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Prioritizing the Solutions to Overcome Lean Six Sigma 4.0 Challenges in SMEs: A Contemporary Research Framework to Enhance Business Operations

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Abstract: The research aims to prioritize the solutions to overcome the challenges of Lean Six Sigma 4.0 (LSS 4.0). It is an integrated approach with lean, six sigma, and Industry 4.0 attributes. This integrated approach helps to achieve organizational excellence and sustainable development goals. Fuzzy stepwise weight assessment ratio analysis (fuzzy-SWARA) was used to estimate the weights of LSS 4.0 challenges. Furthermore, fuzzy-weighted aggregated sum product assessment (fuzzy-WASPAS) was used to prioritize the LSS 4.0 solutions. In this study, 23 challenges and 23 solutions of LSS 4.0 implementation were identified with the help of an extensive literature review and discussion with the area experts having vast experience. Management participation in LSS 4.0 implementation and planning for long-term vision were found to be the topmost solutions to overcome LSS 4.0 challenges. To the best of our knowledge, to date, the prioritization of solutions to overcome the challenges of LSS 4.0 have not yet been investigated in the developing economic context.

Keywords: Lean Six Sigma (LSS 4.0); quality; customer satisfaction; Lean Six Sigma (LSS); Fuzzy-WASPAS; Fuzzy-SWARA

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1. Introduction

There has been a tremendous increase in competition in the last few decades. The applications of big data analytics and artificial intelligence have increased organizational performance [1]. To stay competitive, businesses must satisfy dynamic customer demand patterns and provide high-quality products at competitive prices. However, industries are confronted with various issues due to the complexity of operations. The significant way to stay competitive is to increase productivity by the optimum utilization of resources and minimizing waste and faults in products and processes [2]. So, lean six sigma 4.0 is a pivotal methodology to meet dynamic customer needs [3]. Industries face various hardships to survive in today's globalized landscape. Therefore, industries are continuously focused on improving their processes [4]. Vacillated customer demands for high-quality products at a reasonable cost in a short time have forced the industry to adopt the latest tools and state-of-the-art facilities in the manufacturing system. After three marked revolutionary stages, the manufacturing era is going through the fourth industrial revolution, which has been found to give magnificent benefits in terms of financial and operational performance. It entails using technologies such as the Internet of Things (IoT), Cyber–Physical Systems (CPS), Cloud computing, Big data analytics, Augmented reality, etc. Scholarly literature [5,6] reveals that lean six Sigma (LSS 4.0) results in increased customer satisfaction, high quality, reduced cost, faster delivery, and much more. Implementing LSS 4.0 provides industries a competitive edge to excel in the marketplace [1–3].

Furthermore, past research studies reveal that the performance of the organizations is directly proportional to the effectiveness of the manufacturing system [4]. The advent of digital technologies has led to the fourth revolution of Lean Six Sigma [2]. Over-Production, Waiting, Non-Utilized Talent, Transportation, Inventory, Motion, and Extra-Processing are among the eight types of waste that can be eliminated using a combination of lean manufacturing and Six Sigma [5]. Since traditional methods cannot deal effectively with the introduction of vast amounts of data, Industry 4.0 technologies are coming up with innovative solutions to address these concerns [6]. Lean Six Sigma combines two continuous improvement techniques, Lean and Six Sigma, being focused on decreasing waste and variation in processes [7–9]. Furthermore, lean six sigma-integrated Industry 4.0 gives magnificent benefits [10,11]. However, many businesses are still having difficulty implementing LSS 4.0 successfully. As a result, the primary goal of this research is to identify LSS 4.0 challenges and solutions and prioritize remedies utilizing the fuzzy-SWARA and fuzzy-WASPAS approach.

Lean Six Sigma is a methodology that combines the principles of Lean and Six Sigma to improve the efficiency and effectiveness of processes. Industry 4.0, also known as the Fourth Industrial Revolution, is a term used to describe the integration of advanced technologies such as IoT, AI, and automation into manufacturing processes. The motivation for integrating Lean Six Sigma with Industry 4.0 is to achieve even greater efficiency and quality in manufacturing processes through these advanced technologies. This integration can reduce waste, increase productivity, and improve overall performance in manufacturing operations.

A literature study and expert comments indicate that only a few studies are available dealing with lean six sigma and I4.0 integration [12]. Moreover, it is exceedingly difficult for practitioners to overcome these challenges simultaneously. In this case, a strategic approach would be to rank these challenges in order of priority and propose remedies using a hybrid framework. Individual challenges have varying degrees of relevance, depending on the organization's nature, kind, and preferences. This also applies to solutions for overcoming LSS 4.0 challenges, which should be offered and ranked carefully. Indeed, it would be great if both challenges and solutions can be managed through a structured approach. Therefore, the objectives of the research are presented as follows:

- To explore the challenges of LSS 4.0 in Indian SMEs.
- To rank the solutions of LSS 4.0 that may be used as a benchmark for its effective implementation.

The remaining sections of the research paper are as follows: A literature review is described in Section 2. The research methodology is mentioned in Section 3. After that, an application is discussed in Section 4. The penultimate section illustrates discussion and managerial implications. Finally, the conclusion and scope for future work are described in the concluding paragraph.

2. Literature Review

2.1. Lean Six Sigma

Integrating lean and six sigma is one way for organizations to maximize their potential. Some benefits of adopting LSS 4.0 include reduced lead time, increased flexibility, reduced errors, reduced wastages, and improved efficiency. Lean Six Sigma management has progressed to the point where they also have a much broader framework [12]. For each circumstance, its persuasive application requires social changes in organizations, new ways of dealing with customer development and adjustment, and a high degree of staff preparation and training from senior management to the line worker [13]. The LSS 4.0 measure is a comprehensive and integrated presentation of both Lean, Six Sigma, and Industry 4.0, allowing for maximum performance gains via the use of the tools as stated by [14]. LSS combines lean manufacturing with the six-sigma concept to enhance quality, decrease process variation, and eliminate non-value-added tasks. It enables every employee in a firm or factory to succeed at work. Human resources benefit from LSS assistance in increased productivity and professional performance. Employees that have taught LSS may detect and eliminate bottlenecks, waste, and process variances in a manufacturing or service system. This is accomplished through identifying and eliminating waste in the workplace.

Global executives realize that Lean Manufacturing is more than a collection of simple management tools and processes; it is a comprehensive strategy that Toyota has implemented throughout the company for long-term corporate culture and a commitment to continual improvement. Before implementing any quality improvement approach within the business, it is critical to identify any obstacles [15–17]. Inappropriate use of quality tools and techniques may become challenging for practitioners. Six Sigma's goal is to achieve "zero defect," or, in statistical words, to limit the number of faults to 3.4 per million chances [2]. As a result, combining Lean thinking with the Six Sigma technique improves both non-value-adding tasks and defect removal [8]. Even though the study focuses solely on prioritizing obstacles and solutions, an attempt was made to explore facilitators to obtain a better knowledge of LSS 4.0 ideas and associated concepts.

