exemplify the combined effect of Lean methodology, Six Sigma ideas, and Industry 4.0 concepts. The search was further restricted from the year 2016 onwards, as the year 2016 was earmarked as a threshold year for the idea of Industry 4.0 to have got some traction. It was ensured that the keywords are explicitly mentioned in the abstract and the body of the document. In this respect, all the published literature was reviewed and considered for the present work. Finally, 1492 articles, in all segments are shortlisted.

A systematic database is prepared to capture the publishing journals, authors and their country of affiliations, methodologies followed, and key observations made. These data were further analyzed to understand their focus, implications, and contributions in the business improvement fields.

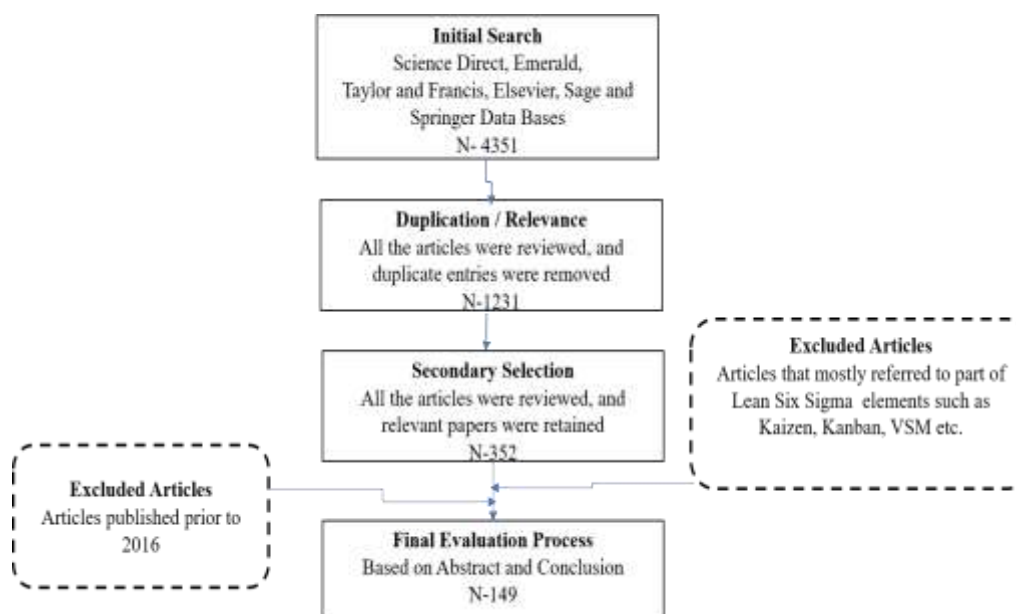


Figure 1: Methodology for Random choice of academic literature

Description of Findings

How the integrated approach benefits industry

In the light of the impact of the integrated approach, an honest endeavor is made to understand the various avenues the KPIs are dealt in Organizational performance factors such as in financial, employee, operational, environmental and innovation performances. In this section, these five departmental performances are analyzed in further detail.

Financial performance

The combination (LSSI) of the elements of Industry 4.0 (I4.0) and the Lean Six Sigma (LSS) methodologies is found to have significantly enhanced the financial performance of various practicing industries (Table 1). Studies conducted by Tortorella et al. (2019, 2020) shows how the elements of I4.0, such as IoT and Big Data Analysis, integrated with LSS

significantly contribute to the a0 product and process cost reductions, b) increased profitability and c) improved Return on Investment (ROI) (Sader, et al., 2021).

The adoption of these technologies helps the organizations monitor process data on real-time, make decisions reasoned with data. These lead to more efficient use of current resources leading to reduced operations costs.

Table 1 : Key publications with LSSI implementation and impact on financial performances

Reference	Title	Key Points
Sharma, M., Kamble, S. S., Gunasekaran, A., & Kumar, V. (2020).	"A systematic literature review on machine learning applications for sustainable agriculture supply chain performance"	Highlights the financial benefits of integrating Lean Six Sigma with Industry 4.0 technologies in supply chain management, including cost reduction and revenue growth.
Tortorella, G. L., & Fettermann, D. C. (2018).	"Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies"	Discusses the financial impact of implementing Lean Six Sigma and Industry 4.0, noting significant cost savings and increased profitability in Brazilian manufacturing companies.
Sony, M., & Naik, S. (2019).	"Ten lessons for managers while implementing Industry 4.0"	Provides insights into the financial performance improvements achieved by combining Lean Six Sigma methodologies with Industry 4.0 technologies, emphasizing ROI and cost efficiency.

