FACTA UNIVERSITATIS
Series: **Mechanical Engineering** Vol. 21, Nº 3, Special Issue, 2023, pp. 453 - 478
https://doi.org/10.22190/FUME230831037B

Original scientific paper

A SPHERICAL FUZZY BASED DECISION MAKING FRAMEWORK WITH EINSTEIN AGGREGATION FOR COMPARING PREPAREDNESS OF SMEs IN QUALITY 4.0

Sanjib Biswas[1], Darko Božanić[2], Dragan Pamučar[3,4,5], Dragan Marinković[6,7]

[1]Decision Sciences & Operations Management Area,
Calcutta Business School, Diamond Harbour Road, West Bengal, India
[2]Military Academy, University of Defence in Belgrade, Belgrade, Serbia
[3]University of Belgrade, Faculty of Organizational Sciences, Belgrade, Serbia
[4]College of Engineering, Yuan Ze University, Taoyuan City, Taiwan
[5]Department of Computer Science and Mathematics,
Lebanese American University, Lebanon
[6]Faculty of Mechanical Engineering, University of Niš, Niš, Serbia
[7]TU Berlin, Department of Structural Analysis, Berlin, Germany

Abstract. *Researchers work hard to embrace technological changes and redefine the quality management as Quality 4.0 (Q 4.0). In this context, the purpose of the current work is twofold. First, it aims to compare the preparedness of the small and medium enterprises (SMEs) for sustaining in Q4. Second, it intends to propose a novel hybrid spherical fuzzy based multi-criteria group decision-making (MAGDM) framework with Einstein aggregation (EA). A real-life case study on six SMEs is carried out with the help of three experts. For aggregating the individual responses (using spherical fuzzy numbers or SFNs), EA is used. Then two very recent models such as Simple Ranking Process (SRP) and Symmetry Point of Criterion (SPC) are extended using SFN to rank the SMEs. Finally, the validation tests and sensitivity analysis are carried out. It is noted that the application of analytical tools, knowledge management and use of technology under the support and mentorship of visionary leadership are the key criteria for building up the capability to embrace Q 4.0. Interestingly, it is noted that medium scale firms are better prepared than small-scale enterprises. This work is apparently a first of its kind that focuses on SMEs for assessing their quality management practices in Industry 4.0 era.*

Key words: *Quality 4.0, Spherical Fuzzy Sets (SFS), Einstein aggregation, Simple Ranking Process (SRP), Symmetry Point of Criterion (SPC)*

Received: August 31, 2023 / Accepted October 18, 2023
Corresponding author: Darko Božanić
Military Academy, University of Defence in Belgrade, Veljka Lukica Kurjaka 33, 11040, Belgrade, Serbia
E-mail: darko.bozanic@va.mod.gov.rs

1. INTRODUCTION

Quality has been one of the critical factors for the success, survival and growth of any organization irrespective of its scale, products/services, structure and processes. Over the years with the industrial revolutions powered by technological advancement, the fundamental concepts and practices of the quality management have undergone a notable change. Presently, the world is experiencing the phenomenal impact of the fourth industrial revolution (aka Industry 4.0) on the socio-economic, cultural and environmental well-being. Industry 4.0 (I 4.0) is "*the current trend of automation and data exchange in manufacturing technologies, including cyber-physical systems, the Internet of things, cloud computing and cognitive computing and creating the smart factory*" that is characterized by seamless connection and coordination among people, system and technology [1]. The enhanced operational efficiency, creation of new business models, services, and goods, I 4.0 promises to change industrial production. In contrast to traditional forecasting, it allows for real-time production planning and dynamic optimization. Nowadays, affordable and intelligent sensors and wireless networks can capture the product lifecycle data [2-5]. Analysis of data does not require supercomputers anymore [6], and economical cloud and fog computing make data easily approachable [7], for instance, cloud computing services provided by Amazon and Alibaba [8]. IIoT platforms are used for data transmission, storage, and analysis [9].

I 4.0 has prompted Society 5.0 (Soc. 5.0) to place the human being at the center of innovation, technological revolution, and industrial automation. Soc. 5.0, also known as the super intelligent society, aims to leverage sophisticated technology from I 4.0 for the benefit of humanity, promoting connectivity between people and systems in cyberspace with artificial intelligence-assisted results optimization. Soc.5.0 intends to utilize technological developments for improving the quality of living of society by solving socio-economic issues and acts as a driving force in redefining human life. In a nutshell, Soc. 5.0 is a juxtaposition of cyberspace and physical world [10] with the objective of meeting sustainable development goals (SDG).

The bridge between I 4.0 and Soc. 5.0 is by means of Internet of Things (IoT). Case study [11] revealing the enhanced efficacy in the manufacturing industry by reducing the downtime costs have been seen with the use of Industrial- IoT combined with predictive analytics. I 4.0 focuses on enhancing manufacturing efficiency through high-tech techniques [12]. In certain circumstances, the implementation of I 4.0 shows that linkages between persons, systems, and objects can result in an efficient, full, dynamic, and real-time network [13]. Soc. 5.0 is a companion to I 4.0 and promises to transform society for the better welfare of humanity [14]. This civilization serves as a vehicle for social growth, with the goal of having a significant influence on society at all levels, including quality of life and sustainability [15].

Evolution of Quality 4.0 or Q 4.0 [16] alongside the dependency of traditional quality tools unlike Pareto charts and control charts within organizations have been found to emerge. People, Process and Technology are the three driving forces for Q 4.0. A natural evolution from Total Quality Management (TQM) to Q 4.0, not replacing the traditional quality methods; activities inside organizations emerged rapidly and smartly, due to the confluence of Big Data and Artificial Intelligence (AI), united with traditional quality methods. As per KPMG reports, India's budget announcement of an INR50,000 crore fund for the National Research Foundation (NRF) aims to boost the overall research environment in the country, resulting in high-quality innovation. The operational ability of Q 4.0 will encompass a self-diagnostic and self-healing systems with faster delivery for an optimized operating model by providing transformational results in quality [17].

The quality of any product and services is one of the most crucial factor, it gives the company an edge on competitive advantage in the global market. The progression of I 4.0 has provided a catalytic effect to the development in the field of quality management. It is an information driven, real-time, innovation focused, analytical and integrated ecosystem that drives the quality management in the organizations [18-19]. In this regard, we may define Q 4.0 as the digital technology and high-end computation enabled process management to take agile measures for ensuring customer value by providing products and services [20]. Q 4.0 helps to take almost real-time decisions on the product quality using IoT and AI/ML enabled systems and subsequently to discriminate the information to the stakeholders [21-22]. In effect, Q 4.0 provides the organizations the ability to cope up disruptions and uncertainties in a dynamic environment and support the transformation and growth of the organizations [23-27]. However, the concept of Q 4.0 has not been explored comprehensively yet both from conceptual and application perspectives [28-30]. The existing literature shows some recent contributions in exploring various factors that decide the success in embracing Q 4.0. This includes: top management commitment, leadership, ownership to work, organizational culture and transparent communication, capability to critical analysis and problem solving, innovative mind-set, training and development, ability to capture and handle big data, awareness and skill set for conceiving, understanding and applying digital technologies and analytical models for data analysis and drawing actionable insights, organization of wide integration of activities, collaboration of the stakeholders, fund support, etc. [27, 28, 31-39]. Future of Q 4.0 lies in imbibing the essence of quality of work life, ensuring psychological well-being, boosting up morale and character development, empowerment, sharing of knowledge and embracing spirituality coupled with advancement in technology for mankind. The coming era of Society 5.0 calls for upgradation of Q 4.0 to next level, i.e., Q 5.0 [40]. In other words, Q 5.0 shall compose Sociology, Science, Technology, and Religion (SSRT) seamlessly for the development and progress of the humanity and civilization. All these concepts converge to a single point, i.e., inclusive development wherein Small and Medium-Sized Enterprises (SME) are essential part of the movement. Therefore, the need of SMEs to embrace Q 4.0 emerges as a critical issue.

The present work focuses on the assessing the present state of the small and medium enterprises (SMEs) to harness Q 4.0. SMEs play a significant role in gearing India's economic growth in any manufacturing company. They act as effective support systems to large-scale manufacturing, thereby fostering the industries' growth. Many prominent business organizations rely on SMEs as they are the suppliers of the products, and hence SMEs play a vital role in the value creation besides the supply chain management. This sector is currently termed as "engine growth of India" [41]. As of date, approximately 42.50 million registered and unregistered SMEs are operational in India. The Indian Economy experts have said that the SME sector has a huge potential and can contribute to achieving the target of the Nation's Manufacturing policy, which is assumed to contribute 25% of India's GDP in 2022. In India, SMEs generate employment at a cheaper cost of capital, and it also helps balance the imbalances amongst various regions [42]. I 4.0 or Smart Manufacturing has many offerings regarding opportunities for the SME sector, which can help them enhance their competitiveness. Since SMEs do not operate on a very large scale, it becomes comparatively easy for them to implement and experiment with digital transformation faster than the bigger organizations. In recent times, SMEs have been witnessing significant transformations due to new-age technologies driven mainly by AI/ML and IoT. The advanced technologies nowadays are helping SMEs to automate and generate intelligence from their day-to-day activities. The adaptation of new-gen technology has become essential for the growth and survival of SMEs in the new normal [43].

The analysis of the scientific literature also says that there has been a shift in production management towards intelligent manufacturing, which is based on data analytics techniques. SME's needs to embrace I 4.0 at a much faster pace as tech-based solutions have immense potential to enrich and fetch greater revenues for the SME's and help in the continuity of the business during pandemic Disruption. The effectiveness in adapting quality management system for attaining improved performance in SMEs can be found established in ISO 9001:2015. The laid down provision establishes the generic requirements that are applicable to any organization, regardless of its type or size, or the products and services it provides in a two-fold way i.e., to comply by the regulations and meet consistency and enhance customer satisfaction [44]. Effective adaptation of the philosophy of TQM and right intent to implement the soft (e.g., leadership and commitment of the top management, customer focus, organization wide quality culture, training and development of the employees) and hard practices (for instance, process analysis and continuous improvement, adopting advanced technology, implementation of standards and specifications, information analysis) significantly help the organizations to improve the sustainability performance [22]. Implementation of TQM is one of the major sources of competitive advantage for the SMEs [45].

In this paper we present a case study on six SMEs. These SMEs mostly deal with engineering products for supplying to the large organizations from the public sector like Indian railways and private sectors like automobile and industrial products. The SMEs are located in the eastern part of India.

