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*Research Article*

# A New Spherical Fuzzy LBWA-MULTIMOOSRAL Framework: Application in Evaluation of Leanness of MSMEs in India

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The present paper aims to propose a new hybrid multi-criteria decision-making (MCDM) framework with spherical fuzzy numbers (SFNs). We extend two recently developed algorithms such as level-based weight assessment (LBWA) and MULTIMOOSRAL in spherical fuzzy (SF) domain. We present a case study on six MSME units belonging to engineering cluster for examining their leanness. MSMEs form the backbone of the socioeconomic growth and therefore garner attention of the policy makers. Lean manufacturing (LM) has been a key enabler for the last three decades which help the organizations to achieve business growth. We consider the criteria like leadership, supplier focus, customer focus, process management, waste, culture, human resource focus, technology use and communication, and awareness to compare leanness of the MSMEs using expert opinions. We find that committed leadership, waste reduction, and customer value are given more weightage by the experts for achieving leanness in SMEs. Furthermore, the results show that medium and small units with focused product line score high in terms of leanness. We validate the results obtained by our proposed method by comparing with the same derived by using another widely used approach such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). We carry out sensitivity analysis for examining the stability in the solution with the changes in the given condition such as variations in the criteria weights. Our results using SF-LBWA-MULTIMOOSRAL show reasonable accuracy and stability.

## 1. Introduction

The last two decades are characterized by revolutionary progress in technology, extreme volatility and disruption, cut-throat competition, rise in knowledgeable customer base, and rapid speed of innovation. The organizations are challenged by increasing demand from the market in terms of superior quality, variety, quick response, convenience, and affordability with respect to cost [1]. As a result, the organizations have no other choice but to optimize their processes and put all efforts to deliver maximum possible value with optimum utilization of resources [2]. In other words, organizations strive to become lean. The concept of lean management and/or lean manufacturing (LM) was first defined by Krafcik [3] and later got popularized in 1990 with explanations given by Womack and his colleagues [4]. Gupta et al. [5] defined LM as "an integrated multi-dimensional approach encompassing a wide variety of management practices based on the philosophy of eliminating waste through continuous improvement." The work in [6–8] portrays the benefits of practicing the principles and tools of LM as reduction in defect rates and waste, human efforts, process hours, space requirement, and operational cost while increasing value, customer satisfaction, demand, flow of the process, and morale of the employees among others. LM paves the way to global excellence through continuous introspection and improvement for the organizations by imbibing the philosophy and implementing the concepts and tools [9]. In this regard, leanness is the extent to which the concepts and practices of LM are adapted and implemented vis-à-vis organizational goals and customers' requirement. In simple term, leanness indicates how lean is an organization [10].

In India as per the provisions of Micro, Small, and Medium Enterprises Development (MSMED) Act, 2006, the micro, small, and medium-sized enterprises (MSMEs) are defined as the organizations having investment up to 10 crores with an annual turnover ranging from 5 to 250 crores. The market size of MSMEs in India is around 6.3 crores with an increase in number by CAGR 18.5 percent in 2020 [11]. MSMEs provide foundation to the socioeconomic growth of a nation, contributing to employment generation, empower the youth and improving livelihood (especially self-help groups and women), income distribution, provide support to large-scale industries, resource mobilization, reduce regional disparity, export balancing, and accelerate social reform [12–18]. Needless to mention that for the inclusive development of the country like India, empowerment and growth of MSMEs are very important. The estimated growth of India's manufacturing sector is USD 1 trillion by 2025 wherein MSMEs play the role as one of the key enablers for fostering the promise of "Make-in-India" initiative taken by the Govt. of India (GOI). LM helps to improve the dynamic capabilities and competitiveness of the MSMEs by combating the constraints like fund, space, skill, waste, imbalanced process, manpower, maintenance, and facilities, among others [19, 20].

Therefore, from the facts and figures, it is evident that MSME sector has huge potential for the growth of India. Further, LM plays an important role in accelerating the growth of MSMEs and improving their competitiveness. Having understood the benefits and relevance of LM for MSMEs, it is quite imperative to assess the leanness of MSMEs. In this context, the present study attempts to find answers of the following research questions. (RQ1) How to measure the leanness of MSMEs? (RQ2) How to compare the competitiveness of the MSMEs from multiple perspectives? However, in this regard, we observe that the extant literature does not show adequate evidence in favour of competitive assessment of leanness of MSMEs. Our paper fills the gap to the literature by providing a framework for comparing the achievement of leanness of a group of MSMEs.

It is evident that for a holistic comparison of MSMEs in terms of their leanness, a complex multi-criteria analysis is involved. The problem can be formally expressed as

$$X = \begin{pmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{pmatrix}_{m\times n}.$$

Here, $m$ is the number of MSME units under comparison with respect to $n$ criteria that are manifesting leanness of the organization, and $x_{ij}$ is the leanness achievement of $i^{th}$ MSME unit with respect to $j^{th}$ criterion. In this paper, we present a sample case study of six MSMEs located in the eastern part of India wherein the sample units are compared on the basis of the on-field diagnostic study and opinions by a group of three experts. The dimensions or criteria for comparison are derived from literature supported by the opinions of the experts vis-à-vis RQ1. Hence, the present study calls for a complex and subjective opinion-based group decision-making approach to answer RQ2. We address this problem by carrying out our analysis in SF domain.

The concept of fuzzy sets (FSs) and fuzzy numbers (FNs) were introduced to handle impreciseness of information under uncertain and ambiguous environment by Zadeh [21]. Unlike the crisp sets, FS considers the varying degree of membership of the elements ranging from 0 to 1. However, there are real-life situations wherein the degree of non-membership and neutrality add significant complexity. In view of the requirement to provide additional flexibility to the analyst for decision making in uncertain environment, Atanassov [22] introduced intuitionistic fuzzy sets (IFSs) as a generalization of FS. IFS considers both degree of membership ($\mu$) and non-membership ($\upsilon$) with the condition that $0 \le \mu + \vartheta \le 1$. Moving further, Atanassov and Gargov [23] extended the concept of IFS with interval values, aka interval-valued IFS (IVIFS). The strand of literature that worked on FS, IFS, and IVIFS later observed the conditions where $\mu + \vartheta > 1$. To solve this problem, Yager [24] propounded a new variant, called Pythagorean fuzzy set (PyFS) as a generalization of IFS. PyFS follows the norms $0 \le \mu^2 + \vartheta^2 \le 1$. As a further generalization of PyFS, $q$ rung orthopair fuzzy set (qROFS) was proposed (with a relation $0 \le \mu^q + \vartheta^q \le 1$) [25]. In effect, $q = 2$ converts qROFS into PyFS and for $q = 1$, it becomes IFS. However, researchers [26, 27] felt the importance of considering the degree of membership, non-membership, neutrality ($\Upsilon$), and refusal too. As a result, a new branch of the broad domain of FS, known as picture fuzzy sets (PFSs), was introduced. PFS is more capable of countering the issue of vagueness and imprecise information and satisfies the condition $0 \le \mu + \vartheta + \gamma \le 1$. The rationale behind use of the recently developed wings of extended fuzzy sets such as spherical fuzzy set (SFS) stems from the disadvantage of PFS in some cases wherein $\mu + \vartheta + \gamma > 1$ [28]. SFS is grounded on the concept of three-dimensional spherical geometry and the membership degrees follow the condition $0 < \mu^2 + \vartheta^2 + \gamma^2 < 1$. SFS is an advanced extension of neutrosophic fuzzy sets [29] and type 2 IFS [30]. SFS provides a number of advantages [31, 32] such as

(i) Unlike IFS, it considers the sum of membership and non-membership degrees greater than 1.

(ii) In contrast to PyFS, it considers the degree of hesitancy.

(iii) Compared to PFS, SFS works well in a typical situation wherein, for instance, $\mu = 0.7$; $\vartheta = 0.3$; $\gamma = 0.5$ that does not satisfy $\mu + \vartheta + \gamma < 1$ (PFS) but does not violate the assumption of SFS, i.e., $\mu^2 + \vartheta^2 + \gamma^2 < 1$. Therefore, SFS provides the decision makers more flexibility and larger space.