How the Financial KPIs are achieved

This synergy of the LSSI implementation leverages advanced technologies to a) optimize processes, b) reduce costs, and c) increase profitability. Here are some key ways in which this integration boosts financial performance:

The LSSI implementation essentially help in a) Cost Reduction and Efficiency Gains, b) Enhanced Productivity, c) Improved Decision-Making, d) Increased Revenue and Market Share, and e) Return on Investment (ROI). These are the five key indicators which are realized while achieving a positive impact on the organization's financial performance (Fig.2).

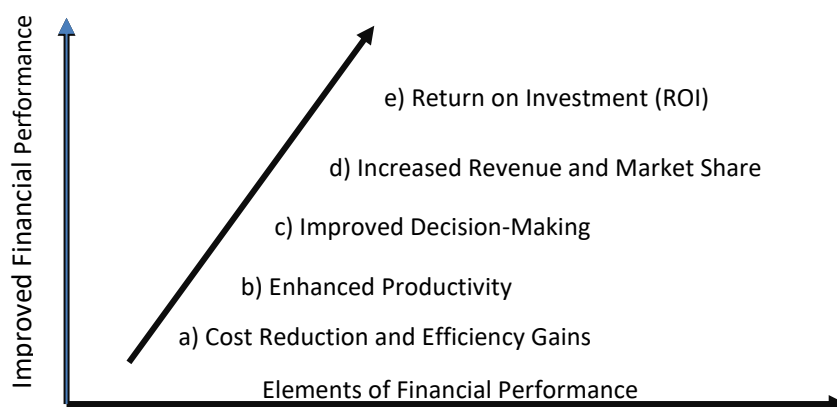


Figure 2 Schematic representing how the Improved Financial Performances are achieved.

Usually, when LSS projects are executed by applying Industry 4.0 technologies strategically, there is a high return on investment (ROI). In the beginning, huge investments in smart technologies may appear very demanding in terms of capital but later they pay back through significant long-term savings and performance. Research indicates that companies using these integrated approaches have shorter payback periods and high returns on their investments in technology

Operational Performance

The objectives of the Lean Six Sigma in industry are primarily to improve operational performance. Elements of Industry 4.0 further enhances these benefits (Table 2). Sony and Naik (2020) has shown that when organizations embrace smart manufacturing technologies, they streamline the production process, which in turn reduces cycle times, and reduce product and process defects. Similarly, combinations of elements such as CyberPhysical Systems (CPS) and Artificial Intelligence (AI) in manufacturing practices helps organizations take full control of their predictive maintenance schedule

of plant and machinery and better-quality control of their processes. Beside helping in these fundamental LSS processes, these new age technologies provide process transparency and better control over the daily operations, which result in enhanced key productivity indicators (Santos, et al. 2019).

Table 2 : Key publications with LSSI implementation and impact on operational performances

Reference	Title	Key Points
Sharma, M., Kamble, S. S., Gunasekaran, A., & Kumar, V. (2020).	"A systematic literature review on machine learning applications for sustainable agriculture supply chain performance"	Discusses the integration of Lean Six Sigma with Industry 4.0 technologies in improving supply chain performance, highlighting sustainability and efficiency gains.
Tortorella, G. L., & Fettermann, D. C. (2018).	"Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies"	Examines the combined implementation of Lean Six Sigma and Industry 4.0 in Brazilian manufacturing companies, noting significant improvements in operational performance and quality.
Sony, M., & Naik, S. (2019).	"Ten lessons for managers while implementing Industry 4.0"	Provides insights into how Lean Six Sigma methodologies can be integrated with Industry 4.0 technologies to enhance overall organizational performance, with a focus on practical lessons for managers.

How the Operational KPIs are achieved

The operational efficiency of an organization can be improved significantly by blending Lean Six Sigma methodologies and Industry 4.0 technologies. These sustainable technologies are used to simplify procedures, reduce wastage and enhance effectiveness resulting in a more agile and flexible business climate.

The LSSI implementation essentially help in a) Real-Time Data and Analytics, b) Enhanced Process Control, c) Enhanced Process Control, d) Improved Supply Chain Management, and e) Enhanced Collaboration and Communication. These are the five key indicators which are realized while achieving a positive impact on the organization's operational performance (Fig.3).