We aim to investigate their capabilities or readiness in sustaining in the era of I 4.0 and Soc. 5.0. We derive a list of critical factors that decide the success or failure in I 4.0 and Soc. 5.0 for the SMEs. A group of three experts participated in the investigation process. The experts have substantial expertise in quality engineering, lean manufacturing, process analysis, strategy formulation and technology management with work experiences of 18 years, 21 years and more than 25 years respectively. The experts visited the plants of the SMEs along with a support team, observed the process, discussed with the management and staff and collected evidences. Based on their opinions the alternatives were compared on the attributes that manifest the critical success factors as identified through literature review and experts' views. For analysis purpose, an integrated MAGDM framework using SPC (used to derive the criteria weights) and SRP (applied for ranking the SMEs). To deal with the subjective bias associated with the opinions of the experts, SFS is used. The original framework of SPC and SRP are extended by using SFNs.

This paper offers two contributions:

Managerial contributions: The present paper provides a comparison of readiness of SMEs based on critical success factors of total quality management in I 4.0 while heading towards Soc. 5.0. The growth of the economy of a country largely depends on the contributions of the SMEs. The competitiveness of the SMEs is significantly dependent on quality. Furthermore, as the large organizations have been gearing to adapt new technologies, it is quite imperative for the SMEs to rise on the occasion and usher in implementing Q 4.0.

Based on the findings within our search we contend that this kind of study in Indian context adds value due to scantiness of literature vis-à-vis our problem.

Technical contributions: The ongoing work proposes a new hybrid SFN based decision support system using an integrated SPC-SRP model applying EA. The SRP method is free from the effect of selection of appropriate normalization scheme, which acts as a potential cause of improper outcome and instability of the solution. Further, SRP model is able to consider individual criterion impact and works considerably under complexities [46]. To complement the benefits of the SRP method, the present work uses another newly developed model such as SPC [47] for deriving criteria weights. SPC method considers the symmetry point (a middle point of the interval decided by the upper and lower values) for each criterion. The method balances the effect of the criteria and is free from normalization. Further, it considers absolute deviation and is very easy to implement.

The concept of SFS has evolved gradually as an advanced extension of Fuzzy Sets (FS) [48], Intuitionistic Fuzzy Sets (IFS) [49], type 2 IFS [50], interval valued IFS [51], Neutrosophic Fuzzy Sets (NFS) [52], Picture Fuzzy Sets (PFS) [53-54], Pythagorean Fuzzy Sets (PyFS) [55], and q Rung Orthopair Fuzzy Sets (qROFS) [56]. SFS uses three dimensional geometrical properties with degree of positive (μ), neutral (η) and negative memberships (ϑ) [57]. The relative advantages of SFS [57-59] over the others are given below:

- SFS considers μ, η and ϑ unlike FS, IFS, PyFS and qROFS,
- Greater flexibility in selection of membership values such that sum of square of such values lie between 0 and 1 and that way it solves the issue with PFS,
- Enables the researchers to better work with vagueness and uncertainty for a granular analysis,
- Three-dimensional space is comparatively lesser complex than qROFS and Fermatean Fuzzy Sets (FFS) [60].

The existing literature shows a very limited number of applications of SPC method [61-63] and almost no application of SRP model. Also, prior to the present work no other studies have attempted to combine these two models that do not require any consideration for the type of normalization. Furthermore, the present work provides a novel SFS based extension of SRP and SPC methods using EA as an aggregate operator (AO). EA provides flexibility to the researchers and enables a granular analysis under uncertainty. Hence, the framework proposed in this paper extends substantial technical benefits in solving complex real-life problems.

2. Preliminaries

In this section, some of the preliminary definitions and operations related to SFS are briefly described. For detailed descriptions of the concepts and operations and their proofs the readers may refer to the past contributions [57-59, 64-67]. SFS has been extensively used by the researchers in building decision-making models and their applications in several real-life problems. Some of the recent applications are mentioned in Table 1.

Table 1 Examples of applications of SFS

Application area	References
Medical diagnosis	[68-69]
3D printer selection	[70]
Location selection for waste disposal	[71]
Insurance policy selection	[72]
Supplier selection	[73]
Process analysis	[74-75]
Planning for drone based city logistics services	[66]
Energy management	[76]
Formulation of advertisement strategy	[77]
Agricultural management	[78]
Personnel selection for sales profession	[79]

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

$$\tilde{S} = \left\{ \left\langle x, (\mu(x), \eta(x), \vartheta(x)) \middle| x \in U \right\rangle \right\} \tag{1}$$

where U is the universe of discourse, μ, η and ϑ: $U \rightarrow [0, 1]$.

The relationship is given below:

$$0 \leq \mu^2 + \eta^2 + \vartheta^2 \leq 1 \tag{2}$$

Definition 2. *Basic Operations.* Let, a Spherical Fuzzy Number (SFN) is represented as $S = \{\mu, \eta, \vartheta\}$ and S_1 and S_2 are the two SFNs. Some of the basic operations are defined as:

Addition:

$$S_1 \oplus S_2 = \left\{ (\mu_1^2 + \mu_2^2 - \mu_1^2\mu_2^2)^{\frac{1}{2}}, \vartheta_1\vartheta_2, ((1-\mu_2^2)\eta_1^2 + (1-\mu_1^2)\eta_2^2 - \eta_1^2\eta_2^2)^{\frac{1}{2}} \right\} \tag{3}$$

Multiplication:

$$S_1 \otimes S_2 = \left\{ \mu_1\mu_2, (\vartheta_1^2 + \vartheta_2^2 - \vartheta_1^2\vartheta_2^2)^{\frac{1}{2}}, ((1-\vartheta_2^2)\eta_1^2 + (1-\vartheta_1^2)\eta_2^2 - \eta_1^2\eta_2^2)^{\frac{1}{2}} \right\} \tag{4}$$

Multiplication by a scalar; w > 0

$$wS = \left\{ (1-(1-\mu^2)^w)^{\frac{1}{2}}, \vartheta^w, ((1-\mu^2)^w - (1-\mu^2-\eta^2)^w)^{\frac{1}{2}} \right\} \tag{5}$$

Power of SFN

Let $w > 0$ denotes the power of S wherein w is a scalar quantity. Then we have the following definition

$$S^w = \left\{ \mu^w, (1-(1-\vartheta^2)^w)^{\frac{1}{2}}, ((1-\vartheta^2)^w - (1-\vartheta^2-\eta^2)^w)^{\frac{1}{2}} \right\} \tag{6}$$

Compliment of S

$$S^c = \{\vartheta, \eta, \mu\} \tag{7}$$

Definition 3. *Weighted Aggregation Operators (AO)*. Let w = {w_1, w_2 …w_n} be the weights of the SFNs S_1, S_2….S_n, n is a finite number and sum of weights = 1. Then the basic weighted averages are defined as follows:

Spherical fuzzy weighted arithmetic average (SFWAA)

$$SFWAA_w(S_1, S_2, S_3, \ldots\ldots S_n) = \left\{(1-\prod_{i=1}^{n}(1-\mu_i^2)^{w_i})^{\frac{1}{2}}, \prod_{i=1}^{n}\vartheta_i^{w_i}, (\prod_{i=1}^{n}(1-\mu_i^2)^{w_i} - \prod_{i=1}^{n}(1-\mu_i^2-\eta_i^2)^{w_i})^{\frac{1}{2}}\right\} \tag{8}$$

Spherical fuzzy weighted geometric average (SFWGA)

$$SFWGA_w(S_1, S_2, S_3, \ldots\ldots S_n) = \left\{\prod_{i=1}^{n}\mu_i^{w_i}, (1-\prod_{i=1}^{n}(1-\vartheta_i^2)^{w_i})^{\frac{1}{2}}, (\prod_{i=1}^{n}(1-\vartheta_i^2)^{w_i} - \prod_{i=1}^{n}(1-\vartheta_i^2-\eta_i^2)^{w_i})^{\frac{1}{2}}\right\} \tag{9}$$

Definition 4. *Einstein t-norm and s-norm*. The t-norm and s-norm are defined as:

$$\tilde{T}_e = \frac{dl}{\sqrt{1+(1-d^2).(1-l^2)}} \tag{10}$$

$$\tilde{S}_e(d,l) = \frac{\sqrt{d^2+l^2}}{\sqrt{1+d^2\cdot l^2}} \tag{11}$$

For details about the properties of Einstein t-norm and s-norm and related spherical fuzzy Einstein operators, one may refer to the work of [80].

Definition 5. *Spherical fuzzy Einstein weighted average (SFEWA)* is defined [80] as:

$$SFEWA(S_1, S_2, S_3, \ldots\ldots S_n) = \left(\begin{array}{c} \dfrac{\sqrt{\prod_{k=1}^{n}(1+\mu_k^2)^{w_k} - \prod_{k=1}^{n}(1-\mu_k^2)^{w_k}}}{\sqrt{\prod_{k=1}^{n}(1+\mu_k^2)^{w_k} + \prod_{k=1}^{n}(1-\mu_k^2)^{w_k}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{n}(\eta_k)^{w_k}}{\sqrt{\prod_{k=1}^{n}(2-\eta_k^2)^{w_k} + \prod_{k=1}^{n}(\eta_k^2)^{w_k}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{n}(\vartheta_k)^{w_k}}{\sqrt{\prod_{k=1}^{n}(2-\vartheta_k^2)^{w_k} + \prod_{k=1}^{n}(\vartheta_k^2)^{w_k}}} \end{array}\right) \tag{12}$$

Definition 6. *Score and Accuracy Function.* The score and the accuracy functions are defined [59, 64] as:

$$\Im = \frac{1}{3}(2 + \mu - \eta - \vartheta) \tag{13}$$

$$\Re = \mu - \vartheta \tag{14}$$

The certainty function is found as:

$$\mathbb{C} = \mu \tag{15}$$

Rules for comparison of the SFNs

If $\Im_{S_1} > \Im_{S_2}$ then $S_1 \succ S_2$

Else if $\Im_{S_1} < \Im_{S_2}$ then $S_1 \prec S_2$

If $\Im_{S_1} = \Im_{S_2}$ then if $\Re_{S_1} > \Re_{S_2}$ then $S_1 \succ S_2$

Otherwise, if $\Re_{S_1} < \Re_{S_2}$ then $S_1 \prec S_2$

If $\Im_{S_1} = \Im_{S_2}$ and $\Re_{S_1} = \Re_{S_2}$ then if $\mathbb{C}_{S_1} > \mathbb{C}_{S_2}$ then $S_1 \succ S_2$

Definition 7. Defuzzification

The defuzzified value of a SFN is obtained as:

$$\partial = \left(\left|100 \times [(3\mu - \frac{\eta}{2})^2 - (\frac{\vartheta}{2} - \eta)^2]\right|\right)^{\frac{1}{2}} \tag{16}$$

3. Proposed Framework using SF-SPC-SRP with EA

The present section illustrates the procedural steps of the proposed framework briefly.

