A novel stochastic fuzzy decision model for agile and sustainable global manufacturing outsourcing partner selection in footwear industry

AKHTAR, Mohammad, GUNASEKARAN, Angappa and KAYIKCI, Yasanur <http://orcid.org/0000-0003-2406-3164>

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A Novel Stochastic Fuzzy Decision Model for Agile and Sustainable Global Manufacturing Outsourcing Partner Selection in Footwear Industry

Abstract

Purpose – The decision-making to outsource and select the most suitable global manufacturing outsourcing partner (MOP) selection is complex and uncertain due to multiple conflicting qualitative and quantitative criteria as well as multiple alternatives. Vagueness and variability exist in ratings of criteria and alternatives by group of decision makers (DMs). The paper provides a novel Stochastic Fuzzy (SF) method for evaluation and selection of agile and sustainable global MOP in uncertain and volatile business environment.

Design/methodology/approach – Four main selection criteria for global MOP selection were identified such as economic, agile, environmental, and social criteria. Total 16 sub-criteria were selected. To consider the vagueness and variability in ratings by group of DMs, SF method using t-distribution or z-distribution was adopted. The criteria weights were determined using the Stochastic Fuzzy-CRriteria Importance Through Intercriteria Correlation (SF-CRITIC), while MOP selection was carried out using Stochastic Fuzzy-VIseKriterijumskaOptimizacija I KompromisnoResenje (SF-VIKOR) in case study of footwear industry. Sensitivity analysis was performed to test the robustness of the proposed model. A comparative analysis of SF-VIKOR and VIKOR was made.

Findings – The worker's wages and welfare, product price, product quality, green manufacturing process, and collaboration with partners are the most important criteria for MOP selection. The MOP3 was found the best agile and sustainable global MOP for the footwear company. In sensitivity analysis, significance level is found to have important role in MOP ranking. Hence, study concluded that integrated SF-CRITIC and SF-VIKOR is an improved method for MOP selection problem.

Originality/value – To the best of the authors' knowledge, SF method has not been used to select MOP in the existing literature. For the first time, integrated SF-CRITIC and SF-VIKOR method were applied to select the best agile and sustainable MOP under uncertainty. Unlike other studies, this study considered agile criteria along with triple bottom line sustainable criteria for MOP selection. The novel method of SF assessment contributes to the literature and put forward the managerial implication for improving agility and sustainability of global manufacturing outsourcing in footwear industry.

Keywords: Global manufacturing outsourcing partner selection, Probability theory, Stochastic Fuzzy CRITIC, Stochastic Fuzzy VIKOR, Footwear industry.

1. Introduction

Supply chain management (SCM) encompasses activities such as procurement, movement and storage of raw materials, considers inventory management and distribution of finished goods to deal with fulfilment of orders between the manufacturer and the consumer (Mehdikhani & Valmohammadi 2019). An effective SCM is essential for companies producing goods or services in both developed and developing economies to run smooth business operations, increase performance and ensure customer satisfaction (Wu et al., 2014). Outsourcing manufacturing activities to a strategic outsourcing partner is an advantageous and effective way to reduce operating costs, increase profits and make production capacity more flexible to meet business objectives and gain competitive advantage (Choy and Lee, 2002; 2003). Therefore, manufacturing outsourcing partner (MOP) selection is one of the most critical and important aspects for any company. Through the manufacturing outsourcing partnership, supply chain managers can incorporate sustainability and improve competitive positions of the company (Govindan et al., 2013; Luthra et al., 2017). The outsourcing partner selection affects downstream, upstream and reverse supply chain operations and therefore both qualitative and quantitative factors need to be examined carefully (Prakash and Barua 2016).

Sustainable SCM has recently become a significant issue for companies of all sizes and across all sectors. It is considered a new framework for companies to achieve environmental efficiency and social responsibility in order to meet stakeholder needs, increase profit and competitiveness in their supply chain (Gualandris et al., 2014). Due to increasing environmental awareness and global pressure, companies and decision-makers must consider environmental issues in all business activities as they affect almost all segments of society (Alfred and Adam, 2009). To implement successful sustainable business practices, companies should consider economic, social and environmental sustainability criteria to evaluate the performance of their outsourcing partners (Govindan et al., 2013). Companies should share their resources and capabilities to guide their partners in the area of green and technological innovations, sustainable initiatives, corporate social responsibilities and environmental management systems (Luthra et al., 2017). Companies need to align with their supply partners for efficiency and to achieve the required supply chain agility in volatile business environment (Wu and Barnes, 2011). Hence, an agile and sustainable supply chain is desired to meet the sustainability obligation and business volatility.

The process of outsourcing partner selection is still very complex due to inclusion of various criteria, the number of vendors for a single item, and the presence of multiple DMs in the decision-making process (Choy and Lee 2002). Several Multi-Criteria Decision-Making (MCDM) techniques have been used by various researchers for OPS. However, the vagueness in ratings of the criteria and the strategic MOP by the DMs can be resolved by applying fuzzy set theory, but variation in ratings is not considered in any deterministic MCDM method. Therefore, the authors proposed probability theory extension to the deterministic model along with fuzzy theory. Numerous MCDM techniques and their fuzzy variants have been used in the literature for MOP selection across various industries and sectors, but limited applications are available in footwear. The footwear industry is of great importance in any country. Footwear is produced in large bulky quantities and India being the second-largest global footwear producer, while China has first place. Various categories of footwear are produced in India, such as sandals, shoes, boots, open toe shoes, sports wear shoes, sliders. They are made from different materials including leather, PVC, rubber and other synthetic materials and these products serve both the domestic market and export to many other countries. However, in developing countries such as India, where millions of workers are involved, footwear manufacturing has remained mostly labour-oriented. Today's modern machineries and efficient techniques can create better opportunities in the footwear industry. In this sense, the footwear industry requires strategically MOP selection in a developing country where upstream supplies are mostly first or second tier suppliers. It is highly important to select the right criteria, derive its weight and rank the strategic outsourcing partner using a structured approach. Several studies covered economic and operational aspects only and less attention has been paid in integrating environmental and social sustainability in global manufacturing outsourcing. On the other hand, majority of the studies considered either deterministic or fuzzy variant of MCDM methods, which did not cover the variability in ratings by group of DMs. To answer these research gaps, following research questions (RQs) are framed:

RQ1: What are the important agile criteria for global MOP selection in footwear industry?

RQ2: What are the important triple bottom line sustainability criteria for global MOP selection in footwear industry?

RQ3: Which is the suitable method to determine criteria weight and relative importance considering vagueness and variability in ratings by group of decision makers in outsourcing decision?

RQ4: Which is the suitable method to assess and rank MOP in footwear industry considering vagueness and variability in ratings by group of decision makers?

To answer above RQs, this study follows three phases. First phase, identification of agile and sustainable selection criteria from the literature and validation by industry experts. The second and third phases refer to proposing an integrated method, respectively:computation of criteria weight using Stochastic Fuzzy-CRiteria Importance Through Intercriteria Correlation (SF-CRITIC) method and assessment and selection of MOP using Stochastic Fuzzy-VIseKriterijumskaOptimizacija I KompromisnoResenje (SF-VIKOR) method in a case study of an Indian footwear company. To the best of our knowledge, the proposed integrated SF-CRITIC and SF-VIKOR method is being applied for the first time for global MOP selection, and there is no previous study in the literature that reveals such research gaps in footwear industry in developing economies.

The paper is organised in the following sections. Section two summarises the literature review; section three describes the methodology, section four demonstrates the case study of SF-CRITIC and SF-VIKOR method application in Indian footwear company; section five presents the result and discussion; and finally, the section six provides the conclusion, implications, and direction for future research.

2. Literature Review

Outsourcing is the activity in which the company hires another company to do some of its non-core activities in order to save time, be more efficient, increase profits and focus on core activities. The strategic importance of supplier evaluation and selection received considerable attention in literature as it affects supply chain operations and performance (Malviya et al., 2018). Selecting the wrong supplier can affect the company's financial and operational position (Bhattacharya and Singh, 2019), whereas, selecting the right suppliers significantly reduces purchasing costs, increases competitiveness in the market and enhances the end-user satisfaction (Onut et al., 2009). Zulkiffli and Padlee (2021) studies the impact of sustainable outsourcing decisions on competitive capabilities and business performance of Malaysian manufacturing SME using confirmatory factor analysis. Arrigo (2021) considered strategy of local and global sourcing, cost, time, social and environmental sustainability for offshore manufacturing outsourcing in fast fashion industry. Tan et al. (2021) used block chain and smart contract to ensure the effectiveness and efficiency of business services between the cloud manufacturing service providers and cloud manufacturing service consumers. Helo et al. (2021) developed a cloud-based platforms providing manufacturing ecosystems where machine owners, product designers and customers may collaborate and compete simultaneously in real-time. Zhou and Yuen (2021) proposed optimal remanufacturing strategy through contract manufacturer or independent remanufacturer for original equipment manufacturer. Akhtar (2022) carried out literature review of agile and sustainable MOP selection. Lahiri et al. (2022) carried out meta-analysis of 106 primary studies from 1992 to 2019 to examine the effect of industrial nature of activity (manufacturing vs. services), value chain activity (core vs. non-core), and provider's location (domestic vs. international) in sourcing on firm performance and found that outsourcing has positive relationship with firm performance for non-core and international outsourcing equally manufacturing and service sector.