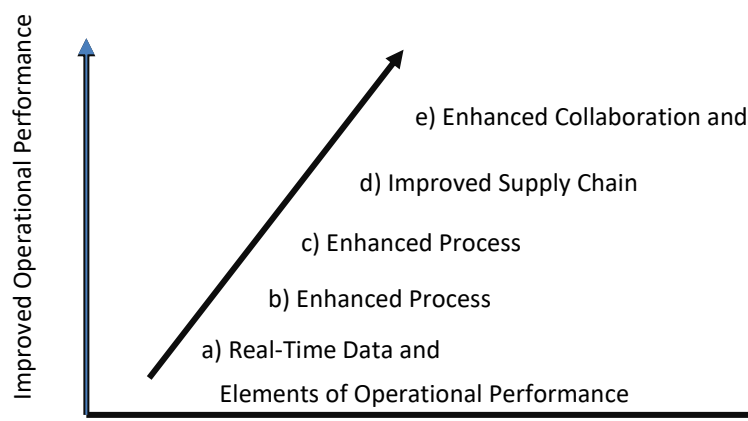


Figure 3 Schematic representing how the Improved Operational Performances are achieved.

Industry 4.0 technologies enhance better collaboration and communication among different organizational levels and functions. Cloud-based platforms and digital twin technologies, for instance, will allow the seamless sharing of information and insights that enables continuous improvement culture while responding to operating issues more quickly.

Environmental Performance

Another performance factor revolves around environment and it has gained critical importance owing to its overarching impact on the global health (Table 3). Studies conducted by Kamble et al. (2020) show that the integrated LSSI approach helps organizations achieve their environmental management and related sustenance goals by primarily reducing process wastes and improving the resource utilization efficiency. In this context, advanced data analytics and IoT elements helps organizations monitor environmental data in real-time and thereby reduce energy consumption and emissions. The elements of the integrated approach also help develop eco-friendly processes and products, which in turn help lower overall environmental footprint.

Table 3 Key publications dealing with LSSI implementation and impact on Environmental performances

Reference	Title	Key Points
Jabbour, C. J. C., Jabbour, A. B. L. d. S., Godinho Filho, M., & Roubaud, D. (2018).	"Industry 4.0 and the circular economy: a proposed research agenda and original roadmap for sustainable operations"	Explores how Industry 4.0 technologies can enhance environmental performance through the circular economy by reducing waste, improving resource efficiency, and promoting sustainable practices.
Cherrafi, A., Elfezazi, S., Garza-Reyes, J. A., Benhida, K., & Mokhlis, A. (2017).	"Barriers in Green Lean implementation: A combined systematic literature review and interpretive structural modelling approach"	Discusses the integration of Lean Six Sigma and green practices, highlighting the positive impact on environmental performance by reducing emissions, waste, and resource consumption.
Duarte, S., & Cruz-Machado, V. (2019).	"Exploring linkages between lean and green supply chain and the Industry 4.0"	Investigates how the combination of Lean Six Sigma and Industry 4.0 technologies can improve environmental performance by optimizing processes, minimizing waste, and enhancing energy efficiency.

How the Environmental KPIs are achieved

The implementation of the combination enables more efficient resource utilization, reduced waste, and improved sustainability practices. Here are some key ways in which this integration impacts environmental performance. The LSSI implementation essentially help in a) Resource Efficiency improvement through Waste Reduction, b) Energy Management, c) Sustainable Supply Chain Management, d) Emissions Reduction, and e) Circular Economy Practices in the practicing organization ((Fig.4).