Step 1. Identification of the criteria for comparing the SMEs included in the study. It is seen from the past studies that there is a scantiness of work concentrating comprehensively on exploring the critical issues pertaining to adaptation of Q 4.0 and subsequently, Soc. 5.0. Further, it is observed that apparently no prior work exists that attempted to compare the readiness of the SMEs to embrace Q 4.0. However, from the allied studies [22, 27-28, 31-39, 44] it can be made out that for a successful transition to Q 4.0 and eventually, to Soc. 5.0, the SMEs need to be mentored by the visionary leadership, supported with resources in a congenial work environment, trained to use advanced technologies and analytical tools and develop a knowledge base. In line with the crux of the past studies, the present work decided to include the criteria listed in Table 2 for assessing the preparedness of the SMEs.

Table 2 Description of the criteria

S/L	Criteria	Description	Effect
C1	Organizational Structure	Lean and flat structure	(+)
C2	Leadership Support	Governance, commitment, resource support, adaptable, clarity in the vision and mission, approachable, fast decision making	(+)
C3	Organizational Culture	Focus on process, problem solving and team work attitude, open to ideas and suggestions, innovativeness	(+)
C4	Level of Automation	Use of technology in process	(+)
C5	Information Sharing	Assimilation and dissipation of information, access to information, open communication, transparency	(+)
C6	Data Management and Use of Analytical Tools	Data capturing, storage, database management and analysis of data using scientific methods	(+)
C7	Collaboration	Collaboration with the suppliers and customers, co-makers, collaboration and coordination with the stakeholders	(+)
C8	Knowledge Management	Continuous learning and use in action, training and upskilling, manpower planning, retention, R&D	(+)
C9	Business Risk	Fund and resource shortage, vulnerability to disruptions, absence of risk management plans, security and privacy	(-)

Step 2. Selection of the linguistic scale for rating of the criteria and compared units (i.e., alternatives). The linguistic scales and corresponding SFNs used for finding the comparative weights of the criteria and rating of the alternatives are given in Table 3.

Step 3. *Selection of the expert panel members*. In this study, a group of three experts (E_1, E_2 and E_3) took part in evaluating the alternatives. The experts have substantial work experience of 15, 22 and 28 years respectively and expertise in quality management, lean manufacturing, process management and analysis, technology implementation, manufacturing and managing large-scale operations.

Table 3 Linguistic scale and SFNs used for rating

Linguistic Term	Code	μ	η	ϑ
Very High/ Very Good	VH/ VG	0.9	0.1	0.1
High/ Good	H/ G	0.7	0.3	0.3
Medium	M	0.5	0.5	0.5
Low/ Poor	L/ P	0.3	0.3	0.7
Very Low/ Very Poor	VL/ VP	0.1	0.1	0.9

Step 4. *Rating of the criteria and alternative units*. Let i = 1, 2…m is the number of alternatives (i.e., the number of sample units under comparison) A_i being the i^{th} alternative; C_j denotes the j^{th} criterion (j = 1,2….n); k=1,2…r is the number of experts/decision maker who took part in the rating/ evaluation. The SFN corresponding to the rating of the performance of A_i with respect to C_j as opined by the k^{th} decision maker in linguistic term is given by:

$$\xi_{ij}^{r} = \{\mu_{ij}^{r}, \eta_{ij}^{r}, \vartheta_{ij}^{r}\}$$

Step 5. Aggregation of individual ratings and formulation of the decision matrix. Using EA as the AO (see expression (12)), the aggregation is done as follows:

$$\xi_{ij} = \{\mu_{ij}, \eta_{ij}, \vartheta_{ij}\} = SFEWA(\xi_{ij}^1, \xi_{ij}^2, \xi_{ij}^3, ...\xi_{ij}^r) = \begin{pmatrix} \dfrac{\sqrt{\prod_{k=1}^{r}(1+(\mu_{ij}^k)^2)^{w_k} - \prod_{k=1}^{r}(1-(\mu_{ij}^k)^2)^{w_k}}}{\sqrt{\prod_{k=1}^{r}(1+(\mu_{ij}^k)^2)^{w_k} + \prod_{k=1}^{r}(1-(\mu_{ij}^k)^2)^{w_k}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{r}(\eta_{ij}^k)^{w_k}}{\sqrt{\prod_{k=1}^{n}(2-(\eta_{ij}^k)^2)^{w_k} + \prod_{k=1}^{n}((\eta_{ij}^k)^2)^{w_k}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{r}(\vartheta_{ij}^k)^{w_k}}{\sqrt{\prod_{k=1}^{r}(2-(\vartheta_{ij}^k)^2)^{w_k} + \prod_{k=1}^{r}((\vartheta_{ij}^k)^2)^{w_k}}} \end{pmatrix} \tag{17}$$

Similarly, the performance values of all the alternatives with respect to all criteria are obtained and the decision matrix is formulated as:

$$\tilde{D} = (\xi_{ij})_{m\times n} = \begin{pmatrix} \xi_{11} & \xi_{12} & \dots & \dots & \xi_{1n} \\ \xi_{21} & \xi_{22} & \dots & \dots & \xi_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \xi_{m1} & \xi_{m2} & \dots & \dots & \xi_{mn} \end{pmatrix}_{m\times n} \tag{18}$$

It is to be noted that all the elements of the decision matrix are SFNs, i.e.:

$$\xi_{11} = \{\mu_{11}, \eta_{11}, \vartheta_{11}\},\ \xi_{12} = \{\mu_{12}, \eta_{12}, \vartheta_{12}\},\ \xi_{mn} = \{\mu_{mn}, \eta_{mn}, \vartheta_{mn}\}$$

Step 6. Derive the score matrix. Using the definition given by Eq. (13), the scores of the elements of the decision matrix are obtained as

$$\Im_{ij} = Score(\xi_{ij}) = \frac{1}{3}(2+\mu_{ij} - \eta_{ij} - \vartheta_{ij}) \tag{19}$$

Accordingly, the score matrix is given as:

$$\Psi = (\Im_{ij})_{m\times n} = \begin{pmatrix} \Im_{11} & \Im_{12} & \dots & \dots & \Im_{1n} \\ \Im_{21} & \Im_{22} & \dots & \dots & \Im_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \Im_{m1} & \Im_{m2} & \dots & \dots & \Im_{mn} \end{pmatrix}_{m\times n} \tag{20}$$

Now the weights of the criteria are calculated using the conventional steps of the SPC method [47].

S*tep 7*. *Calculate the symmetry points of the performance values with respect to each criterion*. The symmetry point for each criterion is the middle value of the interval and is calculated as:

$$SP_j = \frac{Min(\Im_{ij}) + Max(\Im_{ij})}{2}; \; i = 1,2...m; \; \forall j \in [1,n] \tag{21}$$

Step 8. *Construct the absolute distance matrix*. The elements of the absolute distance matrix are given by:

$$\Delta = (\delta_{ij})_{m\times n} = \begin{pmatrix} \delta_{11} & \delta_{12} & .... & \delta_{1n} \\ \delta_{21} & \delta_{22} & .... & \delta_{2n} \\ ..... & ..... & .... & ..... \\ \delta_{m1} & \delta_{m2} & .... & \delta_{mn} \end{pmatrix}_{m\times n} \tag{22}$$

$$\delta_{11} = \left|\Im_{11} - SP_1\right|, \delta_{12} = \left|\Im_{12} - SP_2\right|, ..., \delta_{mn} = \left|\Im_{mn} - SP_n\right|$$

Step 9. *Construct the matrix of the moduli of the symmetry*. The modulus of the ith alternative with respect to the jth criterion is defined as the averaged absolute distance from C_j. The values (r_{ij}) are calculated as:

$$r_{mn} = \frac{\frac{\sum_{i=1}^{m} \delta_{in}}{m}}{\Im_{mn}} \tag{23}$$

Accordingly, the matrix R is formulated.

Step 10. *Derive the modulus of the symmetry criterion*. The modulus of the symmetry criterion is obtained by averaging the elements of the corresponding column of *R* matrix. Accordingly, a row vector is formulated whose elements are given by:

$$Q = (q_{1j})_{1\times n} = \left(\frac{\sum_{i=1}^{m} r_{i1}}{m}, \frac{\sum_{i=1}^{m} r_{i2}}{m}, ..., \frac{\sum_{i=1}^{m} r_{in}}{m} \right); \; j = 1,2...n \tag{24}$$

Step 11. Derive the weights of the criteria. The weight of the j[th] criterion is obtained as:

$$\omega_j = \frac{q_j}{\sum_{j=1}^{n} q_j};\ \sum_{j=1}^{n} \omega_j = 1 \tag{25}$$

Using the weights as derived at step 11, the ranking of the alternatives are done in the subsequent steps based on SRP [46].

Step 12. Formulation of the ranking matrix. Using the score matrix (obtained at step 6) the alternatives are ranked with respect to each criterion. The alternative with highest $\Im_{ij}$ value will be ranked first if the desirable effect is maximization whereas the alternative with lowest $\Im_{ij}$ value will be ranked first if the desirable effect is minimization. Accordingly, the ranking matrix is formulated as Φ whose each element is the rank of the i[th] alternative with respect to the j[th] criterion, $O_{i(j)}$.

Step 13. Formulate the weighted ranking matrix. The elements of the weighted ranking matrix is given by:

$$v_{i(j)} = \omega_j O_{i(j)} \tag{26}$$

Step 14. Calculate the total ranking score for each alternative. The total ranking score for each alternative is calculated as:

$$RS_i = \sum_{j=1}^{n} v_{i(j)} \tag{27}$$

Step 15. Find out the priority score of the alternatives. The priority score for each alternative is calculated as:

$$P_i = m - RS_i \tag{28}$$

Decision rule:

The higher is the value of the priority score, preferred is the alternative over the others.

4. CASE STUDY

In this paper we present a case study on six SMEs (which we call as alternatives in our study), located in the eastern part of India. We aim to investigate their capabilities or readiness in sustaining in the era of I 4.0 and Soc. 5.0. Our analysis is grounded on the theoretical perspectives of Q 4.0. We derive a list of critical factors that decide the success or failure in I 4.0 and Soc. 5.0 for the SMEs. A group of three experts have participated in the investigation process. The experts visited the plants along with a support team, observed the process, discussed with the management and staff and collected evidences. Based on their opinions the alternatives have been compared on the attributes that manifest the critical success factors as identified through literature review and experts' views. For analysis purpose, we use a new integrated SF-SPC-SRP framework in this paper. The research framework for this paper is illustrated by Fig. 1.