2.1 Outsourcing Partner Selection Criteria

Selecting the right criteria is a significant aspect in MOP. Since partner selection is crucial, it is imperative for DMs to design effective selection criteria, as well as evaluation method for outsourcing partners prior to outsourcing activities. Numerous researchers have identified evaluation criteria for outsourcing partner selection. Chen and Hung (2010) used financial consideration, quality, service performance, compliance and culture for the selection of MOP in pharmaceutical research and development (R&D). Garg and Sharma (2020) adopted economic factors, environmental factors and social factors for sustainable outsourcing partner evaluation and selection in electronics company in India. Kabus et al. (2022) proposed price, service quality, reputation, finance and security as selection criteria for outsourcing operator in manufacturing companies in Poland.

For sustainable supplier selection, Ulutas et al. (2016) used financial position, technological capability, reputation, sectoral price compliance, communication issues, cost, late delivery percentage, defect percentage, order requirement, production capacity and volume flexibility for supplier selection. Luthra et al. (2017) adopted price of product, profit on product, quality of product, flexibility, technological & financial capability, production facilities and capacity, delivery and service of product, lead time required, transportation cost, environment management systems, green design and purchasing, green manufacturing, green management, green packing and labelling, waste management and pollution prevention, environmental costs, environmental competencies, green R&D and innovation, occupational health & safety systems, the interests & rights of employees, the rights of stakeholders and information disclosure as criteria. Awasthi et al. (2018) used five sustainable criteria of economic, quality, environment, social, and global risk. Goren (2018) adopted thirteen criteria: price, productivity, capacity of the supplier, long-term relationship, lead time, quality, production technology, responsiveness, occupational health and safety management system, supportive activities, environmental management system, environment friendly product design, resource consumption. Sinha and Anand (2018) used cost, quality, delivery reliability, technology capability service, financial situation, pollution production, environmental management system, green product, pollution control, green image, health and safety contractual, stakeholder influence, local community influence and social responsibility management system as criteria. Arabsheybani et al. (2018) considered cost, quality, delivery, environmental management system, green supply chain, suppliers of the supplier, worker safety and labour health, interests and rights of employee, worker safety and worker dismissal as criteria.

For agile contract manufacturer selection, Hu and Yu (2015) considered flexibility, quality, delivery and cost; and Adali and Isik (2017) adopted material quality, on-time delivery, reliability, equipment, geographic location, production capacity, and cost of the product criteria. Barhmi (2019) considered supply chain agility and resilience to show impact on supply chain performance in Moroccan manufacturing companies. Supply chain agility has been studied across a wide range of industries; auto components through research-based view (Dubey et al., 2018), electronics (Tse et al., 2016; Wu et al., 2017), fashion and textiles (Chan et al., 2017), oil and gas (Yusuf et al., 2014), and manufacturing industries (Al-Shboul, 2017; Kim and Chai, 2017). Babber and Keshav (2022) carried out systematic review from 1991-2020 on manufacturing leanness, agility, innovativeness, and sustainability in manufacturing industries. Kumar et al. (2022) investigates the influence of agile manufacturing attributes namely leadership support, human related issues, customer-related issues, and information technology on business performance using PLS-SEM.

2.2 Techniques for Strategic Outsourcing Partner Evaluation

Lin et al. (2010) demonstrated the Analytic Network Process (ANP) method for outsourcing vendor selection in a semiconductor company in Taiwan. Chen and Hung (2010) proposed an integrated Fuzzy Analytic Hierarchy Process (F-AHP) and Fuzzy Technique for Order Preference by Similarity to Ideal solution (F-TOPSIS) method in pharmaceutical R&D. Hsu et al. (2013) used Decision-Making Trail and Evaluation Laboratory (DEMATEL), ANP and Grey Relational Analysis (GRA). Hu and Yu (2015) integrated the voting method and the goal programming for the electronics contract manufacturer selection. Sivakumar et al. (2015) used AHP and Taguchi loss functions for green vendor selection for production outsourcing in mining industry. Momeni and Vandchali (2017) adopted Data Envelopment Analysis (DEA) and Evidential Reasoning algorithm for ranking strategic outsourcing partners. For OPS, Rezaeisaray et al. (2016) applied DEMATEL-F-ANP-DEA in pipe and fittings manufacturing company; Ji et al. (2018) proposed neutrosophic linguistic sets based on Multi-Attributive Border Approximation Area Comparison (MABAC) and Elimination and Choice Expressing Reality (ELECTRE) methods - (MABAC-ELECTRE); Song (2019) applied AHP in pharmaceutical R&D in Korea; Chen et al. (2019) developed a model based on capability index and manufacturing time performance index; and Percin (2019) adopted integrated Fuzzy Stepwise Weight Assessment Ratio Analysis (F-SWARA) and fuzzy axiomatic design method in Turkish chemical manufacturing company. Buyukozkan and Gocer (2019) proposed F-AHP and F-COPRAS under pythagorean fuzzy sets for digital supply chain partner selection. Liaw et al. (2020) proposed DEMATEL-CRITIC method for criteria weight and classifiable TOPSIS to classify green manufacturing outsourcing providers in Taiwanese multinational machine tool manufacturing firm. Wang et al. (2019) proposed a clustering and searching model of a web outsourcing service based on Ontology Web Language for Services and an ANN and improved Shuffled Frog Leaping Algorithm for cement equipment manufacturing outsourcing in cloud manufacturing. Singh and Sarkar (2021) applied integrated AHP and VIKOR method for sustainable contract manufacturer selection in automotive industry. Wang et al. (2021) adopted F-AHP, F-TOPSIS and DEA for manufacturing outsourcing selection in apparel and textile supply chain. Yang and Chen (2021) proposed a novel process capability analysis of products with multiple quality characteristics and Pareto optimality to re-examine eligible contract manufacturer in machinery manufacturing industry. Lo et al. (2022) proposed neutrosophic Indifference Threshold-based Attribute Ratio Analysis (ITARA) and neutrosophic TOPSIS for sustainable strategic alliance partner selection in electronics component manufacturing firm. Li et al. (2023) studied the impact of tax and tariff regulations on original equipment manufacturer outsourcing decisions in remanufacturing contexts. Merghemet al. (2023) proposed mathematical programming for integrated production and maintenance planning in a hybrid manufacturing-remanufacturing context with outsourcing options.

For sustainable supplier selection, various method and techniques are used such as a Best-Worst Method (BWM), Mixed-Integer Linear Programming (MILP) and revised multi-choice goal programming (Cheraghalipour and Farsad, 2018); AHP and TOPSIS (Mohammed et al., 2018); two-stage DEA (Zarbakhshnia and Jaghdani, 2018); F-AHP and F-VIKOR (Awasthi et al., 2018); F-MOORA and Failure Modes and Effects Analysis (Arabsheybani et al., 2018); Hybrid Entropy and F-TOPSIS in the furniture industry (Dos Santos et al., 2019). For sustainable supplier selection, Rabbani et al. (2019) proposed interval-valued fuzzy reference point systems with fuzzy possibilistic statistical concept; Wang et al. (2019) applied F-AHP and TOPSIS with triple bottom line in Vietnamese garment industry; Guarnieri and Trojan (2019) proposed a hybrid AHP-ELECTRE-TRI model based on economic, environmental, social and ethical for outsourcing in the textile industry; and Ecer and Pamucar (2020) used Fuzzy BWM (F-BWM) and Fuzzy Combined Compromise Solution (F-CoCoSo) with Bonferroni (CoCoSo'B) method with triple bottom line sustainability for home appliance manufacturer in Serbia. Feng and Gong (2020) proposed Integrated Linguistic Entropy Weight Method and Multi-Objective Goal Programming in automobile manufacturing company, and Nasr et al. (2021) proposed a F-BWM and Multi-Objective Mixed-Integer Linear Programming (MOMILP) model for sustainable supplier selection and order allocation in garment industry. Kumari and Mishra (2020) introduced Intuitionistic F-Entropy and Intuitionistic F-COPRAS method for green supplier selection. Akhtar and Ahmad (2021) applied SF-TOPSIS for sustainable vendor selection for spare parts supplies in the Indian petroleum refining sector.

For agile supplier selection, Fuzzy Multi-Level MCDM method compared with F-TOPSIS and F-MOORA (Matawale et al., 2016); DEMATEL, ANP and TOPSIS (Alimardani et al., 2014); Interpretive Structural Modelling (ISM), TOPSIS and AHP– (Beikkhakhian et al., 2015); and F-AHP and F-TOPSIS (Lee et al., 2015). Wu et al. (2017) applied F-DEMATEL and ANP to assess supply chain agility. Adali and Isik (2017) used CRITIC and Multi-Attribute Utility Theory (MAUT) methods for agile contract manufacturer selection. Goker (2021) applied Intuitionistic Fuzzy Cognitive Map (FCM) and COPRAS method for agile outsourcing provider selection in Turkish white goods industry. Sahu et al. (2022) applied

DEMATEL-ANP-AHP, MOORA and Simple Additive Weighting (SAW) for supplier selection in a lean-agile-resilient-green environment in Indian automotive sector.