Many big businesses, such as American Express, Ford, DuPont, General Electric, Honeywell, and others, have reaped significant benefits from using LSS in their core operations [18]. In addition, LSS has been effectively implemented in several large businesses to improve overall productivity. Despite its enormous success in large companies, small and medium-scale industries need to be made aware of the benefits of LSS 4.0, as they are having difficulty implementing it successfully. However, due to structural, financial, and technical constraints, many businesses need help to simultaneously address a significant number of barriers. This scenario is problematic, and the deployment of lean in small businesses, such as supply chains [10], manufacturing industries [19], the textile sector [20], and higher education institutes (HEI) [21], faces substantial challenges [16]. As a result, tangible and practical solutions must be presented and prioritized to overcome these hurdles stepwise to encourage LSS 4.0 adoption in SMEs.

Indian Small and Medium Enterprises (SMEs) face several challenges when adopting Lean Six Sigma integrated with Industry 4.0. Many SMEs need to become more familiar with the concepts and principles of Lean Six Sigma and Industry 4.0 and may need to understand the potential benefits of adopting these methodologies. SMEs often need more financial and human resources for adopting advanced manufacturing technologies. Many SMEs need help finding employees with the necessary skills and training to implement and sustain Industry 4.0 technologies and techniques. The initial costs of adopting Industry 4.0 technologies can be high, which can be a barrier for SMEs with limited financial resources. SMEs often face difficulties accessing government support and subsidies for Industry 4.0 adoption. With the integration of Industry 4.0 technologies, SMEs may also meet concerns about the security of their data and intellectual property. The adoption of Industry 4.0 technologies may raise concerns about data privacy and security, which can hinder SMEs for LSS 4.0 adoption. Overall, Indian SMEs face several challenges when trying to adopt Lean Six Sigma integrated with Industry 4.0. Still, with the proper support and systematic implementation, SMEs can overcome these challenges and benefit from the increased efficiency and productivity that these methodologies can provide.

Lean Manufacturing has the potential to transform an organization on a massive scale, but it may take time to implement. The adoption of Lean Manufacturing should be properly planned, personnel must have a thorough grasp of the idea. The top management must plan and execute strategically while keeping people engaged. Based on their investigations in various settings and working situations, researchers offer several ways to overcome LSS 4.0 obstacles. Tables 1 and 2 list the LSS 4.0 challenges and solutions identified through an extensive literature review [22]. Management commitment to LSS adoption is critical for managing resources and developing procedures for LSS project implementation [23]. Setting up an LSS 4.0 dashboard at work allows operators and managers to keep track of current operations, decrease non-value-added (NVA) activities, and focus on bottlenecks in real-time [24]. Incorporating LSS 4.0 improves the operational process in coordination with vendors at both the input and output phases, which is critical to the overall structure [25]. Employee engagement in the implementation process is crucial to the LSS 4.0 implementation's success. Focusing solely on tools and procedures while disregarding the human aspect is one of the most well-known causes of the failure of LSS 4.0 adoption. Staff and top management awareness and a defined implementation plan are necessary for a successful LSS 4.0 deployment. Management involvement in LSS 4.0 implementation aids in the provision of project resources, reducing implementation time [16].

Table 1. Challenges of implementing LSS 4.0.

S. No.	Challenges in Implementation of Lean Six Sigma 4.0	References
C1	Lack of long-term strategic vision and mission	[26–39]
C2	Lack of communication	[40–42]
C3	Lack of training and educational programs	[37–39,43]
C4	Lack of knowledge about benefits of LSS 4.0	[2,10,44]
C5	Cultural barriers	[22,39,45,46]
C6	Employee resistance to adopting advanced technologies	[23,24]
C7	Lack of top management and associated leadership skills	[26,37,47]
C8	Lack of optimum utilization of resources	[35,37]
C9	Lack of proper data collection strategies	[30,34]
C10	Lack of IT infrastructure	[18,21,24]
C11	Wrong tool selection for LSS strategies	[9,14,18]
C12	Deficiency of collaboration among stakeholders	[10,14,18]
C13	Lack of consultants in the field	[7,10,48]
C14	Lack of motivation	[12,23]
C15	Lack of empowerment and process thinking capabilities	[15,19,49]
C16	Lack of estimation of execution cost	[18,22]
C17	Ineffective roadmap for implementation	[25,37]
C18	Lack of knowledge of LSS 4.0 tools	[23,29]
C19	Poor organizational capabilities	[27,40,44]
C20	Lack of performance measurement system	[50,51]
C21	Conflicts among cross-functional teams	[47,52]
C22	Wrong perception of LSS 4.0 as a technique, tool, or practice	[39,51,53]
C23	High implementation cost	[40,54]

Table 2. Solutions to overcome LSS 4.0 challenges.

S.No.	Solutions to Overcome Lean Six Sigma Challenges	References
S1	LSS 4.0 project tracking and assessment	[2,11]
S2	Formation of team of experts with a project leader	[15,18,35]
S3	Mutual knowledge sharing and continuous improvement culture	[30,32,39,55]
S4	Developing strong project management skills	[1,19]
S5	LSS 4.0 training and educational programs	[4,26,31,41]
S6	Use of dedicated information technology facilities	[21,48]
S7	Planning and long-term vision	[35,41,52]
S8	Development of strong quality assurance system	[48,53]

Table 2. *Cont.*

S.No.	Solutions to Overcome Lean Six Sigma Challenges	References
S9	Strong data analytics capabilities	[45,49]
S10	Alignment of LSS 4.0 objectives with strategic goals	[28,38,46]
S11	Create LSS4.0 dashboard	[19,24,38]
S12	Providing sufficient time for transformation	[25,29,47]
S13	Management participation in LSS 4.0 implementation	[17,20,29]
S14	Strong communication network for change progress	[39,48]
S15	Dedicated long-term planning of goals	[27,37,44]
S16	Establishing supportive organizational culture	[28,41]
S17	Applying change management strategies	[47,55]
S18	Top management awareness regarding LSS 4.0 benefits	[37,56]
S19	Optimum utilization of resources	[27,41,47]
S20	Increase employee participation	[50,51,57]
S21	Uniformity of work methods	[57,58]
S22	Developing project management skills	[34,44,47]
S23	Strong cooperation among stakeholders	[41,53]

Furthermore, information technology is required for data sharing and transfer [26]. The team's ability to take action is aided by the availability of funds and the conduct of training and educational programs [27]. When LSS is combined with Industry 4.0, excellent relationships with suppliers can be developed, which is critical for developing process planning [6].