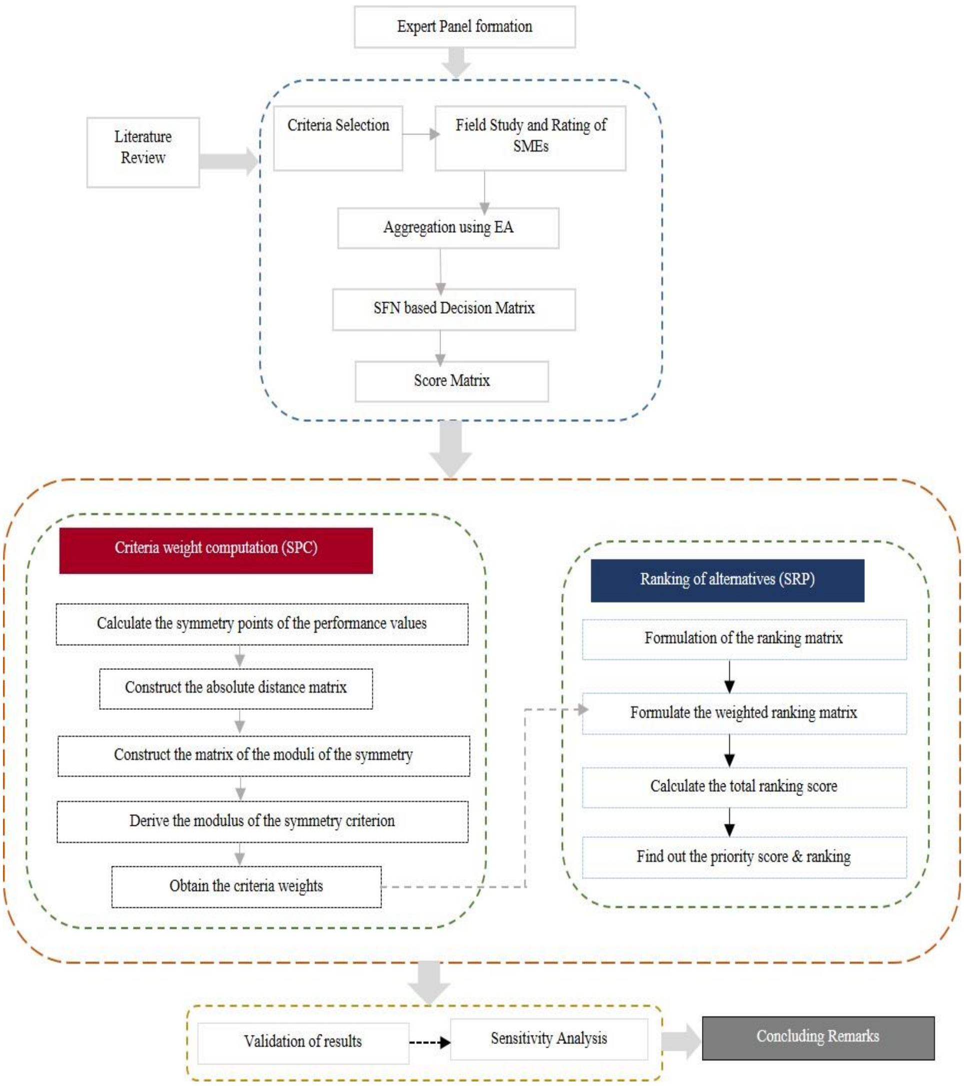

Fig. 1 Flow chart of the research

Table 4 provides the short description of the sample units. The sample units have been visited, diagnosed and rated with respect to the criteria as given in the Table 2 by the experts. The rating and concerned data analysis is presented in the next section.

Table 4 SME organizations under study

Unit	Scale of Business	Product/Service	Annual Turnover (Rs. Crore)
A1	Small	Fabrication, Forging, and Heat treatment machine items	28
A2	Small	Machine Tools and inspection instruments, and spare parts	20
A3	Medium	Welding items	200
A4	Small	Battery charger, transformer, L.T. control panel	30
A5	Medium	Conveyor components, heavy structural fabrication items	15
A6	Small	PVC Pipe and related products	12

5. Findings

In this section, we present the brief summary of the data analysis. Table 5 provides the rating given by the experts for evaluating the SMEs under study. The corresponding SFN values can be obtained from the Table 3. Putting the corresponding SFNs we apply the AO such as SFEWA (see Eq. (17)) to aggregate the opinions of the experts (in our case the number of experts, $r = 3$). All experts are given equal priority (i.e., 1/3). Table 6 provides the SFN based decision matrix, obtained by aggregating the ratings of the three experts on the six SMEs under consideration.

Table 5 Evaluation of SMEs by the Experts

Expert	Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
	Alternatives	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
Expert 1	A1	VG	VG	M	G	G	M	M	VG	M
	A2	G	VG	M	G	M	P	P	M	M
	A3	VG	VG	G	M	G	G	VP	G	P
	A4	M	G	P	VG	VP	M	M	P	VP
	A5	G	M	VG	M	G	M	G	M	M
	A6	P	G	M	G	P	VP	M	M	VP
Expert 2	A1	G	VG	M	G	G	G	G	VG	P
	A2	G	M	M	M	M	P	M	G	M
	A3	M	G	G	P	P	VG	P	M	VP
	A4	G	M	VP	VG	VP	M	VP	P	VP
	A5	M	VP	VG	M	G	P	G	M	M
	A6	P	M	M	G	VP	VP	M	M	VP
Expert 3	A1	VG	VG	G	VG	M	G	M	G	M
	A2	VG	G	G	M	G	VP	P	M	P
	A3	G	G	M	P	M	G	VP	M	M
	A4	P	M	P	G	VP	M	P	VP	P
	A5	G	P	G	M	G	P	M	P	M
	A6	VP	M	M	G	P	VP	M	M	VP

$$\xi_{14}\{\mu_{14},\eta_{14},\vartheta_{14}\} = SFEWA(\xi_{14}^{1},\xi_{14}^{2},\xi_{14}^{3}) =$$

$$= \left(\begin{array}{c} \dfrac{\sqrt{\prod_{k=1}^{3}(1+(\mu_{14}^{k})^{2})^{\frac{1}{3}} - \prod_{k=1}^{3}(1-(\mu_{14}^{k})^{2})^{\frac{1}{3}}}}{\sqrt{\prod_{k=1}^{3}(1+(\mu_{14}^{k})^{2})^{\frac{1}{3}} + \prod_{k=1}^{r}(1-(\mu_{14}^{k})^{2})^{\frac{1}{3}}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{3}(\eta_{14}^{k})^{\frac{1}{3}}}{\sqrt{\prod_{k=1}^{3}(2-(\eta_{14}^{k})^{2})^{\frac{1}{3}} + \prod_{k=1}^{3}((\eta_{14}^{k})^{2})^{\frac{1}{3}}}}, \\ \dfrac{\sqrt{2}\prod_{k=1}^{3}(\vartheta_{14}^{k})^{\frac{1}{3}}}{\sqrt{\prod_{k=1}^{3}(2-(\vartheta_{14}^{k})^{2})^{\frac{1}{3}} + \prod_{k=1}^{3}((\vartheta_{14}^{k})^{2})^{\frac{1}{3}}}} \end{array} \right) = (0.791, 0.209, 0.209)$$

Table 6 SFN based decision matrix

Criteria		C1			C2			C3	
Alternatives		(+)			(+)			(+)	
A1	0.85	0.145	0.145	0.900	0.100	0.100	0.579	0.424	0.424
A2	0.791	0.209	0.209	0.751	0.250	0.250	0.579	0.424	0.424
A3	0.751	0.250	0.250	0.791	0.209	0.209	0.645	0.357	0.357
A4	0.535	0.357	0.479	0.579	0.424	0.424	0.252	0.209	0.766
A5	0.645	0.357	0.357	0.344	0.250	0.693	0.855	0.145	0.145
A6	0.252	0.209	0.766	0.579	0.424	0.424	0.500	0.500	0.500
Criteria		C4			C5			C6	
Alternatives		(+)			(+)			(+)	
A1	0.791	0.209	0.209	0.645	0.357	0.357	0.645	0.357	0.357
A2	0.579	0.424	0.424	0.579	0.424	0.424	0.252	0.209	0.766
A3	0.380	0.357	0.629	0.535	0.357	0.479	0.791	0.209	0.209
A4	0.855	0.145	0.145	0.100	0.100	0.900	0.500	0.500	0.500
A5	0.500	0.500	0.500	0.700	0.300	0.300	0.380	0.357	0.629
A6	0.700	0.300	0.300	0.252	0.209	0.766	0.100	0.100	0.900
Criteria		C7			C8			C9	
Alternatives		(+)			(+)			(-)	
A1	0.579	0.424	0.424	0.855	0.145	0.145	0.445	0.424	0.562
A2	0.380	0.357	0.629	0.579	0.424	0.424	0.445	0.424	0.562
A3	0.192	0.145	0.833	0.579	0.424	0.424	0.344	0.250	0.693
A4	0.344	0.250	0.693	0.252	0.209	0.766	0.192	0.145	0.833
A5	0.645	0.357	0.357	0.445	0.424	0.562	0.500	0.500	0.500
A6	0.500	0.500	0.500	0.500	0.500	0.500	0.100	0.100	0.900

The next step is to derive the score values of all elements of the decision matrix for constructing the score matrix (see Table 7).

Table 7 Score matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Alternatives	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
A1	0.855	0.900	0.577	0.791	0.643	0.643	0.577	0.855	0.486
A2	0.791	0.750	0.577	0.577	0.577	0.426	0.464	0.577	0.486
A3	0.750	0.791	0.643	0.464	0.566	0.791	0.405	0.577	0.467
A4	0.566	0.577	0.426	0.855	0.367	0.500	0.467	0.426	0.405
A5	0.643	0.467	0.855	0.500	0.700	0.464	0.643	0.486	0.500
A6	0.426	0.577	0.500	0.700	0.426	0.367	0.500	0.500	0.367

Using the definition given by Eq. (19), the score of the element of the decision matrix are obtained as:

$$\Im_{14} = Score(\xi_{14}) = \frac{1}{3}(2+\mu_{14}-\eta_{14}-\vartheta_{14}) = \frac{1}{3}(2+0.791-0.209-0.209) = 0.791$$

Now the weights of the criteria are calculated using the conventional steps of the SPC method. First, the symmetry points of the performance values with respect to each criterion are calculated. For example, the symmetry point for the 4th criterion is calculated as:

$$SP_4 = \frac{Min(\Im_{i4})+Max(\Im_{i4})}{2}\ (where,\ i=1,2...6) = \frac{0.855+0.464}{2} = 0.660$$

Similarly, the other values are calculated as:

$$SP_1 = 0.640; SP_2 = 0.683; SP_3 = 0.640; SP_5 = 0.533;$$
$$SP_6 = 0.579; SP_7 = 0.524; SP_8 = 0.640; SP_9 = 0.433$$

The next step is to construct the absolute distance matrix as given in Table 8.