The CRITIC method is an efficient method for determining objective weights of criteria. Ghorabaee et al. (2017) used CRITIC and Weighted Aggregated Sum Product Assessment (WASPAS) with Interval Type-2 Fuzzy Sets for assessment of 3PL providers. Liaw et al. (2020) proposed DEMATEL-CRITIC-classifiable TOPSIS method for green MOP selection in Taiwanese multinational machine tool manufacturing firm. Garg and Sharma (2020) proposed BWM-VIKOR framework for sustainable outsourcing partner selection in electronics company in India. Fei et al. (2019) proposed Dempster–Shafer (DS) evidence theory based DS-VIKOR for supplier selection. Various techniques applied used for agile and sustainable MOP and supplier selection in the recent literature is summarised in Table 1.

>INSERT TABLE 1HERE<

3. Proposed Methodology: Integrated SF-CRITIC and SF-VIKOR

Although large number of researchers has addressed the supplier evaluation and selection problem, relatively few papers exist on strategic MOP selection in agile and sustainable supply chain. Different MCDM techniques and its fuzzy variant have been used in the literature, but stochastic and fuzzy variant is rarely available. The outsourcing partner selection process involves multiple quantitative and qualitative and multiple vendors. The ratings are done by multiple procurement experts and hence, globalMOP selection is a multi-criteria group decision-making problem (Wood, 2016). Such decision-making problems involves inherentlyimprecise and uncertain environments in ratings. Generally, inconsistency and ambiguity in ratings by group of DMs can be captured by fuzzy theory (Zadeh, 1965), but stochasticity and variation in ratings by group of DMs have not been considered by the majority of deterministic or fuzzy variant MCDM techniques. Therefore, the authors extended the probability theory in this studyto calculate the stochastic value using t-distribution or z-distribution at the desired significance level. The stochastic fuzziness is based on both probability theory and fuzzy set theoryand incorporates uncertainty and vagueness as well as stochasticity and variation in the ratings by group of DMs to evaluate the structured decision problem (Buvaneshwari & Anuradha, 2022). This study proposes an integrated SF-CRITIC and SF-VIKOR to evaluate the global MOP selection in a case study of an Indian footwear company. The method starts with checking the normality test of the data depending on the number of DMs, then SF-CRITIC is used to determine the weights of the selection criteria, as this method not only considers the distribution of the data of each criterion evaluation set, but also captures the linear (and nonlinear)correlation of the criteriamore precisely, and the method is easy to calculateand finally SF-VIKOR is employed to choose the best MOP from among the alternatives, as this method focuses on the selection and ranking of several alternatives with conflicting criteria, suggesting a compromise solution to the results based on the estimated ideal solution.

3.1 Relative Ratings of Alternative with respect to Criteria

Relative ratings of the alternatives with respect to criteria in linguistics terms is done by the group of DMs. Then Triangular Fuzzy Number (TFN) are assigned to linguistics terms.

3.2 Data Normality Test

Shapiro-Wilk test for normality of ratings by group of DMs is to be carried out. If p-value is greater than 0.05, data is approximately following normal distribution.

3.3 Stochastic Fuzzy Rating

In MCDM problem, relative subjective ratings of criteria and alternatives by DMs involve vagueness, ambiguity and impreciseness due to unquantifiable and incomplete information (Chen and Hwang, 1992). Fuzzy set theory, introduced by Zadeh (1965), has been used to dispose vague information in decision-making. Group decision-making also involves randomness and variability which can be resolved with probability theory and standard normal distribution. Such variability is not accounted for in any deterministic or fuzzy model whereas stochastic value accounts for the variability and randomness of qualitative judgement by group of DMs (Akhtar and Ahmad, 2021).

$\tilde{x}_{ij}^{k}$: fuzzy performance value of i^{th} alternative with respect to j^{th} criterion by k^{th} decision-maker.

i: alternatives, 1, 2, . . ., m.

j: criterion, 1, 2, . . ., n.

k: decision makers. 1,2,…,k.

$\bar{x}_{ij}$: mean fuzzy rating of i^{th} alternative with respect to j^{th} criteria.

σ_{xij}: standard deviation of fuzzy ratings of i^{th} alternative with respect to j^{th} criteria.

t: t-score taken from t-table at degree of freedom and significance level

z:z-score from standard normal table at a desired confidence level.

$\tilde{y}_{ij}$: SF rating of i^{th} alternative with respect to j^{th} criteria.

The fuzzy number (x) is denoted by $\tilde{x}$ which has triangular fuzzy values (a, b, c). Calculate mean fuzzy rating ($\bar{x}_{ij}$), standard deviation (σ_{xij}) using Eqs. (1-2).If sample size is small (less than 30), use t-value at degree of freedom (df) and desired significance level (α) from t-distribution and determine stochastic rating ($\tilde{y}_{ij}$) of criteria using Eq. (3). If sample size is large (more than 30), use z-value at a desired significance level (α) and determine stochastic rating using Eq. (4).

$$X^k = [\tilde{x}_{ij}^k]$$

$$\bar{x}_{ij} = \tilde{x}_{ij}^k / k \quad (1)$$

$$\sigma_{xij} = \sqrt{\left[\sum_{J=1}^{n} [\tilde{x}_{ij}^k - \bar{x}_{ij}]^2\right] / (k-1)} \quad (2)$$

$$\tilde{y}_{ij} = \bar{x}_{ij} + t.\sigma_{xij} \quad (3)$$

$$\tilde{y}_{ij} = \bar{x}_{ij} + Z.\sigma_{xij} \quad (4)$$

The stochasticdecision matrix Y = [$\tilde{y}_{ij}$]

3.4 Stochastic Fuzzy CRITIC

The CRiteria Importance Through Intercriteria Correlation (CRITIC) method proposed by (Diakoulaki et al., 1995) to determine objective weights. The importance weight of criteria could reflect the amount of information contained in each of them. Contrast intensity of criteria is considered by the standard deviation and conflict between them is measured by the correlation coefficient. The procedure for SF-CRITIC is described below:

$\tilde{r}_{ij}$: normalised SF fuzzy ratings of i^{th} alternative with respect to j^{th} criterion.

$\tilde{\rho}_{jp}$: linear correlation coefficient between criterion j and p.

$\tilde{H}_j$: quantity of information contained in j^{th} criterion

$\tilde{d}_j$: standard deviation of j^{th} criterion from normal matrix

Step 1:Develop Normalised SF Rating matrix (R):

$$R = [\tilde{r}_{ij}]$$

$$\tilde{r}_{ij} = \frac{(\tilde{y}_{ij} - \tilde{y}_j^-)}{(\tilde{y}_j^* - \tilde{y}_j^-)} \quad (5)$$

where, $\tilde{y}_j^*$ is the ideal value (best performance) of j^{th} criterion.

$\tilde{y}_j^-$ is anti-ideal value (worst performance) of j^{th} criterion.

If criterion j is beneficial, $\tilde{y}_j^* = \max(\tilde{y}_{ij})$ and $\tilde{y}_j^- = \min(\tilde{y}_{ij})$

If criterion j is non-beneficial, $\tilde{y}_j^* = \min(\tilde{x}_{ij})$ and $\tilde{y}_j^- = \max(\tilde{y}_{ij})$

Step 2. Calculate the Standard deviation (d_j):

Determine Standard deviation (d_j) for each criterion from normalised matrix (R) using the corresponding vector.

Step 3. Construct n×n square matrix whose elements are the linear correlation coefficient (ρ) between the r_j and r_p.

$$\rho_{jp} = [\tilde{\rho}_{jp}] \text{ where } p=1,2,\ldots,n \quad (6)$$

Step 4.Calculate the SF Information Measure ($\tilde{H}_j$) of each criterion:

$$\tilde{H}_j = \tilde{d}_j \Sigma (1 - \tilde{\rho}_{jp}) \quad (7)$$

Step 5.Determine the SF Objective Weight of Criteria:

$$\tilde{W}_j = \frac{\tilde{H}_j}{\sum_1^n \tilde{H}_j} \quad (8)$$

Step 6.Determine Non-fuzzy Weight of Criteria

If the fuzzy weight is depicted as W (a, b, c), the Best Non-fuzzy Performance (BNP) (Opricovic & Tzeng, 2003) value is determined as:

$$BNP(W) = a + [(c - a) + (b - a)] / 3 \quad (9)$$

3.5 Stochastic Fuzzy VIKOR

The VIseKriterijumskaOptimizacija I KompromisnoResenje (VIKOR) is a multi-criteria optimization and compromise solution method developed by Opricovic for solving multi-criteria optimization problems of complex systems. It selects the best alternative from a set of feasible alternatives in presence of mutually conflicting criteria while determining a compromise solution. The compromise solution is a feasible solution that is closest to the positive ideal solution and farthest from the negative ideal solution (Opricovic and Tzeng, 2003). The compromise ranking is developed from the Lp-metric used in the compromise programming method. $L_{1,i}$ and $L_{\infty,i}$ are used to formulate the ranking measure.

$$L_{p,i} = \left\{ \sum_{j=1}^{n} (w_j [(x_{ij})_{\max} - x_{ij}] / [(x_{ij})_{\max} - (x_{ij})_{\min}])^p \right\}^{1/p} \quad 1 \le p \le \infty;\ i = 1,2,\ldots,m$$

where; *i: i^{th} alternative; i=1,2,…,m.*

j: j^{th} criteria; j=1,2,…,n.

x_{ij} : rating of i^{th} alternative with respect to j^{th} criteria.