2.2. Industry 4.0

Customers' demand for high-quality products at a reasonable cost has forced industries to adopt state-of-art technologies such as robotics, automation, 3D printing, artificial intelligence, machine learning, etc., and cope with changing market conditions [28,29]. The industries that kept themselves up-to-date stayed competitive in the market; other industries have lagged. The industrial processes need to be restructured, redesigned, and reoriented to survive in the marketplace. Producing high-quality products to customers at economical prices is the key to success in modern industry scenarios [30]. Until 2011, the manufacturing era has gone through three marked revolutionary phases with significant technological improvement. In the last decade, the concept of industry 4.0 was coined in Germany through the collaboration of industries and universities. Industry 4.0 is analyzed as a key strategy by researchers and industrialists to meet customized customer requirements, reduce wastage, achieve sustainability, attain a circular economy and operational excellence, etc. [31–33]. Many researchers all over the globe have exemplified the concepts involved in Industry 4.0 and eradicated vagueness. At present, the manufacturing era is transitioning from Industry 3.0 to Industry 4.0. The authors in [34] described how industrial revolutions emerged from Industry 2.0 to Industry 4.0. The vitality of Industry 4.0 has widened exponentially since its inception. According to [35,36], Industry 4.0 entails the use of technologies such as Cyber–Physical Systems (CPS), Cloud computing, Big data analytics, Augmented reality, Virtual reality, etc.

2.3. Integrating Lean Six Sigma and Industry 4.0

Integrating Lean Six sigma with Industry 4.0 impacts organizational excellence [2]. Market dynamics and globalization trends have urged industries to be agile, flexible, resilient, and responsive to uphold the competition. Therefore, the need for an hour to adopt digital technologies provides organizations with a competitive edge. Lean six sigma methodology is reported as a pivotal approach to dealing with complexities and helps drastically in process improvement. Incorporating Industry 4.0 technologies with LSS helps organizations forecast future demands, prospective wastages, and variations, more precisely, thereby enhancing organizational performance. On the other facets, as reported in the scholarly literature, Industry 4.0 technologies are cost extensive and complex in operations [36]. Therefore, it is imperative to reduce running costs, and wastage, so lean automation is required.

2.4. Research Gaps

It is identified that, to date, the LSS 4.0 challenges have yet to be investigated. Various research databases, such as Scopus, Science Direct, and Web of Science, were explored. The names of some of the journals explored include the *Journal of Cleaner Production*, *International Journal of Lean Six Sigma*, *Total Quality Management and Business Excellence*, *The International Journal of Production Economics*, *The TQM Journal*, *Industrial Management*, and *Data Systems*, etc. The current study is unique in identifying and ranking the hurdles for LSS 4.0 adoption in Indian SMEs. Prior research studies have not yet examined LSS 4.0 challenges and solutions simultaneously. The proposed study ranks the challenges and solutions using the fuzzy-SWARA and fuzzy-WASPAS technique, which focuses on hierarchy for assigning the rank to overcome challenges for effective implementation of LSS 4.0.

After analyzing the scholarly literature available to date, the following pivotal points were observed:

- It is found through the scholarly literature that although a lot of literature is available in the context of lean, six sigma, lean six sigma, and Industry 4.0, literature in the context of Lean Six Sigma 4.0 needs to be explored.
- Moreover, the present research studies have yet to identify the solutions to overcome Lean Six Sigma 4.0 challenges.
- Prioritization of solutions to overcome the LSS 4.0 challenges is not available using any mathematical modeling approach.

The research gaps identified above allow for analysis of the challenges and solutions of LSS 4.0. It is worth noting that majorly scholarly literature focuses solely on the LSS 4.0 challenges, only a few studies provided strategies for overcoming these obstacles. The lack of connections between LSS 4.0 obstacles and solutions has been identified as a significant gap. Some researchers have investigated a list of challenges in the pathway of LSS 4.0 adoption. However, to the best of the authors' knowledge, no study has examined the relationship between challenges and solutions of LSS 4.0 utilizing a hybrid method.

3. Research Methodology

In 2013, a novel hybrid methodology (SWARA-WASPAS) was first initiated for developing a site for constructing a shopping mall [59]. The suggested integrated fuzzy-SWARA and fuzzy-WASPAS technique is comprehensive as it relies on the respondent's awareness for establishing the relative importance of identified parameters. It also allows for the efficient and effective prioritization of alternatives to solve problems. Therefore, this study combines fuzzy-SWARA and fuzzy-WASPAS algorithms to create a hybrid Group Decision Making strategy. In the present research, fuzzy-SWARA was used to calculate the weights of identified challenges, followed by ranking the solutions using the fuzzy-WASPAS approach. The research methodology is explained in Figure 1.

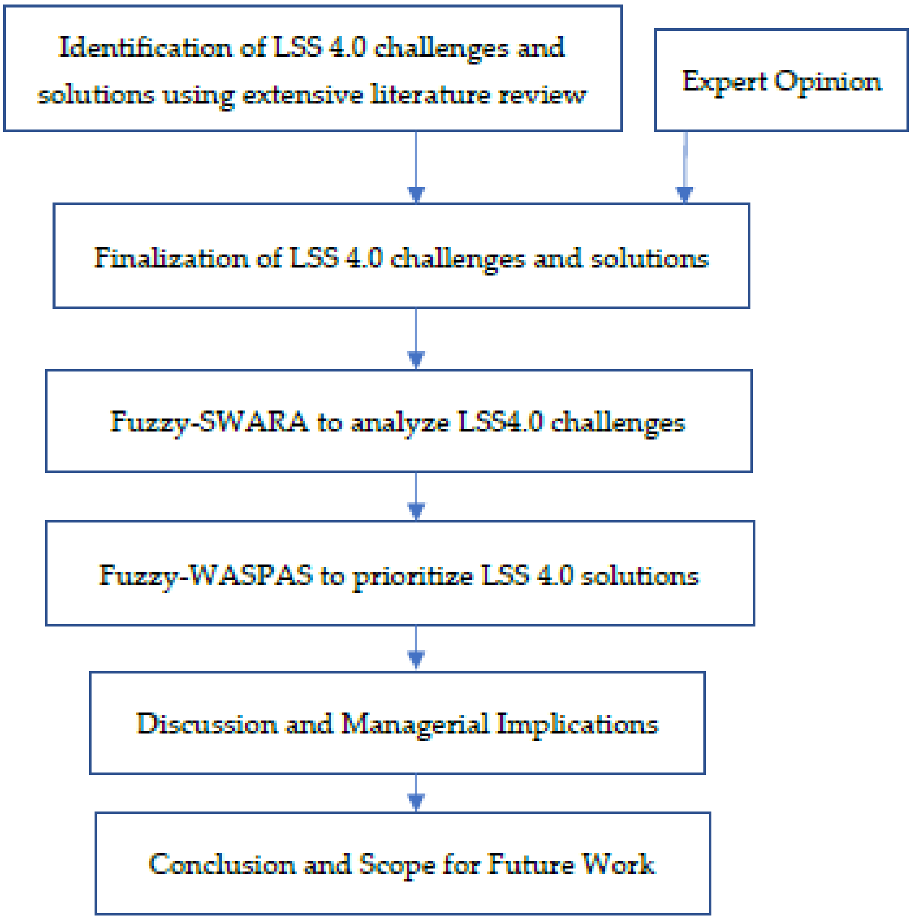

Figure 1. Research Methodology.