Table 8 Absolute distance matrix

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.2148	0.2166	0.0631	0.1311	0.1100	0.0646	0.0532	0.2148	0.0528
A2	0.1505	0.0669	0.0631	0.0826	0.0438	0.1532	0.0595	0.0631	0.0528
A3	0.1100	0.1074	0.0031	0.1953	0.0326	0.2121	0.1194	0.0631	0.0334
A4	0.0743	0.1062	0.2148	0.1953	0.1667	0.0787	0.0572	0.2148	0.0288
A5	0.0031	0.2166	0.2148	0.1597	0.1667	0.1143	0.1194	0.1541	0.0667
A6	0.2148	0.1062	0.1403	0.0403	0.1078	0.2121	0.0239	0.1403	0.0667

$$\delta_{11} = \left|\Im_{11} - SP_1\right| = \left|0.855-0.640\right| = 0.215$$
$$\delta_{14} = \left|\Im_{14} - SP_4\right| = \left|0.791-0.660\right| = 0.131$$
$$\delta_{63} = \left|\Im_{63} - SP_3\right| = \left|0.500-0.640\right| = 0.140$$
$$...$$

In the subsequent step, the matrix of the moduli of the symmetry is constructed (see Table 9). For example:

$$r_{11}=\frac{\frac{\sum_{i=1}^{6}\delta_{i1}}{6}}{\Im_{11}}=0.1496,\ r_{12}=\frac{\frac{\sum_{i=1}^{6}\delta_{i2}}{6}}{\Im_{12}}=0.1519,\ r_{61}=\frac{\frac{\sum_{i=1}^{6}\delta_{i1}}{6}}{\Im_{61}}=0.3005,\ r_{69}=\frac{\frac{\sum_{i=1}^{6}\delta_{i9}}{6}}{\Im_{69}}=0.1369$$

Table 9 Matrix of moduli of symmetry

Alternatives	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.1496	0.1519	0.2019	0.1695	0.1626	0.2163	0.1250	0.1657	0.1033
A2	0.1617	0.1822	0.2019	0.2323	0.1812	0.3270	0.1553	0.2455	0.1033
A3	0.1705	0.1728	0.1811	0.2886	0.1848	0.1760	0.1783	0.2455	0.1075
A4	0.2260	0.2368	0.2738	0.1568	0.2853	0.2783	0.1545	0.3330	0.1241
A5	0.1988	0.2928	0.1363	0.2681	0.1494	0.2997	0.1121	0.2915	0.1004
A6	0.3005	0.2368	0.2331	0.1915	0.2458	0.3795	0.1442	0.2834	0.1369

Now we proceed to derive the modulus of the symmetry criterion (Q_j) using Eq. (23) and subsequently, the criteria weights (W_j) are calculated using Eq. (24). The results are summarized in Table 10.

Table 10 Moduli of the symmetry criteria and weights

	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sum
Q	0.2012	0.2122	0.2047	0.2178	0.2015	0.2795	0.1449	0.2608	0.1126	1.835
Wj	0.1096	0.1156	0.1115	0.1187	0.1098	0.1523	0.0790	0.1421	0.0613	1

$$Q_1=\frac{\sum_{i=1}^{m}r_{i1}}{6}=\frac{0.1496+0.1617+0.1705+0.2260+0.1988+0.3005}{6}=0.2012$$

$$W_1=\frac{0.2012}{0.2012+0.2112+.....+0.1126}=\frac{0.2012}{1.835}=0.1096$$

It is seen that enhanced use of analytical tools (C6), retention and management of knowledge (C8) and automation (C4) under the guidance and support of the top management (C2) are given top priorities by the expert team. The alternatives are now ranked in the subsequent steps based on SRP method. Using the score matrix (see Table 9) the alternatives are ranked with respect to each criterion. Accordingly, the ranking matrix is formulated (see Table 11).

Table 11 Ranking matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Alternatives	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
A1	1	1	3	2	2	2	2	1	4
A2	2	3	4	4	3	5	5	2	5
A3	3	2	2	6	4	1	6	3	3
A4	5	4	6	1	6	3	4	6	2
A5	4	6	1	5	1	4	1	5	6
A6	6	5	5	3	5	6	3	4	1

Now the weighted ranking matrix is obtained by using the criteria weights (given in Table 10). Table 12 provides the weighted ranking matrix.

Table 12 Weighted ranking matrix

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9
Alternatives	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(-)
A1	0.1096	0.1156	0.3346	0.2374	0.2196	0.3046	0.1579	0.1421	0.2454
A2	0.2193	0.3469	0.4462	0.4747	0.3295	0.7615	0.3948	0.2842	0.3067
A3	0.3289	0.2313	0.2231	0.7121	0.4393	0.1523	0.4737	0.4263	0.1840
A4	0.5481	0.4626	0.6692	0.1187	0.6589	0.4569	0.3158	0.8526	0.1227
A5	0.4385	0.6938	0.1115	0.5934	0.1098	0.6092	0.0790	0.7105	0.3681
A6	0.6578	0.5782	0.5577	0.3560	0.5491	0.9138	0.2369	0.5684	0.0613

Finally, the alternatives are ranked using the steps (see steps 14 and 15) defined by Eqs. (26) and (27). Table 13 provides the ranking of the alternatives.

Table 13 Ranking of the alternatives

Alternatives	RSi	Pi	Rank
A1	1.8668	4.1332	1
A2	3.5637	2.4363	3
A3	3.1710	2.8290	2
A4	4.2055	1.7945	5
A5	3.7138	2.2862	4
A6	4.4792	1.5208	6

It is noted that the medium sized firm A1 has an edge over the others in terms of their readiness to embrace Q 4.0. However, the result also suggests that it is not necessary that micro firms are worst as we see A3 holds the 2nd position. The order of performance is as follows: A1 > A3> A2 > A5> A4 > A6.

5.1. Comparison with other MCDM models

It is very important to examine the validity and stability of the results obtained by using a composite MCDM framework like what we have done in our paper [81-82]. MCDM results in many instances get affected significantly by external changes in given conditions relating to criteria and alternative sets and their values, any algorithmic changes and so on [83-87]. The existing literature shows evidences of comparison approach for validation of MCDM results [88-92]. In this regard, we compare the result obtained by using the framework used in the present work with other models such as EAMR [93], COPRAS [94] and CRADIS [95] based on the score matrix. Table 14 provides the result of Spearman's rank correlation test among the ranking results of various MCDM models.

Table 14 Result of Spearman's ranking test (Comparison of MCDM models)

Model	COPRAS	EAMR	CRADIS
SRP	0.829*	0.771*	0.943*

*Correlation is sig at 0.05 level (2-tails)

Therefore, it is contended that the framework used in this work provides a comparable and consistent result with respect to other models.

5.2. Sensitivity analysis

It is quite imperative to investigate about the stability aspect of the result. Accordingly, we perform the sensitivity analysis. There are several ways for carrying out sensitivity analysis such as exchange of criteria weights, vary the weights proportionately among others etc. [96-100]. In this work firstly the weights of the criterion C6 (having highest value) has been decreased by 10% at each step while increasing the weights of the other criteria have been increased proportionately. Then the weight of the criterion C9 (having the lowest value) have been increased by 10% while decreasing the weights of the other criteria proportionately. In this way, beside the initial case 15 experimental cases (Exp. 1 to Exp. 15) have been instituted and the alternatives have been ranked. Table 15 shows the criteria weights under various experimental cases and Fig. 2 depicts the result of the sensitivity analysis.

It is seen from the Fig. 2 that except for some cases (Exp. 9 to Exp. 12), A6 and A4 could hold their initial positions. The alternatives A2 and A3 have interchanged their position only for Exp. 11. The best alternative (A1) remains at the top under all conditions and A5 also remains at its initial position. Hence, the result of the sensitivity analysis indicates that our framework provides a reasonable stable outcome.

Table 15 Experimental cases and criteria weights (sensitivity analysis)

	Criteria weights									
Cases	C1	C2	C3	C4	C5	C6	C7	C8	C9	Sum
Initial	0.1096	0.1156	0.1115	0.1187	0.1098	0.1523	0.0790	0.1421	0.0613	1.00
Exp. 1	0.1115	0.1175	0.1134	0.1206	0.1117	0.1371	0.0809	0.1440	0.0632	1.00
Exp. 2	0.1132	0.1193	0.1152	0.1223	0.1134	0.1234	0.0826	0.1457	0.0650	1.00
Exp. 3	0.1148	0.1208	0.1167	0.1238	0.1150	0.1110	0.0841	0.1473	0.0665	1.00
Exp. 4	0.1162	0.1222	0.1181	0.1252	0.1164	0.0999	0.0855	0.1487	0.0679	1.00
Exp. 5	0.1174	0.1234	0.1193	0.1265	0.1176	0.0899	0.0868	0.1499	0.0691	1.00
Exp. 6	0.1185	0.1246	0.1205	0.1276	0.1187	0.0809	0.0879	0.1510	0.0703	1.00
Exp. 7	0.1196	0.1256	0.1215	0.1286	0.1197	0.0728	0.0889	0.1520	0.0713	1.00
Exp. 8	0.1205	0.1265	0.1224	0.1295	0.1207	0.0656	0.0898	0.1529	0.0722	1.00
Exp. 9	0.1213	0.1273	0.1232	0.1303	0.1215	0.0590	0.0906	0.1538	0.0730	1.00
Exp. 10	0.1220	0.1280	0.1239	0.1311	0.1222	0.0531	0.0914	0.1545	0.0737	1.00
Exp. 11	0.1089	0.1149	0.1108	0.1179	0.1091	0.1515	0.0782	0.1413	0.0675	1.00
Exp. 12	0.1080	0.1140	0.1099	0.1171	0.1082	0.1507	0.0773	0.1405	0.0742	1.00
Exp. 13	0.1071	0.1131	0.1090	0.1161	0.1073	0.1498	0.0764	0.1396	0.0816	1.00
Exp. 14	0.1061	0.1121	0.1080	0.1151	0.1063	0.1487	0.0754	0.1385	0.0898	1.00
Exp. 15	0.1049	0.1110	0.1069	0.1140	0.1051	0.1476	0.0743	0.1374	0.0988	1.00