Opricovic and Tzeng (2007) extended fuzzy theory to the VIKOR method, and the authors extended the probability theory to the F-VIKOR method, called SF-VIKOR, which considers variations in group ratings by DMs. The methodology of SF-VIKOR is described below. The fuzzy number *(x)* is denoted by $\tilde{x}$ which has triangular fuzzy values (a, b, c).

Step 1: Develop Normalised SF decision matrix (U_{ij}):

$U = [\tilde{u}_{ij}]$

$$\tilde{u}_{ij} = \frac{(\tilde{y}_{j*} - \tilde{y}_{ij})}{(\tilde{y}_{j*} - \tilde{y}_{j}^{-})} \quad (10)$$

where, $\tilde{y}_j^*$ is best of j^{th} criterion.

$y\tilde{}_j^-$ is worst value of j^{th} criterion.

If criterion j is beneficial, $y\tilde{}_j^* = \max (y\tilde{}_{ij})$ and $y\tilde{}_j^- = \min (y\tilde{}_{ij})$.

If criterion j is non-beneficial, $y\tilde{}_j^* = \min (y\tilde{}_{ij})$ and $y\tilde{}_j^- = \max (y\tilde{}_{ij})$.

Step 2: Weighted Normalised SFdecision matrix:

The weighted normalized SF values are obtained multiplying normalized SF values ($u\tilde{}_{ij}$) by criteria SF objective weight ($w\tilde{}_j$)

Step 3: Compute Best Non-Fuzzy Weighted Normalised Matrix:

The BNP can be calculated using Eq. (9).

Step 4: Determine the Utility Measure (S_i):

S_i is criteria value distance from fuzzy best value.

$$S_i = \sum w_{j*} u_{ij} \text{ for } j=1\ldots n \quad (11)$$

Step 5: Determine the Regret Measure (R_i)

R_i is criteria value distance from fuzzy worst value.

$$R_i = \max [\, w_{j*} u_{ij}] \text{ for } j=1\ldots n \quad (12)$$

Step 6: Compute Q_i index.

$$Q_i = v\,[(S_i - S_i^*) / (S_i^- - S_i^*)] + (1-v)\,[(R_i - R_i^*) / (R_i^- - R_i^*)] \quad (13)$$

where $S^* = \min_i Si$; $S_i^- = \max_i Si$;

$R^* = \min_i Ri$ and $R_i^- = \max_i Ri$.

S*represents the maximum benefit of the group and R* represents minimum regret of opposite view. v denotes the weight of the strategy or course of action and ($1-v$) is the weight of the individual regret; v = 0.5 mean compromise, v >0.5 mean majority vote and v <0.5 mean veto.

Step 7: Rank the Alternatives after Sorting in Ascending order of Q_i index.

The alternative A(1) with minimum value of Q is best alternative subject to the following conditions are satisfied:

Condition 1: Acceptable advantage:

Alternative A(1) is accepted if $QA(2) – QA(1) \geq 1/(m–1)$

where A(1) and A(2) are first and second ranked alternative; m is the number of alternatives.

Condition 2: Acceptable stability:

Alternative A(1) must also be the first ranked by S (or R) and this must be higher than the second ranked S (or R).

If one of the above-mentioned conditions is not satisfied, then we can get the compromised solution that includes the following two judge rules:

(1) The first ranked alternative is the best alternative when the first and second ranked alternatives satisfy both above conditions and

(2) The first and second ranked alternatives are the best alternatives simultaneously when the first and second ranked alternatives only fail to satisfy the condition 2.

4. Case Application in a Footwear Company

The Indian footwear company started operation in 1970s, produces Hawaiian slippers, light weight slippers, canvas shoes etc. for the masses in domestic market. Its turnover has grown from INR 250K in 1971 to more than INR 20 billion in 2019. The firm manufacturing plants are located at ten places in India that produces non-leather slippers, sandals, and sports shoes. To expand its portfolio of products into non-leather and high-end leather formal shoes and slippers, sandals and slippers for ladies, and footwears for kids, the firm has adopted global manufacturing outsourcing for product design and manufacturing from China, Vietnam, Cambodia, Indonesia and Sri Lanka. The firm is selling the product in the country through company-owned retail outlets as well as exporting to Middle East and African countries. Raw materials required are Ethylene-Vinyl Acetate and Polyurethane for Sole, rubber, adhesive chemicals that cause environmental issues. Footwear industry business environment is very competitive and environmental sustainability pressure due to globalization. Hence, agility and sustainability should be incorporated in MOP decision of the Indian footwear industry to maintain competitiveness. Moreover, imprecise and variability of the ratings by group of DMs exist, so fuzzy and stochastic approach is adopted in this study. Integrated SF-CRITIC and SF-VIKOR method is applied for MOP selection and its applicability and robustness is demonstrated in an Indian footwear company. Proposed research framework for the study is displayed in Figure 1, consisting of the following steps.

>INSERT FIGURE 1 HERE<

4.1 Step-1: Identify Selection Criteria, DMs and MOPs

From the literature, twenty-four criteria for agile and sustainable MOP selection were identified. Five procurement experts from the footwear company participated in the Delphi process to rate the criteria in terms of importance on a Likert scale of 1-7. The criteria with mean rating of 4 and above were selected and further refined with Delphi group members. Finally, the sixteen criteria are determined and clustered with four appropriate performance dimensions as follows: *Economic criteria* (product price, product quality); *Agile criteria* (production flexibility and capability, service level, lead time, delivery flexibility, sourcing flexibility, multi-skilled and flexible workforce, collaboration with partners, customer driven innovation); *Environmental criteria* (green product, green manufacturing process, green R&D, environmental management system); *Social criteria* (workers' wages and welfare, workers' occupational health and safety) coded as EC1, EC2, AG1…AG8, EN1, …, EN4, SO1, SO2, shown in Table 2.

>INSERT TABLE 2 HERE<

Fifteen procurement experts with over five years of SCMexperience were identified as DMs from the footwear company which agreed to participate in the survey. In addition, five important MOPs were determined as potential outsourcing partners from the footwear company for the study. Those to be assessed were coded as MOP1, MOP2,…, MOP5.

4.2 Step-2: Data Collection

A questionnaire was prepared to collect data from DMs. The part-I of the questionnaire is the DM's profile such as name (optional), position, years of experience in supply chain, company name, email etc. while in part-II, DMs were asked to rate the identified MOPs with respect to sixteen criteria in linguistic terms as per Table 3. The questionnaire was emailed to fifteen DMs and ten valid responses were received after repeated follow-ups, they are coded as DM1, DM2, …, DM10. The survey was carried out at a company level; hence the valid responses are few. The ratings in linguistic terms are assigned TFN.

>INSERT TABLE 3HERE<

4.3 Step-3: Data Normality Test

As the sample size is small, the Shapiro-Wilk test for criteria fuzzy ratings was carried out and the p-value was found to be greater than 0.05 for most of the criteria ratings, so it is said to follow the normal distribution.

4.4 Step-4: Stochastic Fuzzy Rating

The mean, standard deviation and SF rating using t-score at significance level 5% and $df=9$ is calculated employing Eqs. (1-3) as shown in Table 4.

>INSERT TABLE 4 HERE<

4.5 Step-5: Criteria Objective Weight using SF-CRITIC

The normalised SF rating is determined using Eqs. (5-6) for benefit and non-benefit criteria respectively and standard deviation is then calculated. Then three separate fuzzy linear correlation matrices of nxn (here $n=16$ criteria) (for each a, b, c values of fuzzy number) of criteria are formed. SF information measure ($\tilde{H}$) and SF objective weight ($\tilde{W}$) of criteria is determined using Eqs. (7-8) respectively, as shown in Table 5. These fuzzy weights will be used in F-VIKOR for MOP ranking. The criteria non-fuzzy weight is computed using Eq. (9), shown in Table 5 and Figure 2. The criteria in decreasing order of weights are:

SO1>EC1>EC2>EN2>AG7>AG6>AG3>AG8>AG1>EN3>AG5>AG4>EN4>AG2>EN1>SO2.

These are respectively: worker's wages and welfare, product price, product quality, green manufacturing process, collaboration with partners, multi-skilled and flexible workforce, lead time, customer driven innovation, production flexibility and capability, green R&D, sourcing flexibility, delivery flexibility, environmental management system (EMS), service level, green product, and worker's occupational health and safety.