The following three phases were used in the proposed integrated fuzzy SWARA–fuzzy WASPAS framework for evaluating and prioritizing the solutions to overcome these Lean Six Sigma 4.0 challenges.

Phase 1: LSS 4.0 Challenges and Solutions were Identified

LSS4.0 challenges and solutions are discovered in the first phase based on a literature study and expert views. Members of different specializations form the decision-making group. The group verified the LSS 4.0 challenges and solutions to overcome them. This research resulted in the identification of 23 LSS 4.0 challenges and 23 solutions.

Phase 2: Using fuzzy-SWARA to calculate the weight of LSS4.0 challenges

The weight of LSS 4.0 challenges was computed in the second phase using fuzzy-SWARA. The expert panel first arranged the LSS 4.0 challenges according to their decreasing relevance in this approach (i.e., starting with the most significant LSS 4.0 challenge and working down to the least essential challenge). Individual LSS 4.0 challenges weights are then computed using standard steps, as explained in Section 3.1.

Phase 3: Using fuzzy-WASPAS to rank the solutions for overcoming LSS4.0 challenges

In the third step, fuzzy-WASPAS is used to prioritize the solutions for overcoming LSS4.0 challenges based on the LSS 4.0 weights collected in phase II. Individual solutions are evaluated by an expert panel utilizing a fuzzy scale, and an evaluation matrix is built using the steps stated in Section 3.2.

3.1. Fuzzy-SWARA

In 2010, a fuzzy step-wise weight assessment ratio analysis (SWARA) was presented. The SWARA technique has the benefit of requiring fewer comparisons than the AHP method, which is equal to n. The number of iterations in AHP is n ($n - 1$), where n represents several criteria. The following are the stages involved in using fuzzy-SWARA.

Step 1: The challenges are listed in descending order of significance based on the expert's judgment. Due to the ambiguity of the choice issues, a triangular fuzzy evaluation scale was utilized, as illustrated in Table 3.

Table 3. Linguistic term and corresponding triangular fuzzy number.

Linguistic Term	Triangular Fuzzy Number
Very Less Important	(0, 0, 0.1)
Less Important	(0, 0.1, 0.3)
Not Important	(0.1, 0.3, 0.5)
Fairly Important	(0.3, 0.5, 0.7)
Important	(0.5, 0.7, 0.9)
High Important	(0.7, 0.9, 1)
Very High Important	(0.9, 1, 1)

Step 2: Starting with the second indication, area specialists provide linguistic terms to every challenge j based on relative importance to the (j − 1) challenge. This is also known as "average value comparative importance".

Step 3: Estimate the fuzzy coefficient, $\hat{k}_a$

$$\hat{k}_a = \begin{Bmatrix} 1 & a = 1 \\ \hat{S}_a + 1 & a > 1 \end{Bmatrix} \tag{1}$$

Step 4: Compute the fuzzy weight

$$\hat{q}_a = \begin{Bmatrix} 1 & a = 1 \\ \frac{\hat{q}_a - 1}{\hat{k}_a} & a > 1 \end{Bmatrix} \tag{2}$$

Step 5: Analyze the evaluation criteria's relative fuzzy weights.

$$\hat{w}_a = \frac{\hat{q}_a}{\sum_{a=1}^{n} \hat{q}_k} \tag{3}$$

Step 6: The relative fuzzy weights are defuzzified.

$$w_a = \frac{\hat{w}_a}{3} = \frac{(\hat{w}_{a\alpha} + \hat{w}_{a\beta} + \hat{w}_{a\gamma})}{3} \tag{4}$$

3.2. Fuzzy-WASPAS

Various studies worldwide have found that the Weighted Aggregated Sum Product Assessment (WASPAS) approach is reliable. It integrates two approaches, the weighted product model (WPM) and the weighted sum model (WSM) approaches. The estimate of different alternatives utilizing WSM in the form of decision-making criteria is one of the distinct optimality criteria used in WASPAS. Second, in the form of a multiplicative exponential, operating WPM was used. It makes easier to rank the variables with more accuracy.

Step 1: Using Triangular Fuzzy Number (TFN), create the fuzzy decision matrix.

$$X_{ab} = \begin{bmatrix} \hat{x}_{11} & \hat{x}_{12} & \ldots.. & \hat{x}_{1n} \\ \hat{x}_{21} & \hat{x}_{22} & \ldots.. & \hat{x}_{2n} \\ \ldots.. & \ldots.. & \ldots.. & \ldots.. \\ \hat{x}_{i1} & \hat{x}_{i2} & \ldots.. & \hat{x}_{in} \end{bmatrix} \quad (5)$$

Step 2: Normalization of fuzzy Decision Matrix

$$\widetilde{\hat{x}}_{ab} = \frac{\hat{x}_{ab}}{max\hat{x}_{ab}}, b = 1, \ldots\ldots\ldots, n; a = 1, \ldots\ldots\ldots, m \quad (6)$$

If the best value must be maximized,

$$\widetilde{\hat{x}}_{ab} = \frac{min\hat{x}_{ab}}{\hat{x}_{ab}}, b = 1, \ldots\ldots\ldots, n; a = 1, \ldots\ldots\ldots, m \quad (7)$$

In the event that the best value must be minimized,

Step 3: Calculate the fuzzy weighted normalized decision matrix for the summation part.

$$\widetilde{\hat{x}}_{ab,sum} = \widetilde{\hat{x}}_{ab} w_b, b = 1, \ldots\ldots\ldots, n; a = 1, \ldots\ldots\ldots, m \quad (8)$$

$$\widetilde{\hat{X}}_{a,sum} = \prod_{b=1}^{n} \widetilde{\hat{x}}_{ab,sum} \quad (9)$$

Step 4: Calculate the fuzzy weighted normalized decision matrix for the multiplication portion.

$$X_{ab,mult} = \hat{\hat{X}}_{ab}{}^{wb},\ b = 1 \ldots\ldots\ldots n,\ a = 1 \ldots\ldots\ldots..m \quad (10)$$

$$\widetilde{\hat{X}}_{a,mult} = \prod_{b=1}^{n} \widetilde{\hat{x}}_{ab,mult} \quad (11)$$

Step 5: Defuzzifying fuzzy performance measurement using the Centre of Area approach

$$Q_{a,sum} = \frac{1}{3}\left(\widetilde{\hat{X}}_a, sum\right) = \frac{1}{3}\left(\widetilde{\hat{X}}_a, sum, \alpha + \widetilde{\hat{X}}_a, sum,\ \beta + \widetilde{\hat{X}}_a, sum, \gamma\right) \quad (12)$$

$$Q_{a,mult} = \frac{1}{3}\left(\widetilde{\hat{X}}_a, mult\right) = \frac{1}{3}\left(\widetilde{\hat{X}}_a, mult, \alpha + \widetilde{\hat{X}}_a, mult, \beta + \widetilde{\hat{X}}_a, mult, \gamma\right) \quad (13)$$

Step 6: For multiplication and summation, calculate the weighted aggregate Qi.

$$Q_a = 0.5Q_{a,sum} + 0.5Q_{a,mult} a = 1, \ldots\ldots\ldots\ldots., m \quad (14)$$

Generally,

$$Q_a{}^{\lambda} = \lambda Q_{a,sum} + (1 - \lambda) Q_{a,mult} a = 1, \ldots\ldots\ldots\ldots., m \quad (15)$$

where the value of λ ranges between 0 and 1.