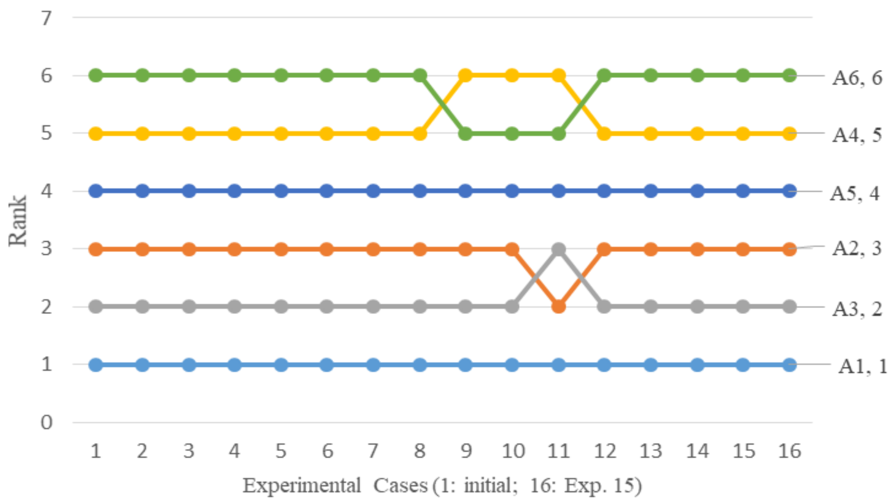

Fig. 2 Result of sensitivity analysis

5.3. Rank reversal test (RRT)

Rank reversal (RR) is a phenomenon wherein the initial ranking order obtained by using a MCDM model gets influenced significantly as a consequence of changes in the given setup such as changes in the alternative and criteria set [101]. In this paper RRT is performed. Given the initial order A1 > A3 > A2 > A5 > A4 > A6 at each stage one alternative was removed and ranking of the remaining alternatives was done. Table 16 exhibits the result of the RRT. The result indicates that our SFN-SPC-SRP framework with EA does not suffer from RR phenomenon.

Table 16 Result of RRT

	Ranking positions					
Cases	1	2	3	4	5	6
Initial	A1	A3	A2	A5	A4	A6
Removal of A6	A1	A3	A2	A5	A4	
Removal of A4, A6	A1	A3	A2	A5		
Removal of A4, A5, A6	A1	A3	A2			
Removal of A2, A4, A5, A6	A1	A3				
Removal of all except A1	A1					

Therefore, overall we contend that the result obtained in the present work is considerably reliable, stable and free from RR phenomenon.

6. Discussion

The present study reveals some interesting observations. It is seen that enhanced use of analytical tools (C6), retention and management of knowledge (C8) and automation (C4) under the guidance and support of the top management (C2) are given top priorities by the expert team. It is observed that C6 and C8 are quite nearby to each other based on their calculated weight while C4 and C2 are very close to each other. The preferential order supports the general observations made in the past studies [102-103]. Top management commitment and support is necessary to instill quality culture and implement the practices in the organizations with proper strategic intent. The present study finds that understanding and implementation of analytical tools and techniques with extensive applications of automation in redefining the processes and creating a knowledge base are more important. I 4.0 demands a lot of use of automation and data analytics for ensuring the effectiveness and efficiency of the processes towards achieving excellence in quality [104-105]. However, most of the SMEs are driven by the owners' decisions. Hence, top management support is very important. The closeness of the weights of C6, C8, C4 and C2 suggests that these four criteria are not distantly apart from each other. Now, looking at the final ranking of the alternatives, it is observed that a small-scale unit (A1) is better prepared as compared with the medium enterprises. This result is also fascinating. There is a general perception that because of a higher turnover and stronger financial position, a medium scale business is better prepared to invest and adopt new technologies. However, our work reminds that if there is an intent and effective teamwork under the able guidance of the top management, a small-scale unit can adopt technology driven quality practices.

Technically, it is seen that the framework used in this work is free from the selection of normalization schemes. That way it provides a lot of relaxation to the analysts. Further, the outcome is found stable and comparative with no effect of rank reversal. The use of EA as an AO extends the benefit of forming a collective group decision making. However, the SPC model consists of slightly more number of computational steps. SRP also dependent on the initial score matrix. Therefore, changes in AO may have some impact on the outcome of SRP model.

7. CONCLUSIONS

The present age is characterized by cyber-physical space as we call I 4.0, which is progressing toward technology-society space - Soc. 5.0. At this juncture, it is important to focus on holistic development in industrial space. SMEs act as a backbone for any industrial revolution and is instrumental in inclusive growth of society and nation. Keeping pace with technological revolution, traditional quality management has evolved to a stage known as Q 4.0. Therefore, it is essential that SMEs embrace Q 4.0. In this paper, we shed light on this aspect. An attempt has been made to present a primary level analysis of the readiness of the SMEs vis-à-vis implementation of Q 4.0. For this purpose, we have presented a new SFN based integrated MCDM framework of SPC-SRP method with EA as the AO. With a real-life field study on six SMEs in India, we have demonstrated the comparative analysis. The criteria are selected in tune with the conceptual background and theoretical foundation of I 4.0 and Soc. 5.0 as found in the literature. We have used nine criteria such as Leadership Support, Organizational Culture, Organizational Structure, Data Management and Use of Analytical Tools, Information Sharing, Knowledge Management, Level of Automation, Collaboration and Business Risk to compare four small and two medium sized enterprises. We notice that the experts have given more emphasis on use of analytical tools (C6), retention and management of knowledge (C8) and automation (C4) under the guidance and support of the top management (C2) while evaluating the SMEs.

Further analysis has revealed that a small size enterprise (A1) outperformed the medium scale organizations. Our study provides a guideline to the analyst and strategic decision-makers. To our understanding, the present paper is a unique contribution.

There are some further possibilities for future studies. For example, the framework can be applied to a large number of SMEs located at various locations and belong to different types of industries. Furthermore, an empirical scale development research can be done to investigate the impact of the criteria (considered in this paper) on the firm performance. An interesting future study may attempt to apply the same model on large-scale corporates. There is an opportunity to apply our model to solve various other real-life problems. Our model provides some advantages, such as flexibility and granularity in analysis, reasonably accurate and stable solution. However, with an increasing number of criteria having at par importance level may impose a limitation to the method used. Therefore, one may attempt to conduct a simulation-based experiment to check the efficiency of our framework. Also, a future study may be planned to see the effect of changing the AO.

REFERENCES

1. Masood, T., Sonntag, P., 2020, *Industry 4.0: Adoption challenges and benefits for SMEs*, Computers in Industry, 121, 103261.
2. Kusiak, A., 2017, *Smart manufacturing must embrace big data*, Nature, 544(7648), pp. 23-25.
3. Chiang, Y., Lee, D., 2017, *Smart manufacturing with the internet of makers*, Journal of the Chinese Institute of Engineers, 40(7), pp. 585-592.
4. Zheng, P., Sang, Z., Zhong, R.Y., Liu, Y., Liu, C., Mubarok, K., Yu, S., Xu, X., 2018, *Smart manufacturing systems for Industry 4.0: Conceptual framework, scenarios, and future perspectives*, Frontiers of Mechanical Engineering, 13(2), pp. 137-150.
5. Zhong, R.Y., 2018, *Analysis of RFID datasets for smart manufacturing shop floors*. Proc. 15th International Conference on Networking, Sensing and Control (ICNSC) (pp. 1-4). IEEE.
6. Syafrudin, M., Fitriyani, N.L., Alfian, G., Rhee, J., 2019, *An affordable fast early warning system for edge computing in assembly line.* Applied Sciences, 9(1), 84.
7. Marr, B., 2015, *Big Data: Using SMART big data, analytics and metrics to make better decisions and improve performance*, John Wiley & Sons Ltd, Chichester.
8. Tao, W., Lai, Z.H., Leu, M.C., Yin, Z., 2018, *Worker activity recognition in smart manufacturing using IMU and sEMG signals with convolutional neural networks*, Procedia Manufacturing, 26, pp. 1159-1166.
9. Menon, K., Kärkkäinen, H., Wuest, T., Gupta, J.P., 2019, *Industrial internet platforms: A conceptual evaluation from a product lifecycle management perspective.* Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233(5), pp. 1390-1401.
10. Deguchi, A., Hirai, C., Matsuoka, H., Nakano, T., Oshima, K., Tai, M., Tani, S., 2020, *What is society 5.0*, Society, 5, pp. 1-23.
11. Banerjee, A., Datta, D., Gupta, S.K., 2021, *Application of IoT in Industry 4.0 for Predictive Analytics*. In Integration of Cloud Computing with Internet of Things (eds M. Mangla, S. Satpathy, B. Nayak and S. N. Mohanty), https://doi.org/10.1002/9781119769323.ch10.
12. Hermann, M., Pentek, T., Otto, B., 2016, *Design principles for industrie 4.0 scenarios*. Proc. 49th Hawaii International Conference on System Sciences (HICSS) (pp. 3928-3937). IEEE.
13. Tupa, J., Simota, J., Steiner, F., 2017, *Aspects of risk management implementation for Industry 4.0*, Procedia manufacturing, 11, pp. 1223-1230.
14. Costa, J.M., 2018, Human Resources Portugal. https://hrportugal.pt/sociedade-5-0-amudanca-que-ai-vem (last access: 06.02.2022)
15. Serpa, S., Ferreira, C., 2018, *Society 5.0 and social development: Contributions to a discussion*, Sciedu Press, 5, pp. 26-31.
16. Broday, E.E., 2022, *The evolution of quality: from inspection to quality 4.0*, International Journal of Quality and Service Sciences, https://doi.org/10.1108/IJQSS-09-2021-0121.
17. Sreenivasan, S., 2021, *Quality 4.0 – road to excellence in the digital world.* A Report by KPMG. Available https://home.kpmg/in/en/home/insights/2021/02/quality-4-0-road-to-excellence-indigital-world (last access: 06.02.2023)