>INSERT TABLE 5 HERE<

>INSERT FIGURE 2 HERE<

4.6 Step-6: Global Manufacturing Outsourcing Partner Evaluation using SF-VIKOR

From the SF matrix (Table 4), normalized SF matrix for MOP ranking is formed using Eq. (10). The weighted normalized SF matrix is then obtained by multiplying normalized SF matrix with corresponding SF weight of criteria. The defuzzified matrix for MOP is formed using Eq. (9), displayed in Table 6. Next, utility measure (S_i), regret measure (R_i) and relative importance (Q_i) for MOP are computed using Eqs. (11-13) respectively, shown in Table 7. The MOP in ascending order of relative importance (Q_i) score is: MOP3<MOP4<MOP1<MOP5<MOP2; that is, the MOP3 scored the lowest ($Q = 0.134$). The condition 1 ($Q2\text{-}Q2= 0.346–0.134 = 0.212 > 0.125$) and condition 2 ($R= 0.081$ for MOP3 which is lowest) are also satisfied. Therefore, MOP3 is the best agile and sustainable global MOP using integrated SF-CRITIC and SF-VIKOR method. Sensitivity analysis is also carried out to verify the robustness of the proposed method.

>INSERT TABLE 6 HERE<

>INSERT TABLE 7 HERE<

4.7 Step-7: Sensitivity Analysis

Sensitivity analysis of criteria weight and global MOP ranking is carried out by changing the value of significance level (α).

a. Criteria Weight with Significance level (α)

Sensitivity analysis of criteria weight is carried out by changing the value of significance level (α) from 2.5% to 50%as shown in Table 8 and Figure 3. The criteria weights are changing with change in significance level and rank reversal is also taking place. This is mainly due to variance in criteria rating by group of DMs. A comparison of criteria weight at significance level of 5% (SF-CRITIC) and 50% (fuzzy CRITIC) is shown in Figure 4, where the effect of variation in criteria rating by group on criteria weight and rank reversal is more clearly visible. It can therefore be concluded that SF-CRITIC, which takes into consideration the variance in rating, is an improved and robust method to determine criteria weight at a desired level of significance.

>INSERT TABLE 8 HERE<

>INSERT FIGURE 3 HERE<

>INSERT FIGURE 4 HERE<

b. Global Manufacturing Outsourcing Partner Ranking

To test the robustness of the SF-VIKOR for ranking MOP, a sensitivity analysis is carried out by changing significance level (α) as shown in Table 9 and Figure 5. The ranking of MOPs is changing with change of significance level due to variance in ratings by group of DMs. At α = 2% to 10%, MOP3 is preferred partner while MOP4 is second but at α = 15% to 50%, MOP1 takes the position of preferred partner while MOP3 becomes the second. This is mainly due to variation in MOP ratings with respect to criteria by group of DMs. At α = 50%, the model becomes deterministic VIKOR method, in which only mean rating is considered.

>INSERT TABLE 9 HERE<

>INSERT FIGURE 5 HERE<

Similarly, sensitivity analysis is also carried out by changing strategy weight (*V)* from 0.0 to 1.0. It is gain observed that MOP ranking as well as rank reversal are taking place with change of *V, shown* in Table 10 and Figure 6. As V =*0*-0.7, MOP3 remains preferred choice but for V = 0.8-1.0, MOP1 becomes a preferred choice. This phenomenon is due to variance is MOP ratings by group of DMs.

>INSERT TABLE 10 HERE<

>INSERT FIGURE 6 HERE<

5. Discussion

Today's supply chains have become increasingly global and longer from sourcing to consumer, but also more fragile and uncertain due to disruption by unforeseen events. Selecting the best MOP remains an important strategic decision for any global company to be more resilient and competitive. The footwear industry faces challenges such as competitive global markets, increased product variety, shorter product life cycles, and fast and responsive customer service, and requires an appropriate method for selecting the best MOP from among the alternatives. In this study, the integrated SF-CRITIC and SF-VIKOR method was proposed to select the best MOP for a footwear company in India.

According to findings, the criterion for worker's wages and welfare (SO1) has the greatest impact for the MOP selection, followed byproduct price (EC1), product quality (EC2), green manufacturing process (EN2), and collaboration with partners (AG7). Furthermore, the weights of these criteria range between 7-11% and therefore, it can be interpreted as the most important criteria for MOP selection in agile and sustainable supply chain. The other criteria, respectively, multi-skilled & flexible workforce (AG6), lead time (AG3), customer driven innovation (AG8), production flexibility and capability (AG1) and green R&D (EN3) weight range between 5-7% and therefore, they are medium important. The rest of the criteria, sourcing flexibility (AG5), delivery flexibility (AG4), environmental management system (EMS) (EN4), service level (AG2), green product (EN1), and worker's occupational health and safety (SO2) scored less than 5% are found to less important in global MOP selection. The worker's occupational health and safety (SO2) possesses the lowest weight value; therefore, it has the lowest impact for the MOP selection in this study. These criteria were used to select the best MOP among five alternatives. According to the lowest relative importance score, MOP3 was found as the best agile and sustainable global MOP for the footwear company. In addition, sensitivity analysis was applied to investigate the validation of the robustness of the proposed method. The sensitivity analysis also gave the same results as the proposed method. The findings of this study reflected the selection conditions of MOPs for the footwear industry from a developing country perspective. The requirements and priorities for MOP selection vary from industry to industry and subject to subject, so results may also vary from country to country.

6. Conclusion

The current business environment is globalised, volatile, uncertain and under the pressure of sustainable development. Many companies outsource their operations to reduce product cost, increase flexibility and agility to remain competitive. It is very challenging to select a strategic MOP in footwear industry that will provide a competitive advantage to the company, as this industry are facing with fundamental challenges in terms of high product variety, short product life cycle, so many different components in a shoe, price sensitivity, and strong competition. Therefore, sustainability and agility in the supply chain should be adopted for business to remain sustainable, agile and competitive. Agile and sustainable practices adoption into supply chain require its partners collaboration and cooperation. It is therefore challenging for enterprises to select suitable global outsourcing partners, who will collaborate to achieve supply chain sustainability and agility effectively. It is expected that the MOP to be selected will have the requiredcapabilities to cope with all theabove-mentioned difficulties.This requires a systematic evaluation process for global MOP selection. In practice, the relative rating of MOPs based on certain criteria by several DMs generally include vagueness and variation in ratings. Deterministic methods do not cover both vagueness and variation while fuzzy methods only cover vagueness in ratings but not variation. Therefore, stochastic methods also need to be considered in the meantime.So,there is a need to propose a method that includes both fuzzy and stochastic solutions. The proposedSF method considers both aspects of vagueness and variation in ratings by group of DMs. In this study, a novel integrated SF-CRITIC and SF-VIKOR method is proposed for selection of the best MOP for the case company in footwear industry. Selection criteria are identified from the literature and finalised by experts. SF-CRITIC method is used to evaluate and weight of criteria, whereas SF-VIKOR is used to rank MOPs at a desired significance level. The worker's wages and welfare, product price, product quality, green manufacturing process, and collaboration with partners are found important selection criteria. Based on the utility measure, regret measure and relative importance, MOP3 is assessed to be the best MOP for the case company. Sensitivity analysis suggests that the criteria weight and the MOP rankings are changing with change of significance level and rank reversal is also happening at lower significance which is mainly due to variance in ratings by DMs group. Higher significance level covers more variability in data, hence higher value should be used. It is concluded that significance level plays important role. Therefore, the variance in rating should be considered and the proposedmethod provides an accurate and reliable assessment.

6.1 Theoretical Implications

In a group decision-making, ambiguity, impreciseness and variability are found in relative ratings. Fuzzy variant MCDM methods cover impreciseness in ratings but not the variability. On the other hand, deterministic models do not cover either. Hence, the stochastic method based on the probability theory combining fuzzy theory is proposedto deal with decision-making problems in imprecise and uncertain environments. Mean and standard deviation of ratings are calculated and then stochastic value at a desired significance level is determined t-distribution or z-distribution depending on number of DMs. The proposed novel integrated

SF-CRITIC and SF-VIKOR method is an improved method over fuzzy and deterministic methods. Most notably, the proposed model has novelty as it captures and reveals both the stochastic perspective and the fuzziness perspective in rating by group of DMs. As per sensitivity analysis, significance level is crucial for criteria weights andMOP ranking. Higher significance levelmay be used as it covers more variability in rating with higher confidence level. A comparison of MOP rating by deterministic and stochastic one further highlights the importance of significance level. The proposed model performs the best with strong robustness and high reliability in addressing MOP selection.

6.2. Managerial Implications

Sustainability practices are very important due to global pressure, increased pollution, waste generation, and enforced regulations. In footwear industry, product variety is high, product life is short, and competition is very strong. This necessitates the integration of agility and sustainability in supply chain practices and selection of a suitable MOP. The selection criteria for economic, agile, environmental and social dimensions will help managers and professionals alike to understand easily and focus on these dimensions that will improve sustainability and agility in their organisations. The proposed integrated SF-CRITIC and SF-VIKOR method can be understood and used by practitioners to evaluate MOPs at a desired significance level, it is also very helpful to managers in decision making, as it also allows the views of expert groups to be reflected. Practitioners may choose MOP selection criteria depending on the industry to be evaluated. New selection criteria or modified criteria that can be suggested due to changing conditions, needs and priorities of the industry that can be easily integrated into the model. The solution methodology provides consistent results and is safe and easy to use. The proposed method provides practitioners with a unique advantage to use methods at distinct significance level, which may further assist in policy formulation for MOP selection that would minimize risks and thereby avoid problems.