Furthermore, if compared with qROFS, SFS provides the benefits like consideration of hesitancy and lesser complexity in computation and visualization. SFS considers three-dimensional space or volume which is more easy to conceptualize, visualize, and handle as compared with qROFS. SFS is also less complex that Fermatean fuzzy sets [33]. In this paper, we apply SFS to solve the issue of performance evaluation of SMEs using a combined novel framework of LBWA and MULTIMOOSRAL approach. LBWA is a recently developed algorithm that works on level-based partitioning of the criteria as per their relative significance to decide the criteria weights [34]. The MULTIMOOSRAL approach combines the weighted sum, weighted product, and logarithmic approximations to rank the alternatives subject to the influence of the criteria [35]. In effect, the MULTIMOOSRAL algorithm is an upgraded synthesis of the popular approaches like multi-objective optimization on the basis of ratio analysis (MOORA), multi-objective optimization on the basis of simple ratio analysis (MOOSRA), multi-objective analysis by ratio analysis plus the full multiplicative form (MULTIMOORA), weighted aggregated sum product assessment (WASPAS), and combined compromise solution (CoCoSo).

The proposed SF-LBWA-MULTIMOOSRAL framework (as used in this paper) provides the following advantages.

(i) Greater flexibility to the decision makers (DM) in rating as SFS allows more space in selecting the values of membership, non-membership, and hesitancy.

(ii) Lesser computational complexity as the framework uses simple arithmetic operators.

(iii) The model uses less number of pairwise comparisons for determining criteria weights and subsequently reduces the possibility of the subjective bias unlike its counterparts like analytic hierarchy process (AHP).

(iv) Ability to work with a large criteria and alternative set with subjective and objective information.

(v) Ability to withstand large variations in the criteria values.

(vi) Combination of addition, subtraction, multiplication, division, and logarithmic approach in evaluation.

(vii) Reasonably accurate and stable results.

The motivations behind the present paper are as follows.

(a) We find that several authors have worked on establishing the importance of practicing LM for achieving competitive advantage for the organizations. Furthermore, the authors have also advocated in favour of maintaining leanness in the processes for optimization and mobilization of the resources and adding value to the customers. The extant literature has provided definitions and measurement of leanness. In the context of MSMEs, past works have shown the utility of practicing LM. However, there is a scantiness of work that measures and compares leanness of MSMEs in Indian context.

(b) From the methodological point of view, SFS has been recently introduced to overcome the drawbacks of IFS and PyFS. SFS as compared with IFS, PyFS, and PFS provides more flexibility in selection of membership, non-membership, and hesitancy grades which allow the researchers to apply in real-life situations. We observe that SFS has not been used for subjective opinion-based group decision-making cases using LBWA and MULTIMOOSRAL.

(c) As we have mentioned the benefits of our proposed model above, we do not find any literature that has used an integrated framework of LBWA and MULTIMOOSRAL.

The major contributions of the present paper are as follows.

(i) The present paper provides a comprehensive multi-criteria-based evaluation framework for comparing leanness of the MSMEs in Indian context. The extant literature shows a scantiness of research in considering multiple dimensions of assessment of leanness through a comparative study.

(ii) A novel hybrid framework of LBWA-MULTIMOOSRAL for multi-criteria group decision making is proposed.

(iii) In the present study, we provide a new extension of LBWA-MULTIMOOSRAL using SFS. The use of SFS in solving various research problems is growing but has not been explored exhaustively for applications in MCDM problems.

The reminder of this paper is organized as follows. In Section 2, we include some of the recent related work. Section 3 presents some preliminary concepts of SFS and SFN. Section 4 navigates the research methodology. The summary of results is included in Section 5. Section 6 provides the discussion on the results and sheds light on some of the research implications. In Section 7, we make the concluding remarks and mention some of the future scopes.

## 2. Related Work

In this section, we present some of the relative work on assessment of leanness, SFS, and applications of LBWA and MULTIMOOSRAL methods.

In the last decade, a number of studies have been conducted towards developing measure of leanness. For instance, Seyedhosseini et al. [36] utilized the balanced scorecard framework to define leanness measures. Azevedo et al. [37] put emphasis on agility for ensuring leanness in the context of supply chain management. The use of an integrated AHP-DEMATEL model is noticed in [38] in exploring the priority of the factors responsible for implementation of LM. The work of Patil et al. [39] focused on the new product development process and contributed five measures such as knowledge management, customer value, design cost, and schedule. Maasouman and Demirli [40] stressed on leadership, people management, facility management, process, working condition, quality, and just-in-time operations to assess the leanness of cellular manufacturing. In this regard, Basu et al. [41] advocated for ensuring employee welfare for supporting the successful implementation of LM. In the study [42], the authors presented a leanness assessment framework considering leadership, supplier focus, customer value, process management, and employee development and further developed a value stream map in the context of a large-scale organization belonging to Indian plywood industry. Some authors relied on probabilistic and statistical approaches to examine the root of lean elements and their interactions [43, 44]. Kroes et al. [45] investigated the causal effect of lean practices on the performance of the retail firms. The study in [46] enquired the preparedness of pharmaceutical organization for implementing LM tools. Tekez and Taşdeviren [47] extended the strand of literature with their advocacy for innovation as a measure of leanness. Therefore, we have noticed that a good number of studies have been done to find out the measures of leanness. However, there is a lack of evidence of using all these dimensions to carry out comparative evaluation of the organizations in terms of leanness.

In the context of MSMEs, there has been a notable number of attempts made towards constructing leanness measurement framework. For example, Ravikumar et al. [48] followed a two-stage approach. The authors considered the attributes like leadership, organizational culture, financial support, communication, performance management system, skill set, training, planning, critical thinking, and customer focus. In the first stage, the authors applied structural equation modelling to ascertain the causal relationship of the attributes with leanness, while in the second stage, a TOPSIS-based MCDM framework was utilized to prioritize the attributes and carry out a comparative assessment of selected MSME units. Prabhakar et al. [49] endeavoured to identify the enablers of LM and prioritize using fuzzy AHP-ISM method. Singh et al. [50] took the discussion to a different level by incorporating the environmental aspect and considered product quality, environmental impact, green product development, and optimization of cost for successfully ensuring leanness in MSMEs. The authors applied the best-worst method (BWM). The work of [51] used the fuzzy AHP-DEMATEL framework to prioritize enablers and barriers and reported that management support, training and knowledge, and technology are some of the top influencing factors. In [52], the researchers attempted to measure leanness in terms of the financial outcomes. In the same line, the study of [53] applied an integrated AHP-ISM model to identify and rank the enablers for leanness in MSMEs. It is evident from the review of the extant literature that the authors have established importance of LM for MSMEs. The authors have applied various algorithms for investigating critical success factors (CSFs) and challenges of implementation of LM for MSMEs. However, there is a lack of confluence of CSF and measurable attributes for LM and subsequently application of MCDM-based approaches for holistically comparing leanness of MSMEs. It is an established fact that LM enables the MSMEs to achieve competitive advantage. But, in a country like India, there is a lack of governance and awareness about leanness particularly for MSMEs. Of late, National Productivity Council (NPC) of India initiated a nationwide drive for assessing leanness and formulating intervention measures for supporting the MSMEs to embrace LM under the Government of India agenda of Make in India. We notice that in Indian context, a comparative multi-criteria-based analysis of extent of implementation of leanness has not been explored in the extant literature. Table 1 provides a comparative study of the present paper with some of the past work.

SFS has garnered attention from the researchers for extensive use in solving various real-life issues like medical diagnosis problem using trigonometric similarity measures and Choquet integral-based SF operation [54]; 3D printer selection using interval valued SF-additive ratio assessment (ARAS) method [55]; waste disposal location selection using SF-REGIME approach [56]; insurance policy selection using SF bi-objective linear decision-making model [57]; SF-analytic hierarchy process for supplier selection [58]; process mining application with SF-AHP [59]; energy management using SF linear Diophantine fuzzy soft rough sets [60]; cosine similarity-based medical diagnosis [61]; advertisement strategy formulation with SF-TOPSIS method [62]; Earth science application with SF [63]; SF-based failure mode and effect analysis in marble manufacturing [64]; assessment of efficacies of Facebook ads using SF-VIKOR in a group decision-making setup [65]; present value analysis in wealth management [66]; agricultural management in Industry 4.0 using interval-valued SF [67]; hospital performance evaluation using interval-valued SF-AHP [68]; and fraud detection with interval-valued AHP-MULTIMOORA method [69], among others. We have found that though there is an increasing number of applications of SFS in variety of areas, there is scope for further extensions of existing MCDM algorithms.