18. Carvalho, A.V., Enrique, D.V., Chouchene, A., Charrua-Santos, F., 2021, *Quality 4.0: an overview*, Procedia Computer Science, 181, pp. 341-346.
19. Zonnenshain, A., Kenett, R.S., 2020, *Quality 4.0—the challenging future of quality engineering*, Quality Engineering, 32(4), pp. 614-626.
20. de Souza, F.F., Corsi, A., Pagani, R.N., Balbinotti, G., Kovaleski, J.L., 2021, *Total quality management 4.0: adapting quality management to Industry 4.0,* The TQM Journal. DOI 10.1108/TQM-10-2020-0238.
21. Brandenburger, J., Schirm, C., Melcher, J., Hancke, E., Vannucci, M., Colla, V., Cateni, S., Sellami, R., Dupont, S., Majchrowski, A., Arteaga, A., 2020, *Quality 4.0-transparent product quality supervision in the age of Industry 4.0,* In Cybersecurity workshop by European Steel Technology Platform (pp. 54-66). Springer, Cham.
22. Ali, K., Johl, S.K., 2021, *Impact of total quality management on SMEs sustainable performance in the context of industry 4.0.* Proc. International Conference on Emerging Technologies and Intelligent Systems (pp. 608-620). Springer, Cham.
23. Dias, A.M., Carvalho, A.M., Sampaio, P., 2021, *Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality,* International Journal of Quality & Reliability Management, doi: 10.1108/IJQRM-07-2021-0247.
24. Escobar, C.A., Chakraborty, D., McGovern, M., Macias, D., Morales-Menendez, R., 2021, *Quality 4.0—Green, Black and Master Black Belt Curricula,* Procedia Manufacturing, 53, pp. 748-759.
25. Sader, S., Husti, I., Daroczi, M., 2022, *A review of quality 4.0: Definitions, features, technologies, applications, and challenges,* Total Quality Management & Business Excellence, 33(9-10), pp. 1164-1182.
26. Shin, W.S., Dahlgaard, J.J., Dahlgaard-Park, S.M., Kim, M.G., 2018, *A Quality Scorecard for the era of Industry 4.0,* Total Quality Management & Business Excellence, 29(9-10), pp. 959-976.
27. Sony, M., Antony, J., Douglas, J.A., 2020, *Essential ingredients for the implementation of Quality 4.0: a narrative review of literature and future directions for research,* The TQM Journal, 32(4), pp. 779-793.
28. Sony, M., Antony, J., Douglas, J.A., McDermott, O., 2021, *Motivations, barriers and readiness factors for Quality 4.0 implementation: an exploratory study,* The TQM Journal, 33(6), pp. 1502-1515.
29. Rowlands, H., Milligan, S., 2021, *Quality-driven industry 4.0. In Key Challenges and Opportunities for Quality, Sustainability and Innovation,* In the Fourth Industrial Revolution: Quality and Service Management in the Fourth Industrial Revolution—Sustainability and Value Co-creation (pp. 3-30).
30. Javaid, M., Haleem, A., Singh, R.P., Suman, R., 2021, *Significance of Quality 4.0 towards comprehensive enhancement in manufacturing sector,* Sensors International, 2, 100109.
31. Chiarini, A., 2020, *Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research,* The TQM Journal, 32(4), pp. 603-616.
32. Emblemsvåg, J., 2020, *On Quality 4.0 in project-based industries,* The TQM Journal, 32(4), pp. 725-739.
33. Gunasekaran, A., Subramanian, N., Ngai, W.T.E., 2019, *Quality management in the 21st century enterprises: Research pathway towards Industry 4.0,* International journal of production economics, 207, pp. 125-129
34. Hernandez-de-Menendez, M., Morales-Menendez, R., Escobar, C.A., McGovern, M., 2020, *Competencies for industry 4.0,* International Journal on Interactive Design and Manufacturing, 14(4), pp. 1511-1524.
35. Kannan, K.S.P., Garad, A., 2020, *Competencies of quality professionals in the era of industry 4.0: a case study of electronics manufacturer from Malaysia,* International Journal of Quality & Reliability Management, 38(3), pp. 839-871.
36. Kupper, D., Knizek, C., Ryeson, D., Noecker, J., 2019, BCG Global, [WWW document]. https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology (last access: 07.02.2023).
37. Santos, G., Sá, J.C., Félix, M.J., Barreto, L., Carvalho, F., Doiro, M., Zgodavová, K., Stefanović, M., 2021, *New needed quality management skills for quality managers 4.0,* Sustainability, 13(11), 6149.
38. Suarta, I.M., Suwintana, I.K., Sudhana, I.F.P., Hariyanti, N.K.D., 2020, *Employability skills for sustainable development and supporting industrial revolution 4.0: a study for polytechnic curriculum development,* Proc. First International Conference on Applied Science and Technology (iCAST 2018) (pp. 36-39). Atlantis Press.
39. Watson, G., 2019, *The Ascent of Quality 4.0 j ASQ,* [WWW Document]. https://asq.org/quality-progress/articles/the-ascent-of-quality-40?id58321f828c7c44634b996b2b1ba25a315 (last accessed: 10.02.2023).
40. Arsovski, S., 2019, *Social oriented quality: from Quality 4.0 towards Quality 5.0.* Proc. 13th International Quality Conference (Vol. 13, pp. 397-404).
41. Sohal, A., Nand, A.A., Goyal, P., Bhattacharya, A., 2022, *Developing a circular economy: An examination of SME's role in India,* Journal of Business Research, 142, pp. 435-447.
42. IBEF Report, 2021, *MSME Industry in India*. https://www.ibef.org/industry/msme.aspx (last access: 07.02.2023).
43. Stentoft, J., Adsbøll Wickstrøm, K., Philipsen, K., Haug, A., 2021, *Drivers and barriers for Industry 4.0 readiness and practice: empirical evidence from small and medium-sized manufacturers,* Production Planning & Control, 32(10), pp. 811-828.
44. Bravi, L., Murmura, F., 2021, *Evidences about ISO 9001: 2015 and ISO 9004: 2018 implementation in different-size organisations,* Total Quality Management & Business Excellence, 33(11-12), pp. 1366-1386.

45. Shuaib, K.M., He, Z., 2021, *Impact of organizational culture on quality management and innovation practices among manufacturing SMEs in Nigeria*, Quality Management Journal, 28(2), pp. 98-114.
46. Zakeri, S., Chatterjee, P., Konstantas, D., Ecer, F., 2023, *A decision analysis model for material selection using simple ranking process*, Scientific Reports, 13(1), 8631.
47. Gligorić, Z., Gligorić, M., Miljanović, I., Lutovac, S., Milutinović, A., 2023, *Assessing Criteria Weights by the Symmetry Point of Criterion (Novel SPC Method)--Application in the Efficiency Evaluation of the Mineral Deposit Multi-Criteria Partitioning Algorithm*, Computer Modeling in Engineering & Sciences, 136(1), pp. 955-979.
48. Zadeh, L.A., 1965, *Fuzzy sets.* Information and control, 8(3), pp. 338-353.
49. Atanassov, KT., 1986, *Intuitionistic fuzzy sets*, Fuzzy Sets and Systems, 20, pp. 87–96.
50. Atanassov, K., 1989, *Geometrical interpretation of the elements of the intuitionistic fuzzy objects*, Preprint IM-MFAIS-1-89, Sofia
51. Atanassov, K.T., Gargov, G., 1989, *Interval valued intuitionistic fuzzy sets*, Fuzzy Sets and Systems, 31, pp. 343–349.
52. Smarandache, F., 1999, *A unifying field in logics: Neutrosophic logic*. In: Philosophy, American Research Press, pp. 1–141.
53. Cuong, B.C., Kreinovich, V., 2013, *Picture fuzzy sets-a new concept for computational intelligence problems*. Proc. 2013 third world congress on information and communication technologies (WICT 2013) (pp. 1-6). IEEE.
54. Cuong, B.C., Kreinovich, V., 2014, *Picture fuzzy sets*, Journal of Computer Science and Cybernetics, 30(4), pp. 409-420.
55. Yager, R.R., 2013, *Pythagorean fuzzy subsets*. Proc. 2013 joint IFSA world congress and NAFIPS annual meeting (IFSA/NAFIPS) (pp. 57-61). IEEE.
56. Yager, R.R., 2016, *Generalized orthopair fuzzy sets*, IEEE Transactions on Fuzzy Systems, 25(5), pp. 1222-1230.
57. Kutlu Gündoğdu, F., Kahraman, C., 2019, *Spherical fuzzy sets and spherical fuzzy TOPSIS method*, Journal of intelligent & fuzzy systems, 36(1), pp. 337-352.
58. Kutlu Gündoğdu, F., Kahraman, C., 2019, *Spherical fuzzy analytic hierarchy process (AHP) and its application to industrial robot selection.* Proc. International Conference on Intelligent and Fuzzy Systems (pp 988-996), Springer.
59. Ashraf, S., Abdullah, S., Mahmood, T., Ghani, F., Mahmood, T., 2019, *Spherical fuzzy sets and their applications in multi-attribute decision making problems*, Journal of Intelligent & Fuzzy Systems, 36(3), pp. 2829-2844.
60. Senapati, T., Yager, R.R., 2020, *Fermatean fuzzy sets*, Journal of Ambient Intelligence and Humanized Computing, 11(2), pp. 663-674.
61. Ayan, B., Abacıoğlu, S., Basilio, M.P., 2023, *A Comprehensive Review of the Novel Weighting Methods for Multi-Criteria Decision-Making*, Information, 14(5), 285.
62. Hezam, I.M., Basua, D., Mishra, A.R., Rani, P., Cavallaro, F., 2023, *Intuitionistic fuzzy gained and lost dominance score based on symmetric point criterion to prioritize zero-carbon measures for sustainable urban transportation*, Kybernetes, https://doi.org/10.1108/K-03-2023-0380.
63. Hezam, I.M., Vedala, N.R.D., Kumar, B.R., Mishra, A.R., Cavallaro, F., 2023, *Assessment of Biofuel Industry Sustainability Factors Based on the Intuitionistic Fuzzy Symmetry Point of Criterion and Rank-Sum-Based MAIRCA Method*, Sustainability, 15(8), 6749.
64. Ali, J., 2021, *A novel score function based CRITIC-MARCOS method with spherical fuzzy information*, Computational and Applied Mathematics, 40(8), 280.
65. Ashraf, S., Abdullah, S., Abdullah, L., 2019, *Child development influence environmental factors determined using spherical fuzzy distance measures*, Mathematics, 7(8), 661.
66. Kovač, M., Tadić, S., Krstić, M., Bouraima, M.B., 2021, *Novel Spherical Fuzzy MARCOS Method for Assessment of Drone-Based City Logistics Concepts*, Complexity, 2021, 2374955.
67. Menekşe, A., Camgöz Akdağ, H., 2022, *Distance education tool selection using novel spherical fuzzy AHP EDAS*, Soft Computing, 26(4), pp. 1617-1635.
68. Mahmood, T., Ilyas, M., Ali, Z., Gumaei, A., 2021, *Spherical fuzzy sets-based cosine similarity and information measures for pattern recognition and medical diagnosis*, IEEE Access, 9, pp. 25835-25842.
69. Unver, M., Olgun, M., Türkarslan, E., 2022, *Cosine and cotangent similarity measures based on Choquet integral for Spherical fuzzy sets and applications to pattern recognition*, Journal of Computational and Cognitive Engineering, 1(1), pp. 21-31.
70. Aydoğdu, A., Gül, S., 2022, *New entropy propositions for interval-valued spherical fuzzy sets and their usage in an extension of ARAS (ARAS-IVSFS)*, Expert Systems, 39(4), e12898.
71. Oztaysi B., Kahraman C., Onar S.C., 2022, *Spherical Fuzzy REGIME Method Waste Disposal Location Selection*. In: Kahraman C., Cebi S., Cevik Onar S., Oztaysi B., Tolga A.C., Sari I.U. (eds) Intelligent and Fuzzy Techniques for Emerging Conditions and Digital Transformation. INFUS 2021. Lecture Notes in Networks and Systems, vol 308. Springer, Cham.