6.3 Key Lessons Learnt

In view of the volatile, uncertain and globalised business environment, agile, environmental and social sustainability criteria in addition to economic and efficiency criteria, should be incorporated in global manufacturing outsourcing decision to achieve sustainability, agility and competitiveness of the firm in footwear industry. Global MOP selection is a complex decision-making problem as it involves multiple criteria and multiple DMs for relative rating.

The proposed SF method incorporates vagueness and variability in ratings. The proposed method at a desired significance level should be used for effective evaluation and selection of global MOP.

6.4 Limitations and Future Research

This study was conducted in a single footwear company in a developing country and tenDMs participated in the study. The sixteen selection criteria related to economic, agile, environmental, and social were selected through literature review and discussion with experts. Future studies may include more DMs from more footwear firms and other developing countries. Future studies may include more qualitative and quantitative criteria. It may also include resilient criteria to improve resilience in outsourcing. The integrated SF-CRITIC and SF-VIKOR model may also be compared with other hybrid models such as fuzzy and stochastic variant of AHP, SWARA, TOPSIS, COPRAS, ELECTRE, MAUT, MOORA to enhance its usefulness and general applicability. The future study could apply the proposed model for other MOP selection problems in the same industry but in the context of different country's economy. Since, the proposed model is generic, it can be also applied to other industries. However, some MOP criteria may be replaced or added depending upon industry and business environment.In this case, DMs should be determined according to the industry that will perform the method.Further study in the future may involve comparing the results of the proposed model in the context of different industries and/or different countries.Finally, the theory extension might be compatible for other industries, if their environments incorporate uncertainty and vagueness as well as stochasticity and variation in the ratings.

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TABLES:

Table 1: Techniques for sustainable and agile outsourcing partner and supplier selection in the literature

Author (s)	Methodology/Techniques	Application
Ji et al. (2018)	Neutrosophic MABAC–ELECTRE method	Outsourcing provider selection
Dos Santos et al. (2019)	Entropy-TOPSIS-F	Sustainable supplier selection
Wang et al. (2019)	F-AHP and TOPSIS	Supplier selection based on triple bottom line
Rabbani et al. (2019)	Interval-Valued Fuzzy sets and possibilistic statistical reference point systems under uncertainty	Sustainable supplier selection
Fei et al. (2019)	Dempster–Shafer evidence theoryand VIKOR	Supplier selection problem
Guarnieri & Trojan (2019)	AHP-ELECTRE-TRI model	Supplier selection based on economic, environmental, social and ethical for outsourcing in the textile industry
Percin (2019)	F-SWARA and Fuzzy axiomatic design method	Outsourcing provider selection in Turkish chemical manufacturing company
Garg & Sharma (2020)	BMW-VIKOR	Sustainable outsourcing partner selection in electronic firm
Liaw et al. (2020)	DEMATEL-CRITIC and classifiable TOPSIS	Evaluate and classify green manufacturing outsourcing providers in Taiwanese multinational machine tool manufacturing company
Goker (2021)	Intuitionistic FCM and COPRAS method	Selection of agile outsourcing provider selection in Turkish white goods industry.
Kumari &Mishra (2020)	Intuitionistic Fuzzy Entropy and Intuitionistic F-COPRAS	Green supplier selection
Ecer & Pamucar (2020)	F-BWM and F-CoCoSo with Bonferroni (CoCoSo'B) method	Supplier selection based on triple bottom line sustainability for home appliance manufacturer in Serbia
Feng & Gong (2020)	LEWM and MOGP	Green supplier selection and order allocation for an automobile manufacturing company in a circular economy
Akhtar & Ahmad (2021)	Stochastic F-TOPSIS	Sustainable vendor selection for spare parts in Indian petroleum refining sector
Nasr et al. (2021)	F-BWM and MOMILP model	Sustainable supplier selection based on economic, environmental, social, and circular criteria and order allocation in a sustainable closed-loop supply chains in garment industry.
Singh and Sarkar (2021)	Integrated AHP and VIKOR	Sustainable contract manufacturer selection in automotive industry
Wang et al. (2021)	F-AHP, F-TOPSIS and DEA	Manufacturing outsourcing selection in apparel and textile supply chain
Lo et al. (2022)	Neutrosophic ITARA and Neutrosophic TOPSIS	Sustainable strategic alliance partner selection in electronics component manufacturing firm
Sahu et al. (2022)	DEMATEL-ANP-AHP, MOORA and SAW	Supplier selection in a lean-agile-resilient-green environment in Indian automotive sector

Table 2: Sustainable and Agile Criteria for Global Manufacturing Outsourcing Partner Selection from the literature

Selection Criteria	Criteria Code	Criteria	Benefit/ Non-benefit	Description	References
Economic Criteria	EC1	Product Price	Non-benefit	Product price	Garg and Sharma (2020), Chen and Hung (2010), Ulutas et al. (2016), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017), Hu and Yu (2015), Adali and Isik (2017), Kabus et al. (2022)
	EC2	Product Quality	Benefit	Product quality and reliability	Liou et al. (2011), Chen and Hung (2010), Ulutas et al. (2016), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017), Hu and Yu (2015), Adali and Isik (2017)
Agile Criteria	AG1	Production flexibility and capability	Benefit	The ability to produce a variety of products to meet customer demand	Chen and Hung (2010),Ulutas et al. (2016), Awasthi et al. (2018), Goren (2018), Luthra et al. (2017), Hu and Yu (2015), Adali and Isik (2017)
	AG2	Service level	Benefit	Providing service without stockout situation	Garg and Sharma (2020), Chen and Hung (2010), Ulutas et al. (2016), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Kabus et al. (2022).
	AG3	Lead time	Benefit	Lead time minimisation	Liou et al. (2011), Goren (2018), Luthra et al. (2017)
	AG4	Delivery flexibility	Benefit	The ability to exploit various dimensions of delivery	Garg and Sharma (2020), Chen and Hung (2010), Ulutas et al. (2016), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017), Hu and Yu (2015), Adali and Isik (2017)
	AG5	Sourcing flexibility	Benefit	Range of sourcing options	Garg and Sharma (2020), Chen and Hung (2010), Luthra et al. (2017), Hu and Yu (2015)
	AG6	Multi-skilled and flexible workforce	Benefit	Multi-skilled workforce and flexible scheduling	Chen and Hung (2010), Ulutas et al. (2016)
	AG7	Collaboration with partners	Benefit	Collaboration with suppliers will enhance innovation and capability	Garg and Sharma (2020), Chen and Hung (2010),Ulutas et al. (2016), Awasthi et al. (2018), Goren (2018), Cheraghalipour and Farsad (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)
	AG8	Customer driven innovation	Benefit	Customer's need-based innovation	Sinha and Anand (2018)
Environmental Criteria	EN1	Green Product	Benefit	Less physical resources input and low environmental impacts	Garg and Sharma (2020), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)
	EN2	Green Manufacturing Process	Benefit	Manufacturing process minimise waste, pollution, and energy use.	Garg and Sharma (2020), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)
	EN3	Green R&D	Benefit	Environmental sustainability in research and development	Garg and Sharma (2020), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)
	EN4	Environmental Management System (EMS)	Benefit	Planning, implementation, monitoring and controlling environmental protection	Garg and Sharma (2020), Chen and Hung (2010), Awasthi et al. (2018), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)
	SO1	Worker's Wages and Welfare	Benefit	Workers' wages and welfare at contract	Garg and Sharma (2020),Cheraghalipour and Farsad (2018), Arabsheybani et al. (2018), Luthra et al. (2017)

				manufacturer company.	
	SO2	Worker's Occupational health and safety	Benefit	Workers' occupational health and safety at contract manufacturer company.	Garg and Sharma (2020), Cheraghalipour and Farsad (2018), Goren (2018), Sinha and Anand (2018), Arabsheybani et al. (2018), Luthra et al. (2017)

Table 3: Linguistic Fuzzy Scale

Linguistic Scale	Triangular Fuzzy Number
Very poor (VP)	(0,1,2)
Poor (P)	(1,2,3)
Medium Poor (MP)	(2,3,4)
Fair (F)	(3,4,5)
Medium Fair (MF)	(4,5,6)
Good (G)	(5,6,7)
Very Good (VG)	(6,7,8)
Strongly Good (SG)	(7,8,9)
Excellent (E)	(8,9,9)

Table 4: Stochastic Fuzzy Ratings of MOP with respect to criteria at Significance level (α) =5%