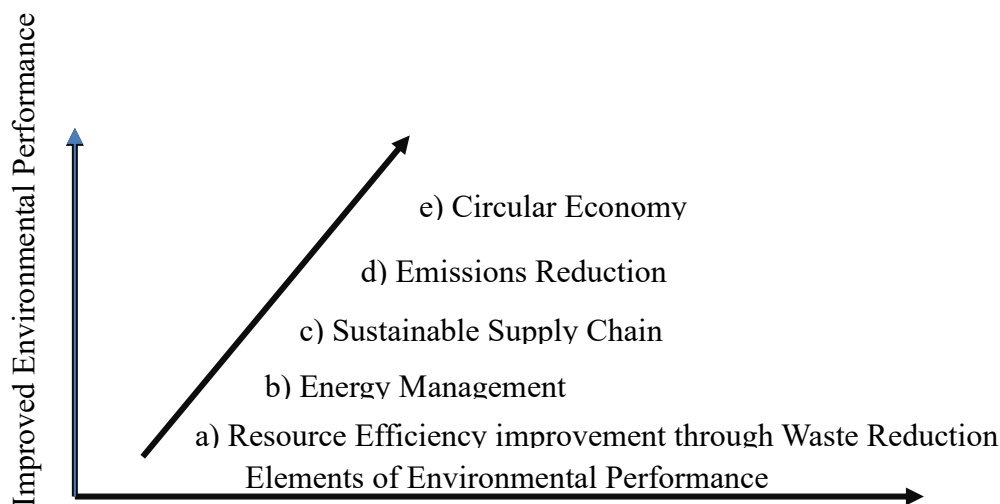


Figure 4 : Schematic representing how the Improved Environmental Performances are achieved.

Circular economy practices can be supported by the combination of Industry 4.0 and Lean Six Sigma. Enhanced data analytics and intelligent manufacturing technology are essential to follow product life cycles and make recycling, remanufacturing, and material reusing possible. This minimizes waste in organizations while encouraging sustainable production practices.

Employee Performance

There is also a multifaceted benefit results from positive impact of the integrated approach on employee performance. According to the research by Buer et al. (2018), the implementation of the integrated approach supports development of a conducive culture of organization-wide continuous improvement and innovation among employees (Table 4). The most prominent impact comes from the reduction repetitive tasks by use of collaborative robots (cobots) and AI driven mechatronics process equipment. The relief from the boring repetitive tasks makes the intellectual human resources free to focus on value-adding activities. In addition, the well-designed training programs for new technology and processes help employees enhance their skills and higher task engagement, leading to higher productivity and job satisfaction.

Table 4: Key publications dealing with LSSI implementation and impact on employee performances

Reference	Title	Key Points
Bortolotti, T., Boscari, S., & Danese, P. (2015).	"Successful lean implementation: & Organizational culture and soft lean practices"	Explores how Lean Six Sigma practices, when integrated with supportive organizational culture, improve employee performance through enhanced engagement, skill development, and teamwork.
Sony, M., & Naik, S. (2020).	"Industry 4.0 integration with socio-technical systems theory: A systematic review and proposed theoretical model"	Discusses the impact of Industry 4.0 technologies on employee performance, highlighting improvements in productivity, job satisfaction, and the development of new competencies.
Ciano, M. P., Pozzi, R., Rossi, T., & Sianesi, A. (2021).	"Lean and Industry 4.0: A comprehensive review"	Examines how the integration of Lean Six Sigma with Industry 4.0 technologies enhances employee performance by streamlining workflows, reducing repetitive tasks, and fostering a more innovative work environment.

How the Employee KPIs are achieved

This synergy of the implementation of the integrated approach helps organizations with more efficient, innovative, and motivated workforce. Here are some key ways in which this integration improves employee performance. The LSSI implementation essentially help in a) Enhanced Skill Development and Training, b) Improved Decision-Making Capabilities, c) Increased Job Satisfaction and Engagement, and d) Enhanced Collaboration and Communication in the practicing organization (Fig.5).

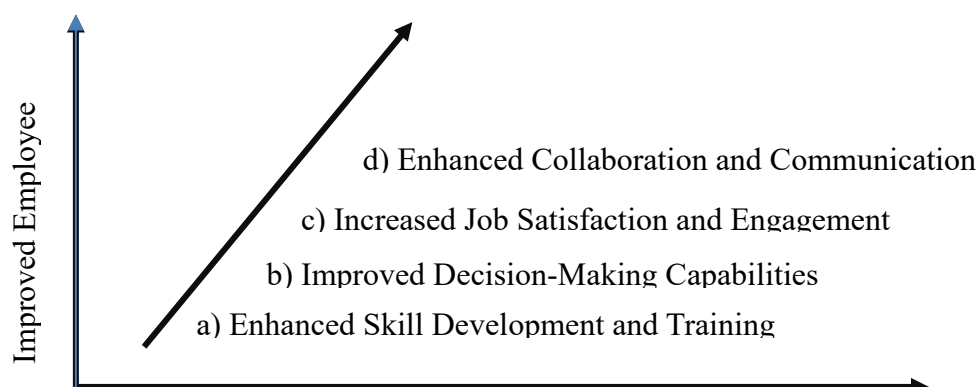


Figure 5 Schematic representing how the Improved Employee Performances are achieved.