4. Case Illustration

This study requirement is being conducted by an auxiliary unit called ABC (name changed), which is specialized in manufacturing fasteners such as nuts and bolts. Management is persuaded toward LSS 4.0 benefits but is a little skeptical about adopting them. A total of 15 area experts of ABC manufacturing company located in the National Capital Region (NCR) of India responded to a developed questionnaire. The company pioneered producing various fasteners such as axle blots, wheel bolts, studs, flange bolts, and screws. The company has a turnover of USD 1.5 billion and has 350 employees. The profile of the experts is shown in Table 4.

Table 4. Expert's profile.

Expert	Current Position	Years of Experience	Academia/Practitioner/Consultant
EX1	CEO	35	Practitioner
EX2	Head-CSR	29	Practitioner
EX3	Project manager	27	Practitioner
EX4	Director of quality management	22	Practitioner
EX5	Lean six sigma projects leader	16	Practitioner
EX6	Head-Quality Control	23	Practitioner
EX7	Deputy General Manager	29	Practitioner
EX8	Chief manufacturing executive	22	Practitioner
EX9	Operations Head	21	Practitioner
EX10	Assistant Project manager	14	Practitioner
EX11	Design Head	22	Practitioner
EX12	Executive Design Engineer	13	Consultant
EX13	Production Manager	21	Consultant
EX14	Executive Production Manager	18	Practitioner
EX15	Senior Production Manager	20	Practitioner

A thorough study analyzed the severity of hurdles and the prioritization of identified solutions to overcome them using an integrated framework. As a result, the circumstance necessitates the determination of LSS 4.0 challenges and a set of remedies that will aid LSS 4.0 deployment. The fuzzy-SWARA–fuzzy-WAPAS framework is proposed to achieve the above goals. The research uses fuzzy-SWARA to evaluate the LSS 4.0 challenges weights, then uses fuzzy WASPAS to prioritize the solutions. As explained in the previous step, the calculations involved in fuzzy SWARA–fuzzy WASPAS are executed and shown in Tables 5–10.

Table 5. Fuzzy SWARA calculations for evaluating weights of LSS 4.0 challenges.

Challenge	Comparative Importance			Coefficient Kj = Sj + 1			Recalculated Fuzzy Weight			Relative Fuzzy Weight			Final Weight
C7				1	1	1	1	1	1	0.250	0.356	0.433	0.347
C4	0.5	0.7	0.9	1.5	1.7	1.9	0.526	0.588	0.666	0.131	0.209	0.288	0.210
C1	0.1	0.3	0.5	1.1	1.3	1.5	0.350	0.452	0.605	0.087	0.161	0.262	0.170
C17	0.5	0.7	0.9	1.5	1.7	1.9	0.184	0.266	0.403	0.046	0.094	0.175	0.105
C14	0.5	0.7	0.9	1.5	1.7	1.9	0.097	0.156	0.269	0.024	0.055	0.116	0.065
C23	0.3	0.5	0.7	1.3	1.5	1.7	0.057	0.104	0.206	0.014	0.037	0.089	0.047
C3	0.1	0.3	0.5	1.1	1.3	1.5	0.038	0.080	0.188	0.009	0.028	0.081	0.039
C18	0.5	0.7	0.9	1.5	1.7	1.9	0.020	0.047	0.125	0.005	0.016	0.054	0.025
C6	0.3	0.5	0.7	1.3	1.5	1.7	0.011	0.031	0.096	0.002	0.011	0.041	0.018
C2	0.1	0.3	0.5	1.1	1.3	1.5	0.007	0.024	0.087	0.001	0.008	0.038	0.016
C15	0.3	0.5	0.7	1.3	1.5	1.7	0.004	0.016	0.067	0.001	0.005	0.029	0.012
C10	0.1	0.3	0.5	1.1	1.3	1.5	0.003	0.012	0.061	0.000	0.004	0.026	0.010
C20	0.5	0.7	0.9	1.5	1.7	1.9	0.001	0.007	0.040	0.000	0.002	0.017	0.006

Table 5. *Cont.*

Challenge	Comparative Importance			Coefficient Kj = Sj + 1			Recalculated Fuzzy Weight			Relative Fuzzy Weight			Final Weight
C12	0.1	0.3	0.5	1.1	1.3	1.5	0.001	0.005	0.037	0.000	0.002	0.016	0.006
C5	0.3	0.5	0.7	1.3	1.5	1.7	0.000	0.003	0.028	0.000	0.001	0.012	0.004
C22	0.1	0.3	0.5	1.1	1.3	1.5	0.000	0.002	0.026	0.000	0.001	0.011	0.004
C19	0.5	0.7	0.9	1.5	1.7	1.9	0.000	0.001	0.017	0.000	0.000	0.007	0.002
C21	0.1	0.3	0.5	1.1	1.3	1.5	0.000	0.001	0.015	0.000	0.000	0.006	0.002
C11	0.3	0.5	0.7	1.3	1.5	1.7	0.000	0.000	0.012	0.000	0.000	0.005	0.001
C13	0.1	0.3	0.5	1.1	1.3	1.5	0.000	0.000	0.011	0.000	0.000	0.004	0.001
C9	0.3	0.5	0.7	1.3	1.5	1.7	0.000	0.000	0.008	0.000	0.000	0.003	0.001
C8	0.5	0.7	0.9	1.5	1.7	1.9	0.000	0.000	0.005	0.000	0.000	0.002	0.000
C16	0.3	0.5	0.7	1.3	1.5	1.7	0.000	0.000	0.004	0.000	0.000	0.001	0.000
							2.305	2.803	3.98524	0.499	0.888	1.55501	0.981

Table 6. Fuzzy WASPAS Decision Matrix.