MOP	EC1			EC2			AG1			AG2			AG3			AG4			AG5			AG6		
MOP1	7.458	8.458	9.458	6.809	7.809	8.809	6.146	7.146	8.253	8.229	9.229	9.780	8.257	9.257	9.848	7.988	8.988	9.507	7.166	8.166	9.166	7.740	8.740	9.740
MOP2	8.039	9.039	10.039	8.939	9.939	10.266	6.919	7.919	8.919	7.360	8.360	9.360	6.825	7.825	8.825	7.572	8.572	9.074	8.439	9.439	10.074	8.856	9.856	8.039
MOP3	7.439	8.439	9.439	7.693	8.693	9.693	8.347	9.347	10.347	7.505	8.505	9.505	7.993	8.993	9.993	7.492	8.492	8.982	7.594	8.594	9.594	6.866	7.866	8.866
MOP4	8.162	9.162	9.739	8.410	9.410	10.024	8.010	9.010	10.010	8.762	9.762	10.388	9.141	10.141	10.456	8.762	9.762	10.410	9.191	10.191	10.539	8.762	9.762	9.984
MOP5	7.905	8.905	9.905	7.360	8.360	9.360	9.471	10.471	10.874	8.645	9.645	10.292	7.146	8.146	9.146	8.866	9.866	10.213	9.039	10.039	10.117	8.010	9.010	9.572

Table 5contd…

MOP	AG7			AG8			EN1			EN2			EN3			EN4			SO1			SO2		
MOP1	7.949	8.949	9.505	9.300	10.300	10.095	5.719	6.719	7.719	7.388	8.388	9.388	6.418	7.418	8.418	5.660	6.660	7.660	6.752	7.752	8.752	5.932	6.932	7.932
MOP2	7.660	8.660	9.660	7.371	8.371	9.371	5.444	6.444	7.444	6.221	7.221	8.221	5.768	6.768	7.768	5.893	6.893	7.893	6.171	7.171	8.171	6.398	7.398	8.398
MOP3	9.446	10.446	10.524	7.693	8.693	9.693	5.866	6.866	7.866	5.905	6.905	7.905	5.299	6.299	7.299	5.221	6.221	7.221	8.124	9.124	9.700	6.292	7.292	8.292
MOP4	7.556	8.556	9.556	8.524	9.524	10.149	5.360	6.360	7.360	6.235	7.235	8.235	7.415	8.415	8.911	5.152	6.152	7.152	7.711	8.711	9.711	7.010	8.010	9.010
MOP5	8.693	9.693	10.363	8.592	9.592	10.592	7.084	8.084	8.547	7.084	8.084	8.547	6.162	7.162	8.162	6.268	7.268	8.268	6.412	7.412	8.412	7.347	8.347	9.347

Table 5: Stochastic Fuzzy Information Measure (H˜),Stochastic Fuzzy Objective Weight (W˜) and Non-fuzzy CriteriaWeight at Significance level (α) =5%

Criteria	**Sum (1-r_{jk}a)**	**Std. dev. (a)**	**H_j(a)**	**Objective Fuzzy Weight (a)**	**Sum (1-r_{jk}b)**	**Std. dev. (b)**	**H_j(b)**	**Objective Fuzzy Weight (b)**	**Sum (1-r_{jk}c)**	**Std. dev. (c)**	**H_j(c)**	**Objective Fuzzy Weight (c)**	**Criteria**	**Objective Fuzzy Weight of Criteria (a,b,c)**			**Criteria Non-Fuzzy Weight (%)**
EC1	16.409	0.405	6.640	0.096	16.409	0.405	6.640	0.098	16.002	0.487	7.797	0.110	**EC1**	0.096	0.098	0.110	10.12
EC2	12.826	0.450	5.770	0.084	11.916	0.450	5.360	0.079	12.711	0.427	5.428	0.076	**EC2**	0.084	0.079	0.076	7.97
AG1	8.159	0.452	3.687	0.053	8.159	0.452	3.687	0.054	8.392	0.453	3.803	0.053	**AG1**	0.053	0.054	0.053	5.38
AG2	7.045	0.456	3.211	0.047	7.045	0.456	3.211	0.047	6.616	0.461	3.049	0.043	**AG2**	0.047	0.047	0.043	4.56
AG3	11.694	0.393	4.590	0.066	11.655	0.393	4.575	0.067	12.843	0.400	5.143	0.072	**AG3**	0.066	0.067	0.072	6.87
AG4	6.520	0.501	3.264	0.047	6.520	0.501	3.264	0.048	6.646	0.462	3.072	0.043	**AG4**	0.047	0.048	0.043	4.62
AG5	7.982	0.432	3.447	0.050	7.982	0.432	3.447	0.051	9.015	0.383	3.450	0.048	**AG5**	0.050	0.051	0.048	4.97
AG6	10.708	0.431	4.617	0.067	10.708	0.431	4.617	0.068	11.978	0.430	5.148	0.072	**AG6**	0.067	0.068	0.072	6.91
AG7	11.143	0.438	4.880	0.071	11.287	0.438	4.943	0.073	9.821	0.485	4.758	0.067	**AG7**	0.071	0.073	0.067	7.01
AG8	10.077	0.464	4.674	0.068	10.437	0.464	4.841	0.071	7.869	0.444	3.495	0.049	**AG8**	0.068	0.071	0.049	6.27
EN1	6.752	0.456	3.077	0.045	6.714	0.456	3.060	0.045	6.884	0.421	2.901	0.041	**EN1**	0.045	0.045	0.041	4.35
EN2	9.960	0.466	4.639	0.067	9.563	0.466	4.454	0.066	12.183	0.456	5.559	0.078	**EN2**	0.067	0.066	0.078	7.03
EN3	8.991	0.375	3.374	0.049	8.064	0.375	3.027	0.045	10.557	0.382	4.029	0.057	**EN3**	0.049	0.045	0.057	5.01
EN4	7.650	0.396	3.031	0.044	7.650	0.396	3.031	0.045	8.890	0.396	3.522	0.049	**EN4**	0.044	0.045	0.049	4.60
SO1	17.395	0.433	7.528	0.109	16.485	0.433	7.134	0.105	15.765	0.468	7.376	0.104	**SO1**	0.109	0.105	0.104	10.60
SO2	6.419	0.404	2.594	0.038	6.261	0.404	2.530	0.037	6.533	0.404	2.640	0.037	**SO2**	0.038	0.037	0.037	3.73

Table 6: Defuzzified Matrix for MOP

MOP	EC1	EC2	AG1	AG2	AG3	AG4	AG5	AG6	AG7	AG8	EN1	EN2	EN3	EN4	SO1	SO2
MOP1	0.003	0.114	0.072	0.027	0.030	0.035	0.050	0.043	0.061	0.007	0.033	0.000	0.020	0.025	0.072	0.050
MOP2	0.090	0.086	0.048	0.042	0.060	0.043	0.052	0.075	0.068	0.058	0.031	0.057	0.038	0.036	0.106	0.034
MOP3	0.000	0.077	0.056	0.043	0.069	0.043	0.048	0.061	0.080	0.060	0.033	0.055	0.036	0.032	0.000	0.037
MOP4	0.083	0.074	0.062	0.048	0.063	0.050	0.054	0.069	0.075	0.067	0.038	0.062	0.040	0.038	0.015	0.012
MOP5	0.070	0.086	0.062	0.049	0.076	0.050	0.055	0.075	0.080	0.070	0.038	0.066	0.046	0.038	0.092	0.000

Table 7: Utility Measure (S), Regret Measure (R), and Relative Importance (Q) for MOP

MOP	S_i	R_i	Q_i	Rank by Q
MOP1	0.642	0.114	0.500	III
MOP2	0.925	0.106	0.837	V
MOP3	0.731	0.080	0.142	I
MOP4	0.850	0.083	0.383	II
MOP5	0.955	0.092	0.677	IV

Table 8: Sensitivity Analysis: Criteria Weight with change of Significance level (α)

Criteria	Significance Level (α)							
	2.5%	**5%**	**10%**	**15%**	**20%**	**25%**	**40%**	**50%**
EC1	9.30	10.12	10.77	10.34	10.38	10.52	10.45	10.16
EC2	7.61	7.97	8.51	9.04	8.98	8.56	6.99	6.11
AG1	5.26	5.38	5.60	5.85	6.26	6.70	7.92	8.43
AG2	4.34	4.56	4.72	4.68	4.80	4.98	5.59	5.64
AG3	7.27	6.87	6.42	6.28	6.20	5.85	5.32	5.31
AG4	4.61	4.62	4.66	4.66	4.81	5.00	5.65	5.92
AG5	4.90	4.97	5.13	5.19	5.21	5.26	4.86	4.46
AG6	6.98	6.91	6.52	6.23	6.15	6.10	5.73	5.40
AG7	7.32	7.01	6.81	6.82	7.05	7.42	8.71	8.93
AG8	6.69	6.27	5.76	5.47	5.40	5.38	4.16	3.13
EN1	4.65	4.35	3.94	3.62	3.40	3.20	2.95	3.53
EN2	7.64	7.03	6.34	5.97	5.66	5.35	5.40	5.68
EN3	5.04	5.01	4.97	4.98	5.13	5.32	5.72	5.77
EN4	4.58	4.60	5.01	5.88	5.76	5.53	5.24	5.16
SO1	10.15	10.60	10.85	10.74	10.68	10.79	11.12	11.62
SO2	3.66	3.73	3.99	4.25	4.13	4.06	4.19	4.75