LBWA has been a popular method of late as is evident from the literature. The extant literature shows application of LBWA in various real-life situations, for example, social entrepreneurship [70], facility location planning [71, 72], talent acquisition [73], technology management [74], risk management in merger and acquisition [75], supplier selection [76], military applications [77–80], fleet management [81], healthcare operation [82, 83], and energy management and preservation [84, 85], among others. On the other hand, the applications of the MULTIMOOSRAL method have not yet reached the level of proliferation. Some of the recent applications of MULTIMOOSRAL method include supplier selection [35] and sustainable energy source selection [86], among others.

## 3. Preliminaries

In this section, we discuss about definitions and some fundamental properties and operations of SFS and SFN based on the past work [28, 31, 32, 87–89].

Let $U$ be the universe of discourse.

*Definition 1.* A spherical fuzzy set (SFS) is defined as

$$\widetilde{S} = \left\{ x, \left( \mu_{\widetilde{S}}(x), \vartheta_{\widetilde{S}}(x), \gamma_{\widetilde{S}}(x) \right) | x \in U \right\}, \quad (1)$$

where $\mu_{\widetilde{S}}(x), \vartheta_{\widetilde{S}}(x), \gamma_{\widetilde{S}}(x)\colon U \longrightarrow [0,1]$; $0 \leq \mu_{\widetilde{S}}(x)^2 + \vartheta_{\widetilde{S}}(x)^2 + \gamma_{\widetilde{S}}(x)^2 \leq 1 \quad \forall x \in U$.

$\mu_{\widetilde{S}}(x), \vartheta_{\widetilde{S}}(x), \gamma_{\widetilde{S}}(x)$, respectively, represent the degree of positive, negative, and hesitancy.

Table 1: Comparison of the present study with some of the related work.

| Author(s) (paper reference) | Objective(s) of the study: Establishing the importance of leanness for business growth | Measures of leanness | Critical success factor for implementation of LM | Multi-criteria-based comparison of leanness achievement of organizations | Application for MSME | Analysis with imprecise information |
|---|---|---|---|---|---|---|
| [36] | ✓ | ✓ | | | | |
| [37] | ✓ | | ✓ | | | |
| [38] | | | ✓ | | | |
| [39] | | ✓ | | | | |
| [40] | | ✓ | | | | |
| [41] | | | ✓ | | | |
| [42] | | ✓ | | | | |
| [45] | ✓ | | | | | |
| [46] | | ✓ | ✓ | | | |
| [47] | ✓ | ✓ | | | | |
| [48] | | ✓ | ✓ | ✓ | ✓ | |
| [49] | | | ✓ | | ✓ | |
| [50] | | ✓ | ✓ | | ✓ | |
| [51] | | | ✓ | | ✓ | |
| [52] | | ✓ | | | ✓ | |
| [53] | | | ✓ | | ✓ | |
| Present study | | ✓ | | ✓ | ✓ | ✓ |

Figure 1 gives a pictorial representation of the difference among IFS, type 2 IFS (IFS2), neutrosophic fuzzy set (NS), and SFS.

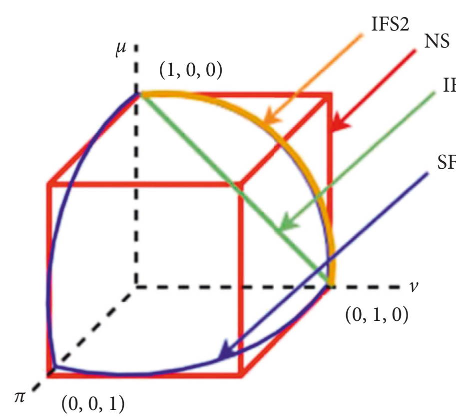


Figure 1: Difference of different types of fuzzy sets (adopted from [28]).

*Definition 2.* Basic operations.

Let us represent the SFS in terms of the spherical fuzzy number (SFN) as $\tilde{S} = \{\mu, \vartheta, \gamma\}$ without losing the meaning of usual terms. Let $\tilde{S}_1 = \{\mu_1, \vartheta_1, \gamma_1\}$ and $\tilde{S}_2 = \{\mu_2, \vartheta_2, \gamma_2\}$ be two SFNs. Some of the basic operations are defined as follows.

Addition:

$$\tilde{S}_1 \oplus \tilde{S}_2 = \left\{\left(\mu_1^2 + \mu_2^2 - \mu_1^2\mu_2^2\right)^{1/2}, \vartheta_1\vartheta_2, \left(\left(1-\mu_2^2\right)\gamma_1^2 + \left(1-\mu_1^2\right)\gamma_2^2 - \gamma_1^2\gamma_2^2\right)^{1/2}\right\}. \tag{2}$$

Multiplication:

$$\tilde{S}_1 \otimes \tilde{S}_2 = \left\{\mu_1\mu_2, \left(\vartheta_1^2 + \vartheta_2^2 - \vartheta_1^2\vartheta_2^2\right)^{1/2}, \left(\left(1-\vartheta_2^2\right)\gamma_1^2 + \left(1-\vartheta_1^2\right)\gamma_2^2 - \gamma_1^2\gamma_2^2\right)^{1/2}\right\}. \tag{3}$$

Multiplication by a scalar: $w > 0$.

$$w.\tilde{S} = \left(1-\left(1-\mu^2\right)^{w}\right)^{1/2}, \vartheta^{w}, \left(\left(1-\mu^2\right)^{w} - \left(1-\mu^2-\gamma^2\right)^{w}\right)^{1/2}. \tag{4}$$

Power of $\tilde{S}$: $w > 0$.

$$\tilde{S}^{w} = \left\{\mu^{w}, \left(1-\left(1-\vartheta^2\right)^{w}\right)^{1/2}, \left(\left(1-\vartheta^2\right)^{w} - \left(1-\vartheta^2-\gamma^2\right)^{w}\right)^{1/2}\right\}. \tag{5}$$

Complement of $\tilde{S}$:

$$\tilde{S}^{c} = \{\vartheta, \mu, \gamma\}. \tag{6}$$

*Definition 3.* Spherical weighted average.

Let $w = (w_1, w_2, w_3, \ldots, w_n)$ be the weights of the SFNs $\tilde{S}_1, \tilde{S}_2, \tilde{S}_3, \ldots, \tilde{S}_n$ where $n$ is finite; $w_j \in [0,1]$; $\sum_{j=1}^{n} w_j = 1$.

Spherical weighted arithmetic average (SWAA) is defined as

$$\begin{aligned} &SWAA_w\left(\tilde{S}_1, \tilde{S}_2, \tilde{S}_3, \ldots, \tilde{S}_n\right) \\ &= \left\{\left[1 - \prod_{i=1}^{n}\left(1-\mu_i^2\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n}\vartheta_i^{w_i}, \left[\prod_{i=1}^{n}\left(1-\mu_i^2\right)^{w_i} - \prod_{i=1}^{n}\left(1-\mu_i^2-\gamma_i^2\right)^{w_i}\right]^{1/2}\right\}. \end{aligned} \tag{7}$$