		C1			C2		....	....		C22			C23	
S1	0.9	1	1	0.1	0.3	0.5	....	....	0.9	1	1	0.9	1	1
S2	0.3	0.5	0.7	0.1	0.3	0.5	....	....	0.1	0.3	0.5	0.3	0.5	0.7
S3	0.5	0.7	0.9	0.7	0.9	1	....	....	0.3	0.5	0.7	0.3	0.5	0.7
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
S21	0.3	0.5	0.7	0.5	0.7	0.9	....	....	0.3	0.5	0.7	0.1	0.3	0.5
S22	0.5	0.7	0.9	0.3	0.5	0.7	....	....	0.3	0.5	0.7	0.5	0.7	0.9
S23	0.3	0.5	0.7	0.3	0.5	0.7	....	....	0.3	0.5	0.7	0.3	0.5	0.7

Table 7. Fuzzy WASPAS normalized decision matrix.

		C1			C2		....	....		C22			C23	
S1	0.9	1	1	0.1	0.3	0.5	....	....	0.9	1	1	0.9	1	1
S2	0.3	0.5	0.7	0.1	0.3	0.5	....	....	0.1	0.3	0.5	0.3	0.5	0.7
S3	0.5	0.7	0.9	0.7	0.9	1	....	....	0.3	0.5	0.7	0.3	0.5	0.7
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
S21	0.3	0.5	0.7	0.5	0.7	0.9	....	....	0.3	0.5	0.7	0.1	0.3	0.5
S22	0.5	0.7	0.9	0.3	0.5	0.7	....	....	0.3	0.5	0.7	0.5	0.7	0.9
S23	0.3	0.5	0.7	0.3	0.5	0.7	....	....	0.3	0.5	0.7	0.3	0.5	0.7

Table 8. Fuzzy WASPAS weighted normalized decision matrix for summarizing part.

		C1			C2		...	...		C22			C23	
S1	0.15	0.17	0.17	0.00	0.00	0.00	...	...	0.00	0.00	0.00	0.04	0.04	0.04
S2	0.05	0.08	0.11	0.00	0.00	0.00	...	...	0.00	0.00	0.00	0.04	0.04	0.04
S3	0.08	0.11	0.15	0.01	0.01	0.01	...	...	0.00	0.00	0.00	0.04	0.04	0.04
....	....	....	....	....	....	....	...	...	....	....	....	....	....	....
....	....	....	....	....	....	....	...	...	....	....	....	....	....	....
S21	0.05	0.08	0.11	0.00	0.01	0.01	...	...	0.00	0.00	0.00	0.00	0.01	0.02
S22	0.08	0.11	0.15	0.00	0.00	0.01	...	...	0.00	0.00	0.00	0.02	0.03	0.04
S23	0.05	0.08	0.11	0.00	0.00	0.01	...	...	0.00	0.00	0.00	0.01	0.02	0.03

Table 9. Fuzzy WASPAS weighted normalized decision matrix for multiplication part.

		C1			C2		...	...		C22			C23	
S1	0.98	1.00	1.00	0.96	0.98	0.98	...	...	0.99	1.00	1.00	0.99	1.00	1.00
S2	0.81	0.88	0.94	0.96	0.98	0.98	...	...	0.99	0.99	0.99	0.99	1.00	1.00
S3	0.88	0.94	0.98	0.99	0.99	1.00	...	...	0.99	0.99	0.99	0.99	1.00	1.00
....	....	....	....	....	....	....	...	...	....	....	....	....	....	....
....	....	....	....	....	....	....	...	...	....	....	....	....	....	....
S21	0.81	0.88	0.94	0.98	0.99	0.99	...	...	0.99	0.99	0.99	0.89	0.94	0.96
S22	0.88	0.94	0.98	0.98	0.98	0.99	...	...	0.99	0.99	0.99	0.96	0.98	0.99
S23	0.81	0.88	0.94	0.98	0.98	0.99	...	...	0.99	0.99	0.99	0.94	0.96	0.98

Table 10. Fuzzy WASPAS Aggregated Matrix for prioritizing LSS 4.0 solutions.

Sol.	**Aggregate Fuzzy Summation Value**			**0.5 Qa, Sum**	**Aggregate Fuzzy Multiplication Value**			**0.5 Qa, Mult**	**Qa**	**Rank**
S1	0.365	0.531	0.706	0.353	0.000	0.000	0.552	0.276	0.298	23
S2	0.515	0.730	0.935	0.467	0.404	0.620	0.825	0.413	0.586	4
S3	0.517	0.726	0.921	0.461	0.406	0.615	0.814	0.407	0.580	5
S4	0.347	0.550	0.735	0.368	0.000	0.419	0.619	0.310	0.387	19
S5	0.546	0.743	0.905	0.453	0.397	0.612	0.791	0.396	0.575	6
S6	0.521	0.726	0.874	0.437	0.303	0.555	0.736	0.368	0.532	11
S7	0.764	0.931	1.021	0.510	0.612	0.801	0.910	0.455	0.713	2
S8	0.278	0.494	0.714	0.357	0.000	0.397	0.610	0.305	0.369	21
S9	0.536	0.721	0.872	0.436	0.339	0.568	0.747	0.374	0.541	10
S10	0.248	0.468	0.687	0.344	0.164	0.374	0.585	0.292	0.380	20
S11	0.336	0.548	0.750	0.375	0.000	0.409	0.627	0.314	0.389	18
S12	0.491	0.704	0.911	0.456	0.379	0.594	0.802	0.401	0.565	7

Table 10. *Cont.*

Sol.	Aggregate Fuzzy Summation Value			0.5 Qa, Sum	Aggregate Fuzzy Multiplication Value			0.5 Qa, Mult	Qa	Rank
S13	0.757	0.954	1.066	0.533	0.642	0.843	0.962	0.481	0.745	1
S14	0.454	0.674	0.891	0.445	0.348	0.566	0.780	0.390	0.543	9
S15	0.377	0.591	0.798	0.399	0.285	0.491	0.696	0.348	0.477	15
S16	0.334	0.554	0.773	0.387	0.222	0.443	0.659	0.330	0.442	16
S17	0.291	0.511	0.731	0.365	0.206	0.417	0.628	0.314	0.416	17
S18	0.400	0.619	0.833	0.417	0.295	0.512	0.723	0.361	0.497	13
S19	0.641	0.860	1.027	0.513	0.535	0.750	0.922	0.461	0.682	3
S20	0.478	0.677	0.851	0.426	0.334	0.549	0.738	0.369	0.525	12
S21	0.212	0.432	0.652	0.326	0.000	0.338	0.548	0.274	0.328	22
S22	0.418	0.632	0.827	0.414	0.279	0.505	0.709	0.355	0.492	14
S23	0.454	0.673	0.884	0.442	0.358	0.569	0.777	0.388	0.543	8

Sensitivity Analysis

A sensitivity analysis was performed to evaluate the robustness of alternative rankings owing to changes in criterion weights. This study looks at how the importance of LSS challenges affects the order of solutions. A total of 15 experiments are carried out in this study. Higher weights were applied to each LSS 4.0 challenge one by one in the first 13 tests, while the importance of the other LSS 4.0 challenges was kept low. For instance, in Experiment 1, challenge 'C1' was assigned a weight of 0.6, and others were held at 0.01818. Accordingly, the rating of the LSS 4.0 solutions was evaluated. S13, S7, S19, S3, and S6 are the best five solutions in this case. Similarly, in the second experiment, the weight of LSS 4.0 challenge 'C2' was set to 0.6, while others assigned 0.01818 weight. In that case, S13, S7, S3, S19, and S20 were the top five solutions for overcoming LSS4.0 challenges. In Experiment 3, LSS 4.0 challenge 'C3' was given a weight of 0.6, but the others were assigned 0.01818. In this case, S7, S13, S5, S19, and S23 were reported as the best five solutions. Similarly, Experiments 4–13 were conducted, and Figure 2 represents the results.