72. Seyfi-Shishavan, S.A., Kutlu Gündoğdu, F., Donyatalab, Y., Farrokhizadeh, E., Kahraman, C., 2021, *A novel spherical fuzzy bi-objective linear assignment method and its application to insurance options selection*, International Journal of Information Technology & Decision Making, 20(2), pp. 521-551.
73. Sharaf, I.M., 2021, *Global Supplier Selection with Spherical Fuzzy Analytic Hierarchy Process*. In: Kahraman C., Kutlu Gündoğdu F. (eds) Decision Making with Spherical Fuzzy Sets. Studies in Fuzziness and Soft Computing, vol 392. Springer, Cham.
74. Gul, M., Ak, M.F., 2021, *A modified failure modes and effects analysis using interval-valued spherical fuzzy extension of TOPSIS method: case study in a marble manufacturing facility*, Soft Computing, 25(8), pp. 6157-6178.
75. Dogan, O., 2021, *Process mining technology selection with spherical fuzzy AHP and sensitivity analysis*, Expert Systems with Applications, 178, 114999.
76. Hashmi, M.R., Tehrim, S.T., Riaz, M., Pamucar, D., Cirovic, G., 2021, *Spherical Linear Diophantine Fuzzy Soft Rough Sets with Multi-Criteria Decision Making*, Axioms, 10(3), 185.
77. Farrokhizadeh, E., Seyfi-Shishavan, S.A., Gündoğdu, F.K., Donyatalab, Y., Kahraman, C., Seifi, S.H., 2021, *A spherical fuzzy methodology integrating maximizing deviation and TOPSIS methods*, Engineering Applications of Artificial Intelligence, 101, 104212.
78. Erdoğan, M., 2022, *Assessing farmers' perception to Agriculture 4.0 technologies: A new interval‐valued spherical fuzzy sets based approach*, International Journal of Intelligent Systems, 37(2), pp. 1751-1801.
79. Biswas, S., Chatterjee, S., Majumder, S., 2022. *A spherical fuzzy framework for sales personnel selection*, Journal of Computational and Cognitive Engineering. https://doi.org/10.47852/bonviewJCCE2202357.
80. Ashraf, S., Abdullah, S., Chinram, R., 2022, *Emergency decision support modeling under generalized spherical fuzzy Einstein aggregation information*, Journal of Ambient Intelligence and Humanized Computing, 13, pp. 2091-2117.
81. Nezhad, M.Z., Nazarian-Jashnabadi, J., Rezazadeh, J., Mehraeen, M., Bagheri, R. 2023, *Assessing Dimensions Influencing IoT Implementation Readiness in Industries: A Fuzzy DEMATEL and Fuzzy AHP Analysis*, Journal of Soft Computing and Decision Analytics, 1(1), pp. 102-123.
82. Bavandi, S., Bigdeli, H., 2023, *A Maximum Flow Network Interdiction Model in Fuzzy Stochastic Hybrid Uncertainty Environments*, Yugoslav Journal of Operations Research, 33(3), pp. 409-424.
83. Biswas, S., Majumder, S., Pamucar, D., Dawn, S.K., 2021, *An Extended LBWA Framework in Picture Fuzzy Environment Using Actual Score Measures Application in Social Enterprise Systems*, International Journal of Enterprise Information Systems, 17(4), pp. 37-68.
84. Biswas, S., Pamučar, D.S., 2021, *Combinative distance based assessment (CODAS) framework using logarithmic normalization for multi-criteria decision making*, Serbian Journal of Management, 16(2), pp. 321-340.
85. Pamucar, D., Torkayesh, A.E., Biswas, S., 2023, *Supplier selection in healthcare supply chain management during the COVID-19 pandemic: a novel fuzzy rough decision-making approach*, Annals of Operations Research, 328, pp. 977–1019.
86. Puška, A., Kozarević, S., Okičić, J., 2020, *Investigating and analyzing the supply chain practices and performance in agro-food industry*, International Journal of Management Science and Engineering Management, 15(1), pp. 9-16.
87. Stević, Ž., Tanackov, I., Puška, A., Jovanov, G., Vasiljević, J., Lojaničić, D., 2021, *Development of Modified SERVQUAL–MCDM Model for Quality Determination in Reverse Logistics*, Sustainability, 13(10), 5734.
88. Puška, A., Kozarević, S., Stević, Ž., Stovrag, J., 2018, *A new way of applying interval fuzzy logic in group decision making for supplier selection*, Economic Computation and Economic Cybernetics Studies and Research, 52(2), pp. 217-234.
89. Biswas, S., Majumder, S., Dawn, S.K., 2022, *Comparing the socioeconomic development of G7 and BRICS countries and resilience to COVID-19: An entropy–MARCOS framework*, Business Perspectives and Research, 10(2), pp. 286-303.
90. Badi, I., Abdulshahed, A., Alghazel, E. 2023, *Using Grey-TOPSIS approach for solar farm location selection in Libya*, Reports in Mechanical Engineering, 4(1), pp. 80–89.
91. Pramanik, P.K.D., Biswas, S., Pal, S., Marinković, D., Choudhury, P., 2021, *A Comparative Analysis of Multi-Criteria Decision-Making Methods for Resource Selection in Mobile Crowd Computing*, Symmetry, 13(9), 1713.
92. Verma, V., Bisht, P., Joshi, S., 2022, *Sustainable Supply chain Systems of Food and Beverages SMEs: Analyzing sustainable performance using Structured Equation Modeling*, Journal of Decision Analytics and Intelligent Computing, 2(1), pp. 53–68.
93. Keshavarz Ghorabaee, M., Zavadskas, E.K., Amiri, M., Antucheviciene, J., 2016, *Evaluation by an Area-based Method of Ranking Interval Type-2 Fuzzy Sets (EAMRIT-2F) for Multi-criteria Group Decision making*, Transformations in Business & Economics, 15(3(39)), pp. 76-95.
94. Zavadskas, E.K., Kaklauskas, A., Peldschus, F., Turskis, Z., 2007, *Multi-attribute assessment of road design solutions by using the COPRAS method*, The Baltic journal of Road and Bridge engineering, 2(4), pp. 195-203.

95. Puška, A., Stević, Ž., Pamučar, D., 2022, *Evaluation and selection of healthcare waste incinerators using extended sustainability criteria and multi-criteria analysis methods,* Environment, Development and Sustainability, 24, pp. 11195–11225.
96. Biswas, S., Anand, O.P., 2020, *Logistics Competitiveness Index-Based Comparison of BRICS and G7 Countries: An Integrated PSI-PIV Approach*, The IUP Journal of Supply Chain Management, 17(2), pp. 32-57.
97. Biswas, S., Pamucar, D., Chowdhury, P., Kar, S., 2021, *A New Decision Support Framework with Picture Fuzzy Information: Comparison of Video Conferencing Platforms for Higher Education in India*, Discrete Dynamics in Nature and Society, 2021, 2046097.
98. Puška, A., Nedeljković, M., Hashemkhani Zolfani, S., Pamučar, D., 2021, *Application of Interval Fuzzy Logic in Selecting a Sustainable Supplier on the Example of Agricultural Production*, Symmetry, 13(5), 774.
99. Ali, A., Ullah, K., Hussain, A. 2023, *An approach to multi-attribute decision-making based on intuitionistic fuzzy soft information and Aczel-Alsina operational laws*, Journal of Decision Analytics and Intelligent Computing, 3(1), pp. 80-89.
100. Dağıstanlı, H.A., 2023, *An Integrated Fuzzy MCDM and Trend Analysis Approach for Financial Performance Evaluation of Energy Companies in Borsa Istanbul Sustainability Index*, Journal of Soft Computing and Decision Analytics, 1(1), pp. 39-49.
101. Görçün, Ö.F., Pamucar, D., Biswas, S., 2023, *The blockchain technology selection in the logistics industry using a novel MCDM framework based on Fermatean fuzzy sets and Dombi aggregation*, Information Sciences, 635, pp. 345-374.
102. Gupta, H., Prakash, C., Vishwakarma, V., Barua, M.K., 2017, *Evaluating TQM adoption success factors to improve Indian MSMEs performance using fuzzy DEMATEL approach*, International Journal of Productivity and Quality Management, 21(2), pp. 187-202.
103. Liu, H.C., Liu, R., Gu, X., Yang, M., 2023, *From total quality management to Quality 4.0: A systematic literature review and future research agenda*, Frontiers of Engineering Management, 10(2), pp. 191-205.
104. Deng, N., Shi, Y., Wang, J., Gaur, J., 2022, *Testing the adoption of blockchain technology in supply chain management among MSMEs in China*, Annals of Operations Research, pp. 1-20. https://doi.org/10.1007/s10479-022-04856-4.
105. Singh, R., Ojha, M.K., Sindhwani, R., 2023, *Identification of Critical Success Factors (CSFs) for Implementation of Industry 4.0 in MSME Sector*. In: Phanden, R.K., Kumar, R., Pandey, P.M., Chakraborty, A. (Eds), *Advances in Industrial and Production Engineering*. FLAME 2022. Lecture Notes in Mechanical Engineering. Springer, Singapore, pp. 103-113.