Spherical weighted geometric average (SWGA) is defined as

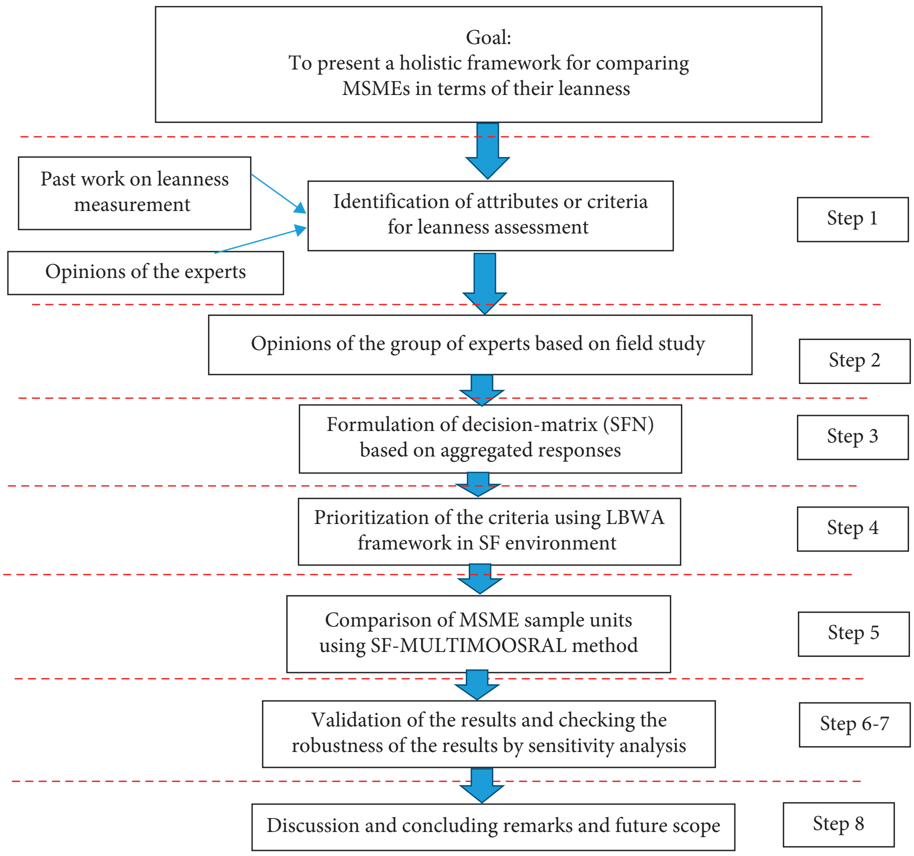


FIGURE 2: Research framework of the present paper.

$$SWGA_w(\tilde{S}_1, \tilde{S}_2, \tilde{S}_3, \ldots, \tilde{S}_n) = \left\{ \prod_{i=1}^{n} \mu_i^{w_i}, \left[1 - \prod_{i=1}^{n} \left(1 - \vartheta_i^2\right)^{w_i}\right]^{1/2}, \left[\prod_{i=1}^{n} \left(1 - \mu_i^2\right)^{w_i} - \prod_{i=1}^{n} \left(1 - \vartheta_i^2 - \gamma_i^2\right)^{w_i}\right]^{1/2} \right\}. \quad (8)$$

*Definition 4.* Score and accuracy function.

The score function is defined as [31]

$$Sc(\tilde{S}) = \frac{1}{3}(2 + \mu - \gamma - \vartheta). \quad (9)$$

The accuracy function is given as [31]

$$Ac(\tilde{S}) = (\mu - \gamma). \quad (10)$$

In this context, the certainty function is defined as [31]

$$Cr(\tilde{S}) = \mu. \quad (11)$$

Rule:

(i) If $Sc(\tilde{S}_1) > Sc(\tilde{S}_2)$, then $\tilde{S}_1 > \tilde{S}_2$.

(ii) If $Sc(\tilde{S}_1) < Sc(\tilde{S}_2)$, then $\tilde{S}_1 < \tilde{S}_2$.

(iii) If $Sc(\tilde{S}_1) = Sc(\tilde{S}_2)$, then
If $Ac(\tilde{S}_1) > Ac(\tilde{S}_2)$, then $\tilde{S}_1 > \tilde{S}_2$.
If $Ac(\tilde{S}_1) < Ac(\tilde{S}_2)$, then $\tilde{S}_1 < \tilde{S}_2$.

(iv) If $Sc(\tilde{S}_1) = Sc(\tilde{S}_2)$ and $Ac(\tilde{S}_1) = Ac(\tilde{S}_2)$, then
If $Cr(\tilde{S}_1) > Cr(\tilde{S}_2)$, then $\tilde{S}_1 > \tilde{S}_2$.

*Definition 5.* Defuzzification.

The defuzzified value of $\tilde{S}$ is given as

$$S = \left(\left|100 \times \left[\left(3\mu - \frac{\gamma}{2}\right)^2 - \left(\frac{\vartheta}{2} - \gamma\right)^2\right]\right|\right)^{1/2}. \quad (12)$$

## 4. Materials and Methods

In this section, we present the overall steps of the research methodology followed in this paper and the case study on six MSME sample units under study. The flow of the steps is shown in Figure 2.

*4.1. Case Study.* In this paper, we consider six MSME sample units belonging to engineering cluster and located in the eastern part of the country. Table 2 provides brief information about the sample units. For confidentiality purpose, we do not disclose their real names in this paper. Therefore, the units are mentioned as $A1, A2, \ldots A6$ in our paper. These units act as alternatives in the multi-criteria decision-making framework presented in this paper. A group of three experts took part in the field study and opinion making. The experts ($E1$, $E2$ and $E3$) have significant experience in

Table 2: Descriptions of the SMEs (sample units or alternatives).

| Unit's no. | A1 |
|---|---|
| Category of unit (micro/small/ medium) | Medium |
| Year of establishment | 2006 |
| Turnover | Rs. 200 crores p.a. |
| Business activity | Manufacturing (main product: welding consumables) |
| Unit's no. | A2 |
| Category of unit (micro/small/ medium) | Micro |
| Year of establishment | 1994 |
| Turnover | Rs. 2 crores p.a. |
| Business activity | Designing and manufacturing<br>Manufacturer of machine tools and inspection instruments, die, and spares |
| Unit's no. | A3 |
| Category of unit (micro/small/ medium) | Micro |
| Year of establishment | 2006 |
| Turnover | Rs. 3 crores p.a. |
| Business activity | Manufacturing of battery charger, transformer, L.T. control panel |
| Unit's no. | A4 |
| Category of unit (micro/small/ medium) | Small |
| Year of establishment | 1986 |
| Turnover | Rs. 9.90 cr. p.a. (Unit I), rs. 5.70 cr. (Unit II) |
| Business activity | UNIT-I: conveyor components, idlers for coal handling plants, steel plants, cement plants, etc. UNIT-II: heavy structural fabrication |
| Unit's no. | A5 |
| Category of unit (micro/small/ medium) | Small |
| Year of establishment | 2008 |
| Turnover | Rs. 12 crore p.a. |
| Business activity | Manufacturer of PVC pipe and related products |
| Unit's no. | A6 |
| Category of unit (micro/small/ medium) | Small |
| Year of establishment | 1992 |
| Turnover | 28 crore p.a. |
| Business activity | Fabrication, forging, heat treatment, machining, assembly of bogie and wagon components, and other engineering goods |

implementation of LM techniques in large organizations with industrial experience of 15, 18, and 22 years, respectively. We consider the criteria as derived from the literature (see Table 3).

Table 3: List of criteria.

| S/L | Criteria | Effect direction |
|---|---|---|
| C1 | Top management support and leadership | Max |
| C2 | Lean culture | Max |
| C3 | Communication and awareness | Max |
| C4 | Customer focus | Max |
| C5 | Human resource focus | Max |
| C6 | Process management | Max |
| C7 | Waste | Min |
| C8 | Supplier partnership | Max |
| C9 | Technology usage | Max |

*4.2. LBWA Method.* The algorithmic steps of LBWA [34] are briefly mentioned below.

Step 1: determination of the most important criterion.

Let $C_j$ (where, $j = 1, 2, 3, \ldots, n$) be the criteria from the criteria set indicated by $C = \{C_1, C_2, C_3, \ldots, C_n\}$. Let the $i^{\text{th}}$ criterion ($C_i \in C$) be the most important criterion according to the decision maker.

Step 2: formation of subsets of criteria by grouping based on level of significance.

The grouping process is demonstrated below.

Level $L_1$: group the criteria and form the subset with the criteria having equal to or up to twice as less as the significance of the criterion $C_i$.