In Experiment 14, the weights of LSS 4.0 challenges 'C1' through 'C15' were set to 0.0666, while others were set to 0.0. In this experiment, the best five solutions to defeat LSS 4.0 challenges are S7, S13, S19, S5, and S23. Experiment 15 assigned a weight of 0.0434 to all LSS 4.0 challenges; doing a similar analysis, S13, S7, S19, S23, and S3 were found to be the top five solutions to tackle LSS 4.0 challenges in this scenario. As the weights of LSS 4.0 challenges vary, the ranks of the alternative solutions to overcome LSS 4.0 challenges change relatively little.

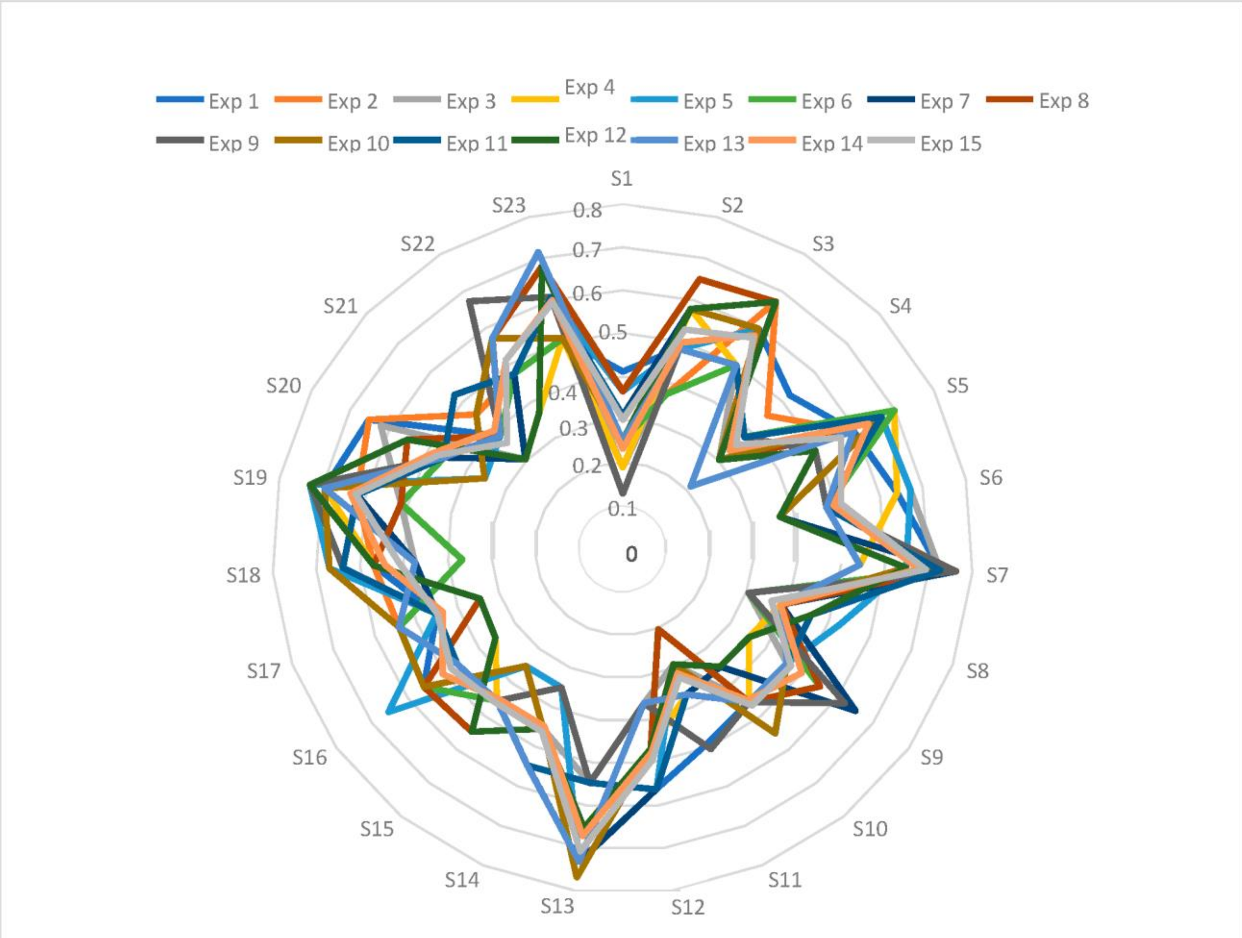

Figure 2. Sensitivity Analysis.

5. Discussion

Scholarly literature reveals that although there are many research studies available on the set of LSS challenges, there are very few studies addressing lean six sigma and Industry 4.0 integration. So, this is the first research study to prioritize LSS 4.0 solutions to overcome challenges. This research not only uses an integrated fuzzy-SWARA and fuzzy-WASPAS framework to bridge the gap between obstacles and solutions but also displays it as a reliable framework. The hybrid framework can assist in overcoming the bulk of the challenges by assessing the challenge weights by fuzzy-SWARA and then prioritizing the identified solutions using fuzzy-WASPAS. As a result, the current research is a significant addition to the literature available to date. Unused knowledge and ineffective information management were found to be new forms of wastage of LSS 4.0 [2]

The other significant finding involves exploring LSS 4.0 challenges and their solution set. This specific area of research might aid in increasing the rate of LSS 4.0 adoption in the industries due to its significant advantages. Professionals in business can use the research results to implement LSS 4.0 successfully. It has been noted that while calculating weights, researchers overlook the ambiguity of decision making. This study attempts to solve this well-known flaw. The framework's usefulness is enhanced with the inclusion of fuzzy-SWARA. It was chosen to manage a vast number of challenges with a varying range of values across each challenge because it successfully handles order preference while altering challenge weights. It indicates that by simply changing the inputs, such as the weights of challenges, the created framework helps industrial managers to showcase various topmost solutions to implement LSS 4.0 efficiently and effectively.