It is noted that advanced communication tools of the integrated approach can facilitate better collaboration among employees. This helps is effective communication and team work, which are essential for achieving the overall performance.

Innovation Performance

Yet another important benefit results in improvement in innovation performance. The integrated approach manifests in multiple ways to accrue benefits in the field of innovation. Studies by Muller et al. (2020) indicate that use of Industry 4.0 elements such as Big Data Analysis and AI help practitioners develop new products and processes faster (Table 5). The structured approach embedded in Lean Six Sigma creates an atmosphere for problem-solving, creates a predictive capability, and accelerates the entire innovation cycle (Dalenogare, et al., 2018. The synergy thus achieved helps in generating novel solutions in products and processes to meet the constantly changing market demands more effectively.

Table 5 Key publications dealing with LSSI implementation and impact on innovation performances

Reference	Title	Key Points
Sony, M., & Naik, S. (2019).	"Ten lessons for managers while implementing Industry 4.0"	Examines the role of Industry 4.0 in fostering innovation, highlighting how digital technologies and smart manufacturing can drive new product development and process innovation.

Salah, S., Rahim, A., & Carretero, J. A. (2010).	Explores how the integration of Lean Six Sigma methodologies can enhance innovation performance by improving processes and fostering a culture of continuous improvement and creativity.
Dombrowski, U., Richter, T., & Krenkel, P. (2017).	Investigates how combining Lean principles with Industry 4.0 technologies can lead to innovative solutions in manufacturing processes, driving product and process innovation.

How the Innovation KPIs are achieved

This implementation of the integrate approach helps organizations achieve a culture of continuous improvement and technological advancement. This leads to increased innovation outputs across the organization. Here are some key ways in which this combination improves innovation performance.

The LSSI implementation essentially help in a) Enhanced Data-Driven Innovation, b) Fostering a Culture of Continuous Improvement, c) Accelerating Product Development Cycles, and d) Encouraging Collaborative Innovation in the practicing organization (Fig. 6).

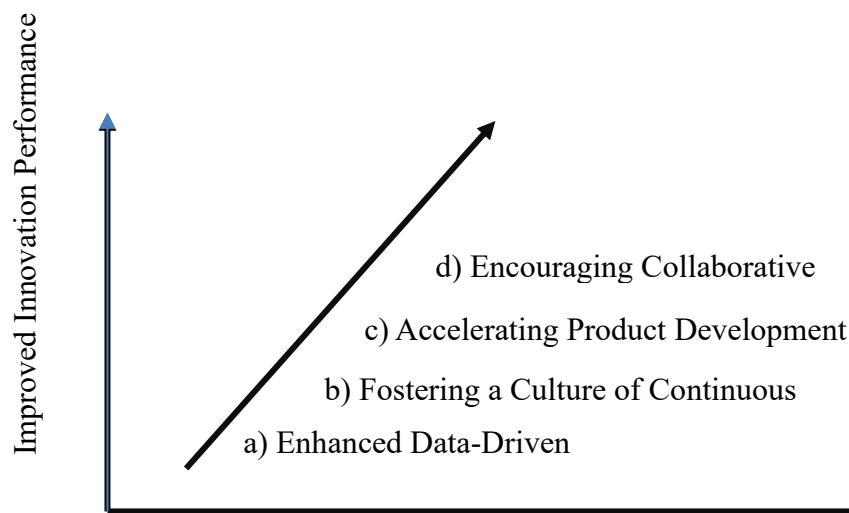


Figure 6 Schematic representing how the Improved Innovation Performances are achieved.

It is noted that advanced communication and collaboration tools are enabled in the integrated approach. This facilitates better collaboration among cross-functional teams. The emphasis on team work and collaborative problem solving enhances this approach. This leads to more effective innovation process.

Conclusion

The prior research highlighting the positive impacts of Industry 4.0 integrated Lean Six Sigma methodology shows that the synergy is multifaceted. These are multi-dimensional and gains can be witnessed in financial profits, operational efficiencies, environmental sustainability, employee performance and augmented innovation capabilities. These key findings provide a robust foundation for empirical studies and strategy based practical implementation in organizations. Therefore, it can be well concluded that these approach will be able to guide organizations towards better market oriented competitive advantage and sustainable business excellence.

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