Level $L_2$: group the criteria and form the subset with the criteria having exactly twice as less as the significance of the criterion $C_i$ or up to three times as less as the significance of the criterion $C_i$

Level $L_3$: group the criteria and form the subset with the criteria having exactly three times as less as the significance of the criterion $C_i$ or up to four times as less as the significance of the criterion $C_i$

Level $L_k$: group the criteria and form the subset with the criteria having exactly "$k$" times as less as the significance of the criterion $C_i$ or up to "$k+1$" times as less as the significance of the criterion $C_i$. Hence,

$$L = L_1 \cup L_2 \cup L_3 \cup L_k. \tag{13}$$

If $l(C_j)$ is the significance of the $j^{\text{th}}$ criterion, it can be stated that

$$L_k = \left\{C_j \in L\colon\ k \leq l\left(C_j\right) \leq k+1\right\}. \tag{14}$$

Also, the following condition holds good to appropriately define the grouping:

$$L_p \cap L_q = \varnothing; \text{where} p, q \in \{1, 2, \ldots, k\}, \quad p \neq q. \tag{15}$$

Step 3: find out comparative significance of the criteria within the subsets.

Based on the comparison, each criterion $C_j \in L_k$ is assigned with an integer value $I_{C_j} \in \{0, 1, 2, \ldots, r\}$ where $r$ is the maximum value on the scale for comparison and is given by

$$r = \max\left\{\left|L_1\right|, \left|L_2\right|, \left|L_3\right| \ldots\ldots \left|L_k\right|\right\}. \tag{16}$$

Conditions followed in this context are

(i) The integer value of the most important criterion, i.e.,

$$I_{C_i} = 0. \tag{17}$$

(ii) If $C_p$ is more significant than $C_q$, then

$$I_{C_p} < I_{C_q}. \tag{18}$$

(iii) If $C_p$ is equally significant with $C_q$, then

$$I_{C_p} = I_{C_q}. \tag{19}$$

Step 4: defining the elasticity coefficient.

The elasticity coefficient $r_0$ is defined as any number belonging the set of real numbers which meets the condition $r_0 > r$ and $r_0 \in \mathbb{R}$ where $\mathbb{R}$ represents a set of real numbers.

Step 5: deriving the influence function of the criteria.

For a particular criterion $C_j \in L_k$, the influence function can be defined as $f\colon L \longrightarrow R$.

It is calculated as

$$f\left(C_j\right) = \frac{r_0}{k r_0 + I_{C_j}}, \tag{20}$$

where $k$ is the number of level or subset to which $C_j$ belongs and $I_{C_j} \in \{0, 1, 2, \ldots, r\}$ is the value assigned to the criterion $C_j$ within that level.

Step 6: calculation of the optimum values of the criteria weights for most significant criterion:

$$w_i = \frac{1}{1 + f\left(C_1\right) + f\left(C_2\right) + \cdots + f\left(C_n\right)}, \tag{21}$$

where $i \in j$; $j = 1, 2, \ldots, n$.

For other criteria: $w_{j \neq i} = f(C_j) w_i$.

### 4.3. MULTIMOOSRAL Method

*4.3. MULTIMOOSRAL Method.* The computational steps are given below [35].

*Step 1.* Formation of the evaluation matrix (EM) for decision making.

Let $A = [a_{ij}]_{m \times n}$ be the EM where $m$ is the number of alternatives and $n$ is the number of criteria.

*Step 2.* Normalize EM.

The normalized EM (NEM) is obtained by

$$b_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m}\left(a_{ij}\right)^2}}. \tag{22}$$

*Step 3.* Calculation of the overall utility of the alternatives using ratio scale (RS) approach.

The following steps are followed.

First, the overall importance of the alternatives is calculated as

$$y_i = \sum_{j \in j^+} w_j b_{ij} - \sum_{j \in j^-} w_j b_{ij}. \tag{23}$$

The overall utility is given by

$$m_i = \begin{cases} y_i; & \text{if } \max\limits_i\left(y_i\right) > 0, \\ y_i + 1 & \text{if } \max\limits_i\left(y_i\right) = 0, \\ -\dfrac{1}{y_i} & \text{if } \max\limits_i\left(y_i\right) < 0. \end{cases} \tag{24}$$

The normalized overall utility is obtained as

$$m_i' = \frac{m_i - \min\left(m_i\right)}{\max\left(m_i\right) - \min\left(m_i\right)}. \tag{25}$$

*Step 4.* Calculate the utility of alternatives using reference point (RP) approach.

First, the reference point is determined as

$$b^* = \left(b_1^*, b_2^*, \ldots, b_m^*\right) = \left\{\max_i b_{ij} \text{if} \quad j \in j^+; \min_i b_{ij} \text{if} \quad j \in j^-;\right\}. \tag{26}$$

The maximal distance of each alternative with respect to the RP is given as

$$t_i = \max_j\left(w_j\left|b_j^* - b_{ij}\right|\right). \tag{27}$$

The normalized maximal distance is obtained as

$$t_i' = \frac{\max(t_i) - t_i}{\max(t_i) - \min(t_i)}. \tag{28}$$

The normalized maximal distance is the overall normalized utility of the alternatives based on RP approach.

*Step 5*. Obtain the utility of the alternatives using full multiplicative form (FMF).

The overall utility using FMF is given as

$$u_i = \frac{\prod_{j\in j^+} w_j b_{ij}}{\prod_{j\in j^-} w_j b_{ij}.} \tag{29}$$

The normalized overall utility of the alternatives is given as

$$u_i' = \frac{u_i - \min(u_i)}{\max(u_i) - \min(u_i)}. \tag{30}$$

*Step 6*. Obtain the utility of the alternatives using addition form (AF).

The overall utility using AF is given as

$$v_i = \frac{\sum_{j\in j^+} w_j b_{ij}}{\sum_{j\in j^-} w_j b_{ij}}. \tag{31}$$

The normalized overall utility of the alternatives is given as

$$v_i' = \frac{v_i - \min(v_i)}{\max(v_i) - \min(v_i)}. \tag{32}$$

*Step 7*. Obtain the utility of the alternatives using logarithmic approach (LA).

The overall utility is given by

$$k_i = \sum_{j\in j^+} \ln\left(1 + w_j b_{ij}\right) + \frac{1}{\sum_{j\in j^-} \ln\left(1 + w_j b_{ij}\right)}. \tag{33}$$

The normalized overall utility of the alternatives is given as

$$k_i' = \frac{k_i - \min(k_i)}{\max(k_i) - \min(k_i)}, \tag{34}$$

*Step 8*. Ranking of the alternatives based on total utility value.

The total utility value of an alternative is obtained as

$$UV_i = m_i' + u_i' + v_i' + k_i'. \tag{35}$$

The higher the total utility, the better the alternative.

*4.4. Proposed SF-LBWA-MULTIMOOSRAL Method.* The procedural steps are in line with the descriptions of LBWA and MULTIMOOSRAL method given in Sections 4.2 and 4.3. The steps are given below.

*Step 1*. Formulate the SF linguistic rating matrix for the criteria for each expert. At this step, SFS-based analysis helps the analyst to select a wide range of values of membership and non-membership.

*Step 2*. Aggregate the expert opinions using SWGA operator (see expression (8)) to obtain the SF criteria rating matrix. SWGA operator helps to offset variations in the selection of membership and non-membership values.

*Step 3*. Obtain the score of the SF criteria rating matrix by using expression (9). The score function includes all membership values including degree of hesitancy and therefore is an improved measure of uncertainty.

*Step 4*. Follow the steps of the LBWA method (see Section 4.2 and expressions (13)–(21)) to derive the criteria weights.

*Step 5*. Formulate the SF linguistic rating matrix for the alternatives with respect to the criteria for each expert.

*Step 6*. Aggregate the expert opinions using SWGA operator (see expression (8)) to obtain the SF evaluation matrix (SFEM).

*Step 7*. Normalize the SFEM (NSFEM), Here,

$$\begin{aligned} \widetilde{S} &= \widetilde{S} \quad \text{for } j \in j^+, \\ \widetilde{S} &= \widetilde{S}^c \quad \text{for } j \in j^-. \end{aligned} \tag{36}$$

Use expression (6).

*Step 8*. Obtain the score values of NSFEM.

*Step 9*. Follow steps 3 to 8 (expressions (23) to (35)) of the MULTIMOOSRAL approach (see Section 4.3) to rank the alternatives.

## 5. Results and Discussion

We use the linguistic rating scale for criteria rating as given in Table 4.