Based on their investigations in various settings and working situations, researchers offer several ways to overcome LSS 4.0 obstacles. Management participation in LSS 4.0 implementation (S13) is ranked first among the identified solutions. Since Industry 4.0 technologies were only introduced in the last decade, there is a crucial need to develop standard operating procedures. It will help the managers to work in the proper direction. Management decision making requires strategic planning that has a beneficial influence on operational performance, aids in developing a productive work environment, and increases the organizational structure's flexibility. Top management commitment plays a crucial role in effective LSS 4.0 implementation. Moreover, Management commitment to LSS 4.0 adoption is critical for formulating the vision and mission for LSS 4.0 project implementation. LSS is a process for eliminating wastages and reducing variations, and integrating Industry 4.0 with LSS results in the exponential growth of organizations. LSS 4.0 is believed to be a trend in today's manufacturing landscape beyond an actual process improvement technique. It is often challenging to integrate it into procedures due to a lack of leadership from senior executives. The second topmost solution is planning and long-term vision (S7). Strategic and long-term vision planning helps to achieve the set objectives through mission statements. LSS 4.0 is not the kind of process that can be implemented incautiously, it requires a long-term vision and planning from the top management to see positive results, and the organization has to make continuous efforts to improve and keep the results in check. A strategic approach and a well-mapped plan must be laid as the foundation to achieve the goals and organizational excellence.

Optimum utilization of resources is found to be the third top solution. It includes human, financial, and temporal resources. Human resources involved in these initiatives require training that ranges in intensity from individual to individual. Furthermore, an organization's resources are finite, and optimum utilization has to be a key focus while implementing LSS 4.0. Furthermore, organizations must strengthen information technology facilities. Moreover, every piece of machinery needs to be equipped with innovative and intelligent networks, so dedicated IT facilities are essential.

Furthermore, one of the significant constraints that organizations are facing in implementing LSS 4.0 is the initial resistance of the employees, which can be supported by the training of the employees and motivating them to adapt to the new and changing scenarios of their organization [58]. Usually, people are averse to changing their working styles and stepping outside their comfort zones. Thus, it becomes crucial for management to motivate and empower the employees to participate in the continuously changing process to keep up with the work demands and increase the efficiency and profits of the firm. Setting up an LSS 4.0 dashboard allows operators and managers to keep track of current operations, decrease non-value-added activities, and focus on bottlenecks.

5.1. Theoretical Implications

This study aims to address the challenges and solutions of adopting Industry 4.0 technologies, specifically in the Lean Six Sigma (LSS 4.0) area. It presents a hybrid multi-criteria decision-making framework and tests its effectiveness. The study also aims to share its findings with scholars and practitioners to improve the success rate of LSS 4.0 adoption, as it is commonly acknowledged to be low. The framework addresses the issue of prioritizing and rating solutions, as executives often face new challenges that can influence their decision-making process. The study employs a fuzzy-SWARA and fuzzy-WASPAS approach to analyze LSS 4.0 challenges using a fuzzy scale, which has proven beneficial in complex and uncertain situations.

5.2. Practical Implications

Adopting Lean Six Sigma integrated with Industry 4.0 can have several practical implications for organizations. Top management commitment is critical for implementing LSS 4.0. Top management can provide the necessary support including financial and human resources to implement and maintain advanced technologies and processes required for LSS 4.0 adoption. Moreover, top management can set a clear vision and goals for LSS 4.0 adoption, which can help to align the efforts of different departments and teams. Furthermore, top management can encourage employee involvement in the LSS 4.0 adoption process, which can help to build a sense of ownership and engagement among employees. Planning and long-term vision are crucial in successfully adopting LSS 4.0. Planning can help organizations identify improvement opportunities. Long-term vision and a clear roadmap can help organizations to plan and implement LSS 4.0 technologies and techniques in a strategic and phased manner.

6. Conclusions

The emergence of digital technologies has shown that the Lean Six Sigma 4.0 concept has a lot of relevance for organizational excellence [2]. In this study, we explored 23 challenges and 23 solutions of LSS 4.0 with the help of an extensive literature review. The area experts who have been working in the field of LSS 4.0 for a long time validated the same. An opinion form was circulated after the literature review and identified the challenges and solutions of LSS 4.0. Moreover, an opinion form contained the solutions in rows and the challenges in columns, for mapping purposes. The fuzzy-SWARA technique was used to find the weights of challenges.

Furthermore, a fuzzy-WASPAS method was used to prioritize the solutions of LSS 4.0. It was found that top management participation in the implementation of LSS4.0 was the most crucial solution. Planning with a long-term vision was examined as the second most important solution, and the optimum utilization of resources was ranked third. A sensitivity analysis analyzed the prioritization of solutions under a different set of conditions. Most of the solutions had the same ranking, and minimal deviation from the order of the solutions was observed, even after assigning additional weightage to challenges. The solutions were prioritized to help the researchers and the industry experts to have a better outlook while implementing LSS 4.0 in the industry. It was seen that management must have a long-term vision and continuous focus as LSS 4.0 implementation takes time; it is a costly affair. The other significant solution is that the organizations should use their resources optimally, may it be funds, human resources, or time. Moreover, the top management must motivate the employees to participate and learn new skills. For that, they should conduct regular training courses on the upcoming technological trends.

The customer's idea of quality is evolving as the market changes fast. It is thus a problematic scenario for producers, who must deliver the highest quality through zero faults. For an organization to implement Six Sigma, senior management engagement is critical. The organization must strive toward its goal through appropriate leadership from the top executives. The employees must learn new techniques to provide excellent service. Training, orientation, and mentoring must utilize quality-improvement techniques. This research is a modest step toward identifying and prioritizing solutions to eliminate the challenges of implementing LSS 4.0. This study can help businesses to understand the value of LSS 4.0. Prioritizing solutions can assist companies in successful LSS 4.0 implementation. The research results would benefit researchers, industrialists, policymakers, and practitioners. The solution rankings will assist organizations in adequately implementing LSS 4.0 by focusing on the prioritized solutions, leading to increased adoption success rates.

This research work has challenges looking beyond the other side of the significant benefits. The opinions of area experts developed the complete framework. As a result, any prejudice in their judgment is unavoidable and would have impacted the outcome. Other Multi-attribute decision-making techniques such as fuzzy-VIKOR and fuzzy-COPRAS may be used to order challenges and priorities for LSS 4.0 adoption. Specifically, when responses are subjective, it becomes exceedingly difficult to anticipate and quantify the issue, as some ambiguity needs to be ruled out. Fuzzy logic is a highly effective method for overcoming this vagueness-based barrier. Furthermore, the current study ranks and prioritizes solutions for LSS 4.0 adoption to overcome its hurdles using a mix of fuzzy-SWARA and fuzzy-WASPAS. In the future, inter-valued intuitionistic fuzzy sets (IVIFS) can be applied to examine unclear situations. Structural equation modeling or systems dynamics modeling also can be used to validate this paradigm statistically in a future study.

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