The experts expressed their rating to prioritize the criteria as per their relative importance as given in Table 5. In our problem, we have 9 criteria. Use of LBWA helps to reduce the number of pairwise comparisons substantially than AHP. In addition, for a large criteria set, AHP finds it difficult to reach the consistency. Therefore, LBWA provides the advantages like reduction in computational complexity and subjective bias.

We apply the SWGA operator (see expression (8)) to aggregate the individual responses for obtaining the SF criteria rating matrix whose elements are SFNs and apply expression (9) to derive corresponding weights. Table 6 provides the SF criteria rating matrix and corresponding score values.

We now proceed to find out the criteria weights using the LBWA method. We follow the procedural steps as given in

Table 4: Linguistic scale and SFN values for criteria rating.

| Linguistic term | $\mu$ | $\nu$ | $\Upsilon$ |
|---|---|---|---|
| Very high (VH) | 0.9 | 0.1 | 0.1 |
| High (H) | 0.7 | 0.3 | 0.3 |
| Moderate (M) | 0.5 | 0.5 | 0.5 |
| Low (L) | 0.3 | 0.7 | 0.3 |
| Very low (VL) | 0.1 | 0.9 | 0.1 |

Table 5: Experts' rating of the criteria.

| Criteria | Expert | | |
|---|---|---|---|
| | E1 | E2 | E3 |
| C1 | VH | H | VH |
| C2 | H | VH | H |
| C3 | L | L | M |
| C4 | VH | VH | H |
| C5 | H | M | H |
| C6 | M | H | H |
| C7 | H | VH | VH |
| C8 | L | VL | L |
| C9 | L | H | M |

Table 6: SF criteria rating values and scores.

| Criteria | $\mu$ | $\nu$ | $\Upsilon$ | Score |
|---|---|---|---|---|
| C1 | 0.57 | 0.329 | 0.323 | 0.638 |
| C2 | 0.44 | 0.424 | 0.401 | 0.538 |
| C3 | 0.05 | 0.897 | 0.327 | 0.274 |
| C4 | 0.57 | 0.329 | 0.323 | 0.638 |
| C5 | 0.25 | 0.616 | 0.534 | 0.365 |
| C6 | 0.25 | 0.616 | 0.534 | 0.365 |
| C7 | 0.57 | 0.329 | 0.323 | 0.638 |
| C8 | 0.01 | 0.975 | 0.133 | 0.300 |
| C9 | 0.11 | 0.807 | 0.419 | 0.293 |

Section 4.2. As we see, C1 has the highest score value of 0.638. Therefore, we compare all other criteria with respect to C1. The integer value assigned to C1 is zero. Following the steps of LBWA, we partition the criteria as C1, C7, C4, C2, C5, and C6 in level 1 and C8, C9, and C3 in the level 2. The final criteria weights are given in Table 7 along with their respective functional values.

Now we move to rank the alternatives using experts' opinions. The experts carried out field visits to investigate the leanness of the organizations and rate the sample units with respect to the criteria considered using the rating scale as given in Table 8.

Accordingly, the sample units (alternatives) are rated by the individual experts (see Tables 9–11).

We then aggregate the opinions using SWGA operator and derive the SFEM (see Table 12). We normalize the SFEM using expression (36) and apply expression (9) to get the score values of the SFEM and NSFEM (see Tables 13 and 14).

To find the weighted NSFEM, we use expression (4), and thereafter, we find the score values of the weighted NSFEM (see Table 15). This is required for the usual steps of MULTIMOOSRAL starting from step 3 (see Section 4.3).

Table 7: Criteria weights (LBWA method).

| Criteria | Function | Weight |
|---|---|---|
| C1 | 1.000 | 0.170 |
| C2 | 0.700 | 0.119 |
| C3 | 0.412 | 0.070 |
| C4 | 0.778 | 0.132 |
| C5 | 0.636 | 0.108 |
| C6 | 0.583 | 0.099 |
| C7 | 0.875 | 0.149 |
| C8 | 0.467 | 0.079 |
| C9 | 0.438 | 0.074 |
| Σ | | 1.0000 |

Table 8: Rating scale for ranking alternatives.

| Linguistic term | $\mu$ | $\nu$ | $\Upsilon$ |
|---|---|---|---|
| Completely lean (CL) | 0.9 | 0.1 | 0.1 |
| Largely lean (LL) | 0.7 | 0.3 | 0.3 |
| Moderately lean (ML) | 0.5 | 0.5 | 0.5 |
| Largely traditional (LT) | 0.3 | 0.7 | 0.3 |
| Completely traditional (CT) | 0.1 | 0.9 | 0.1 |

Table 9: Rating of alternatives by first expert.

| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Alternatives | (+) | (+) | (+) | (+) | (+) | (+) | (−) | (+) | (+) |
| A1 | CL | CL | ML | LL | LL | ML | ML | CL | ML |
| A2 | LL | CL | ML | LL | ML | LT | LT | ML | ML |
| A3 | CL | CL | LL | ML | LL | LL | CT | LL | LT |
| A4 | ML | LL | LT | CL | CT | ML | ML | LT | CT |
| A5 | LL | ML | CL | ML | LL | ML | LL | ML | ML |
| A6 | LT | LL | ML | LL | LT | CT | ML | ML | CT |

Table 10: Rating of alternatives by second expert.

| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Alternatives | (+) | (+) | (+) | (+) | (+) | (+) | (−) | (+) | (+) |
| A1 | LL | CL | ML | LL | LL | LL | LL | CL | LT |
| A2 | LL | ML | ML | ML | ML | LT | ML | LL | ML |
| A3 | ML | LL | LL | LT | LT | CL | LT | ML | CT |
| A4 | LL | ML | CT | CL | CT | ML | CT | LT | CT |
| A5 | ML | CT | CL | ML | LL | LT | LL | ML | ML |
| A6 | LT | ML | ML | LL | CT | CT | ML | ML | CT |

Table 11: Rating of alternatives by third expert.

| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Alternatives | (+) | (+) | (+) | (+) | (+) | (+) | (−) | (+) | (+) |
| A1 | CL | CL | LL | CL | ML | LL | ML | LL | ML |
| A2 | CL | LL | LL | ML | LL | CT | LT | ML | LT |
| A3 | LL | LL | ML | LT | ML | LL | CT | ML | ML |
| A4 | LT | ML | LT | LL | CT | ML | LT | CT | LT |
| A5 | LL | LT | LL | ML | LL | LT | ML | LT | ML |
| A6 | CT | ML | ML | LL | LT | CT | ML | ML | CT |

We now follow the usual steps of MULTIMOOSRAL (see Section 4.3) to find out the normalized overall utility values of the alternatives using RS, RP, AF, FMF, and LA and

Table 12: SF-evaluation matrix.

| Weight | | 0.1698 | | | 0.1189 | | | 0.0699 | |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | | C1 | | | C2 | | | C3 | |
| Alternatives | | (+) | | | (+) | | | (+) | |
| A1 | 0.567 | 0.329 | 0.323 | 0.729 | 0.172 | 0.171 | 0.175 | 0.699 | 0.554 |
| A2 | 0.441 | 0.424 | 0.401 | 0.315 | 0.569 | 0.523 | 0.175 | 0.699 | 0.554 |
| A3 | 0.315 | 0.569 | 0.523 | 0.441 | 0.424 | 0.401 | 0.245 | 0.616 | 0.534 |
| A4 | 0.105 | 0.807 | 0.419 | 0.175 | 0.699 | 0.554 | 0.009 | 0.975 | 0.133 |
| A5 | 0.245 | 0.616 | 0.534 | 0.015 | 0.963 | 0.187 | 0.567 | 0.329 | 0.323 |
| A6 | 0.009 | 0.975 | 0.133 | 0.175 | 0.699 | 0.554 | 0.125 | 0.760 | 0.545 |
| Weight | | 0.1321 | | | 0.1081 | | | 0.0991 | |
| Criteria | | C4 | | | C5 | | | C6 | |
| Alternatives | | (+) | | | (+) | | | (+) | |
| A1 | 0.441 | 0.424 | 0.401 | 0.245 | 0.616 | 0.534 | 0.245 | 0.616 | 0.534 |
| A2 | 0.175 | 0.699 | 0.554 | 0.175 | 0.699 | 0.554 | 0.009 | 0.975 | 0.133 |
| A3 | 0.045 | 0.897 | 0.327 | 0.105 | 0.807 | 0.419 | 0.441 | 0.424 | 0.401 |
| A4 | 0.567 | 0.329 | 0.323 | 0.001 | 0.997 | 0.032 | 0.125 | 0.760 | 0.545 |
| A5 | 0.125 | 0.760 | 0.545 | 0.343 | 0.496 | 0.450 | 0.045 | 0.897 | 0.327 |
| A6 | 0.343 | 0.496 | 0.450 | 0.009 | 0.975 | 0.133 | 0.001 | 0.997 | 0.032 |
| Weight | | 0.1486 | | | 0.0793 | | | 0.0743 | |
| Criteria | | C7 | | | C8 | | | C9 | |
| Alternatives | | (−) | | | (+) | | | (+) | |
| A1 | 0.175 | 0.699 | 0.554 | 0.567 | 0.329 | 0.323 | 0.075 | 0.844 | 0.426 |
| A2 | 0.045 | 0.897 | 0.327 | 0.175 | 0.699 | 0.554 | 0.075 | 0.844 | 0.426 |
| A3 | 0.003 | 0.991 | 0.069 | 0.175 | 0.699 | 0.554 | 0.015 | 0.963 | 0.187 |
| A4 | 0.015 | 0.963 | 0.187 | 0.009 | 0.975 | 0.133 | 0.003 | 0.991 | 0.069 |
| A5 | 0.245 | 0.616 | 0.534 | 0.075 | 0.844 | 0.426 | 0.125 | 0.760 | 0.545 |
| A6 | 0.125 | 0.760 | 0.545 | 0.125 | 0.760 | 0.545 | 0.001 | 0.997 | 0.032 |

Table 13: Score values of SFEM.

| Weight | 0.1698 | 0.1189 | 0.0699 | 0.1321 | 0.1081 | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| Alternatives | | | | | | | | | |
| A1 | 0.638 | 0.795 | 0.307 | 0.538 | 0.365 | 0.365 | 0.307 | 0.638 | 0.268 |
| A2 | 0.538 | 0.407 | 0.307 | 0.307 | 0.307 | 0.300 | 0.274 | 0.307 | 0.268 |
| A3 | 0.407 | 0.538 | 0.365 | 0.274 | 0.293 | 0.538 | 0.314 | 0.307 | 0.288 |
| A4 | 0.293 | 0.307 | 0.300 | 0.638 | 0.324 | 0.273 | 0.288 | 0.300 | 0.314 |
| A5 | 0.365 | 0.288 | 0.638 | 0.273 | 0.466 | 0.274 | 0.365 | 0.268 | 0.273 |
| A6 | 0.300 | 0.307 | 0.273 | 0.466 | 0.300 | 0.324 | 0.273 | 0.273 | 0.324 |

Table 14: Score values of NSFEM.

| Weight | 0.170 | 0.119 | 0.070 | 0.132 | 0.108 | 0.099 | 0.149 | 0.079 | 0.074 |
|---|---|---|---|---|---|---|---|---|---|
| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
| Alternatives | | | | | | | | | |
| A1 | 0.6384 | 0.7954 | 0.3075 | 0.5385 | 0.3652 | 0.3652 | 0.6566 | 0.6384 | 0.2680 |
| A2 | 0.5385 | 0.4074 | 0.3075 | 0.3075 | 0.3075 | 0.3004 | 0.8418 | 0.3075 | 0.2680 |
| A3 | 0.4074 | 0.5385 | 0.3652 | 0.2736 | 0.2927 | 0.5385 | 0.9728 | 0.3075 | 0.2884 |
| A4 | 0.2927 | 0.3075 | 0.3004 | 0.6384 | 0.3241 | 0.2733 | 0.9204 | 0.3004 | 0.3143 |
| A5 | 0.3652 | 0.2884 | 0.6384 | 0.2733 | 0.4656 | 0.2736 | 0.6123 | 0.2680 | 0.2733 |
| A6 | 0.3004 | 0.3075 | 0.2733 | 0.4656 | 0.3004 | 0.3241 | 0.6968 | 0.2733 | 0.3241 |

Table 15: Score values of the weighted NSFEM.

| Criteria<br>Alternatives | C1<br>(+) | C2<br>(+) | C3<br>(+) | C4<br>(+) | C5<br>(+) | C6<br>(+) | C7<br>(−) | C8<br>(+) | C9<br>(+) |
|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.421 | 0.466 | 0.303 | 0.369 | 0.313 | 0.313 | 0.399 | 0.382 | 0.304 |
| A2 | 0.379 | 0.324 | 0.303 | 0.296 | 0.299 | 0.321 | 0.513 | 0.302 | 0.304 |
| A3 | 0.327 | 0.366 | 0.314 | 0.303 | 0.304 | 0.360 | 0.697 | 0.302 | 0.319 |
| A4 | 0.299 | 0.298 | 0.323 | 0.405 | 0.330 | 0.293 | 0.594 | 0.322 | 0.328 |
| A5 | 0.313 | 0.315 | 0.377 | 0.289 | 0.341 | 0.306 | 0.388 | 0.303 | 0.297 |
| A6 | 0.318 | 0.298 | 0.298 | 0.345 | 0.321 | 0.330 | 0.410 | 0.296 | 0.331 |

Table 16: Utility values and final ranking of the alternatives (MULTIMOOSRAL method).

| Alternatives | mi' | ti' | Ui' | Vi' | Ki, | Si | Rank |
|---|---|---|---|---|---|---|---|
| A1 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 5.000 | 1 |
| A2 | 0.204 | 0.381 | 0.038 | 0.348 | 0.368 | 1.339 | 4 |
| A3 | 0.000 | 0.180 | 0.000 | 0.000 | 0.000 | 0.180 | 6 |
| A4 | 0.187 | 0.043 | 0.064 | 0.188 | 0.199 | 0.680 | 5 |
| A5 | 0.446 | 0.000 | 0.195 | 0.813 | 0.867 | 2.321 | 2 |
| A6 | 0.398 | 0.061 | 0.163 | 0.707 | 0.756 | 2.085 | 3 |

Table 17: Ranking comparison.

| Alternatives | Ranking order | |
|---|---|---|
| | SF-MULTIMOOSRAL | SF-TOPSIS |
| A1 | 1 | 1 |
| A2 | 4 | 3 |
| A3 | 6 | 5 |
| A4 | 5 | 6 |
| A5 | 2 | 2 |
| A6 | 3 | 4 |

Table 18: Spearman's rank correlation test.

| Spearman's rho | SF_TOPSIS |
|---|---|
| SF_MULTIMOOSRAL | 0.886* |

*Correlation is significant at the 0.05 level (2-tailed).

to calculate the total overall utility values. Table 16 provides the final ranking of the alternatives.

*5.1. Validation and Sensitivity Analysis.* The results obtained by using multi-criteria decision-making (MCDM) methods, especially in a group decision-making setup, are vulnerable to the changes in the given conditions such as changes in the criteria values, alternative and criteria set, exclusion or inclusion of the criteria and alternatives, and changes in the weights, among others [90–92]. Therefore, it is essential to examine the validity testing and checking of stability in the results.

In this paper, for validation purpose, we use the methodology followed in [93–95]. We utilize the score values of the SFEM to carry out the usual steps of the TOPSIS method [96]. TOPSIS allows the researchers to compare the alternatives in terms of Euclidean distance with respect to two extreme points, i.e., positive and negative ideal solutions. It considers the alternatives having farthest distance from negative ideal as the best one. PROBID considers all possible positive ideal solutions and also takes into account the distance from the average point like EDAS. Table 17 shows that the ranking results obtained from our proposed methodology and SF score based TOPSIS are consistent to each other. Table 18 statistically confirms the statement by Spearman's rank correlation test.

To examine the stability in the result, we carry out the sensitivity analysis as conducted in [97–99]. Table 19 exhibits the scheme for sensitivity analysis. We exchange the weights of the top priority criterion, C1, with all others and carry out eight experiments. Figure 3 provides the result of sensitivity analysis and pictorially confirms that our method provides absolutely stable result. However, to statistically confirm the fact, we conduct Friedman test (Table 20) and Kendall's test (Table 21) using the final overall utility values of the alternatives under different experiments. We observe that statistically no significant change is incurred. Figure 4 reflects the findings of Tables 20 and 21.

*5.2. Comparative Analysis of the Present Framework with Some of the Existing Models.* The MULTIMOOSRAL method considers logarithmic approximations in addition to weighted sum and weighted product (as used in WASPAS and CoCoSo methods). Like COPRAS method, MULTIMOOSRAL algorithm also considers ratio system and reference point. Therefore, MULTIMOOSRAL can be considered as an improved version of MCDM method that works with a wide range of performance values of the alternatives. According to Brauers and Zavadskas [100], a combination of three different types of operators provides more reliable and robust solution. Therefore, MULTIMOOSRAL provides reasonably robust and reliable solutions by combining three different types of operators, namely, weighted sum, weighted product, and logarithmic approximations. Further, unlike MOORA and MULTIMOORA approaches (that uses dominance theory), the present method ranks the alternative units using a combined performance scores of four types of utility values. On the other hand, LBWA works efficiently with a large criteria set, reduces the computational complexity, and reasonably offsets the subjective bias. Furthermore, it provides a greater flexibility to the decision makers by varying the values of elasticity coefficient. With these added methodological benefits and use of SFN, our model allows the decision

Table 19: Sensitivity analysis scheme.

| Criteria | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| Original | 0.1698 | 0.1189 | 0.0699 | 0.1321 | 0.1081 | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
| Exp1 | **0.1189** | **0.1698** | 0.0699 | 0.1321 | 0.1081 | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
| Exp2 | **0.0699** | 0.1189 | **0.1698** | 0.1321 | 0.1081 | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
| Exp3 | **0.1321** | 0.1189 | 0.0699 | **0.1698** | 0.1081 | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
| Exp4 | **0.1081** | 0.1189 | 0.0699 | 0.1321 | **0.1698** | 0.0991 | 0.1486 | 0.0793 | 0.0743 |
| Exp5 | **0.0991** | 0.1189 | 0.0699 | 0.1321 | 0.1081 | **0.1698** | 0.1486 | 0.0793 | 0.0743 |
| Exp6 | **0.1486** | 0.1189 | 0.0699 | 0.1321 | 0.1081 | 0.0991 | **0.1698** | 0.0793 | 0.0743 |
| Exp7 | **0.0793** | 0.1189 | 0.0699 | 0.1321 | 0.1081 | 0.0991 | 0.1486 | **0.1698** | 0.0743 |
| Exp8 | **0.0743** | 0.1189 | 0.0699 | 0.1321 | 0.1081 | 0.0991 | 0.1486 | 0.0793 | **0.1698** |

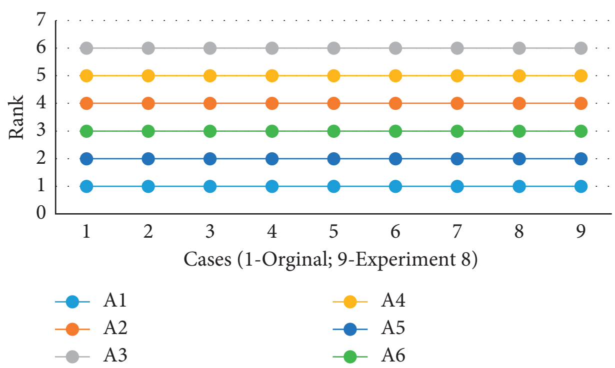


Figure 3: Result of sensitivity analysis.

Table 20: Friedman test result.

| Chi-square | 10.384 |
|---|---|
| df | 8 |
| Asymp. Sig. | 0.239 |

maker to derive more accurate and reliable decisions while working with imprecise information.

## 6. Discussion

We observe that experts put more emphasis on committed leadership, waste reduction, and customer value which are the cornerstone principles of lean. The primary focus is on achieving more with less, and hence, technology usage does not fetch more weight. We find that committed leadership, waste reduction, and customer value are given more weightage by the experts for achieving leanness in SMEs. Furthermore, the results show that medium and small units with focused product line (A1 and A5) score high in terms of leanness. The findings imply that there is a need to focus on microunits and incorporate policies to revive them through effective implementation of LM.

The present paper provides a SFS-based analysis that provides more flexibility with reasonably less complexity to the analysts as compared with IFS, PyFS, PFS, and qROFS. Therefore, our framework has extended the growing strand of literature with a new MCDM framework with uncertain information that can work with

Table 21: Result of Kendall test (Kendall's coefficient of concordance).

| Kendall's W | 0.216 |
|---|---|
| Chi-square | 10.384 |
| df | 8 |
| Asymp. Sig. | 0.239 |

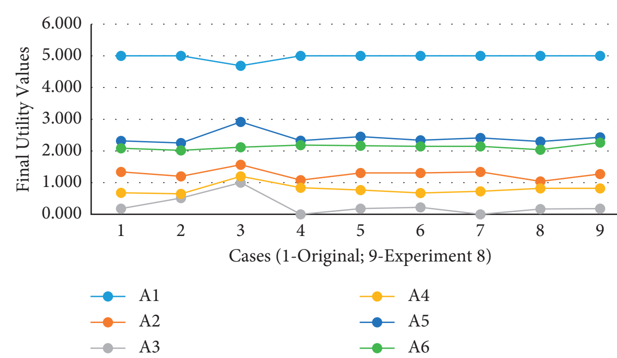


Figure 4: Final overall utility values of the alternatives under different experiments.

larger criteria and alternative set with reasonable accuracy and stability. However, the model proposed in this paper may be fine-tuned with using type 3 fuzzy logic which is an improved version of generalized type 2 fuzzy system for handling susceptibility of MCDM models in handling uncertainties. In recent times, several researchers (for example, [101–103]) have used type 3 fuzzy based analysis in solving complex real-life problems. These models may be used in solving our problem and a comparative analysis may be carried out.

Nevertheless, the findings of the present paper provide an important direction to the strategic decision makers as it is revealed that concentrated effort in product offerings lowers the possibility of waste which might help in achieving leanness. After achieving leanness, the organization may take the practice forward for reaching to the level of maturity and move forward to customization. An organization wide approach supported by top management is the necessity. However, we contend that in Indian context, still microorganizations need policy support and fund mobilization with better governance for achieving leanness.

## 7. Conclusion

In this paper, we have conducted a case study on six MSME sample units producing engineering products. We have presented a new hybrid SF-LBWA-MULTIMOOSRAL framework to carry out a comparative assessment of the leanness of the sample units. We consider 9 criteria from the perspectives of leadership, supplier focus, customer focus, process management, waste, culture, human resource focus, technology use, and communication and awareness. In this aspect, the present study provides a more holistic approach than the existing research papers which multi-criteria-based comparison of MSMEs vis-à-vis leanness is quite rare. The criteria are obtained through literature survey and opinions of the three experts who took part in our study. The experts carried out a field study and rated the sample units. We observe that medium and small units having focused product portfolio score high in terms of leanness. The present paper provides a holistic multi-criteria-based assessment of leanness which is not seen in plenty in Indian context. Further, we propose a novel extension of LBWA and MULTIMOOSRAL with SFN. SFNs have been proven as superior than IFS, PyFS, and PFS as evident from the discussion in the extant literature. Therefore, the present work provides a more flexible and effective framework for group decision making. Further, in the previous work, we have not noticed any attempt to integrate LBWA and MULTIMOOSRAL approach although these methods possess substantial benefits. The result of validation test and sensitivity analysis suggests that our method provides stable and accurate result.

However, one of the limitations of our model is that given the close rating of the criteria, our model may not give distinct partitioning of the criteria. In a further study, one may attempt to examine the causal relationship of the criteria with the soft and hard outcomes of practicing LM. Further, our model may be tested in other complex scenarios. In addition, in the present study, we did not calculate the time complexity which may be another limitation. Nevertheless, we are hopeful that our model may solve other complex real-life problems and the framework of measuring leanness shall provide a holistic and easy way to assess the performance of the MSME units.

## Data Availability

The responses used to support the findings of this study are provided in the paper. For the sake of confidentiality, the names of the respondents are not disclosed.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

All authors contributed equally and significantly in conducting this research work and writing this paper.

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