Table 9: Sensitivity Analysis: MOP Rank with change of Significance level (α)

MOP	Significance Level (α)							
	2%	**5%**	**10%**	**15%**	**20%**	**30%**	**40%**	**50%**
MOP1	0.500	0.500	0.389	0.1975	0.000	0.000	0.000	0.000
MOP2	0.653	0.837	0.972	0.881	0.908	0.914	0.807	0.627
MOP3	0.124	0.142	0.238	0.3083	0.394	0.358	0.586	0.562
MOP4	0.309	0.383	0.348	0.360	0.439	0.452	0.707	0.908
MOP5	0.512	0.677	0.922	1.000	1.000	1.000	1.000	1.000

Table 10: Sensitivity Analysis: MOP Rank with change of Strategy Weight (*V*) @ α=5%

MOP	Strategy Weight (*v*)										
	0.0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**
MOP1	1.000	0.900	0.800	0.700	0.600	0.500	0.400	0.300	0.200	0.100	0.000
MOP2	0.768	0.781	0.795	0.809	0.823	0.837	0.850	0.864	0.878	0.892	0.906
MOP3	0.000	0.028	0.057	0.085	0.113	0.142	0.170	0.199	0.227	0.255	0.284
MOP4	0.100	0.156	0.213	0.270	0.326	0.383	0.439	0.496	0.553	0.609	0.666
MOP5	0.355	0.419	0.484	0.548	0.613	0.677	0.742	0.806	0.871	0.935	1.000

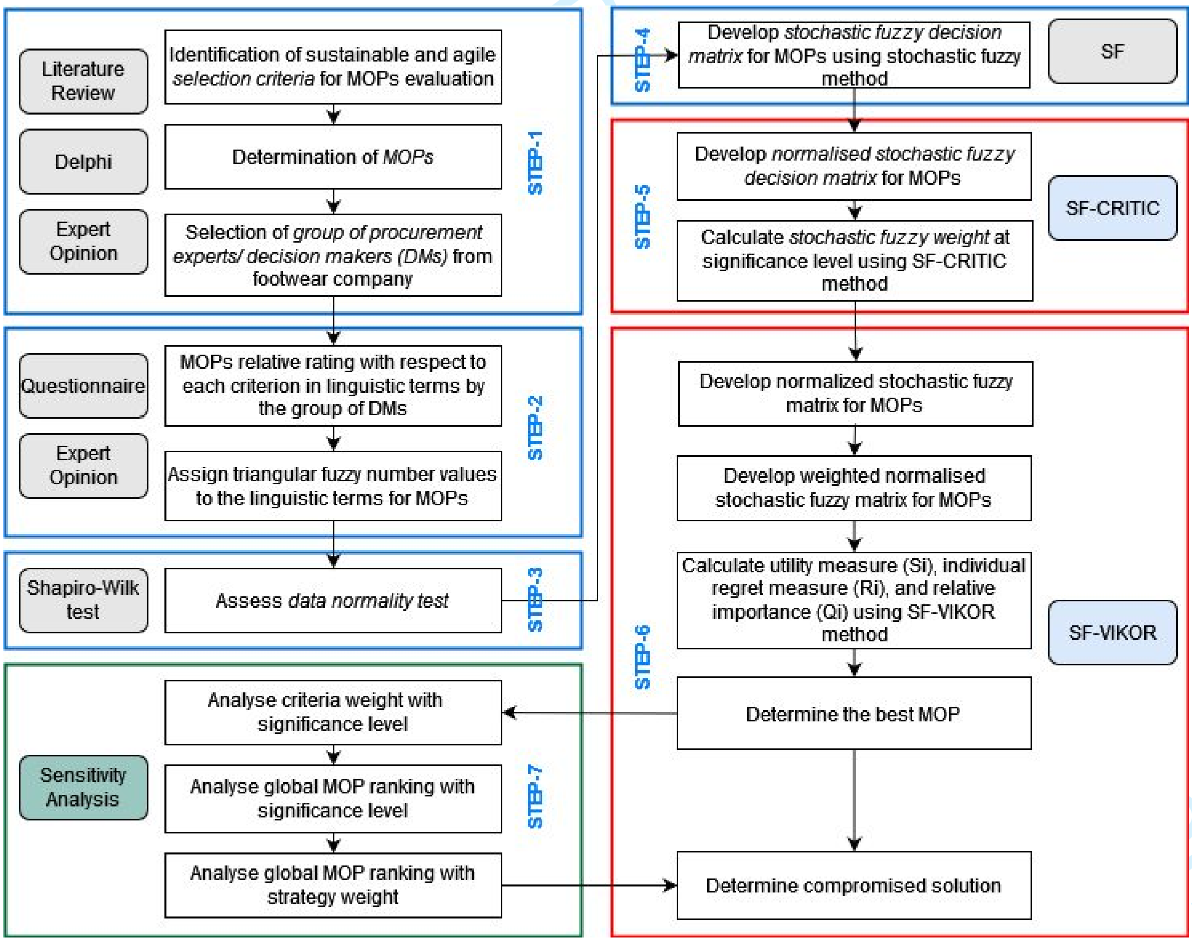

Figure 1: Proposed Research Framework for the Study

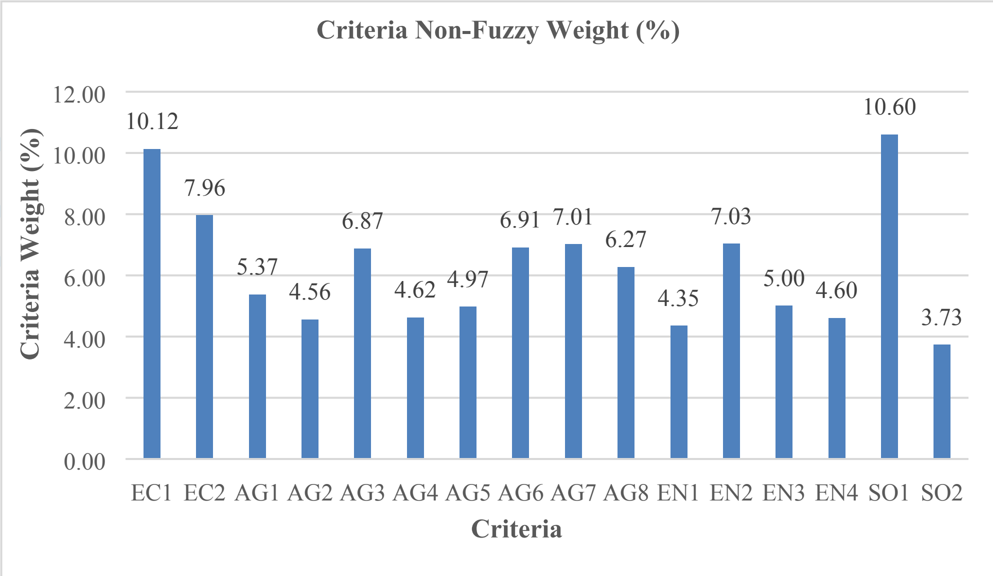

Figure 2: Criteria Non-Fuzzy Weight

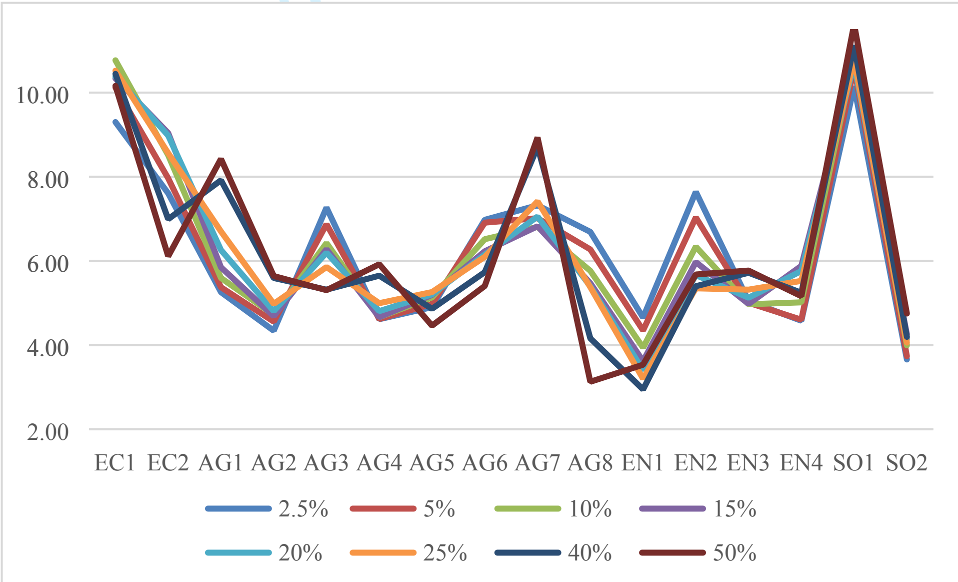

Figure 3: Sensitivity Analysis: Criteria Weight with change of Significance level (α)

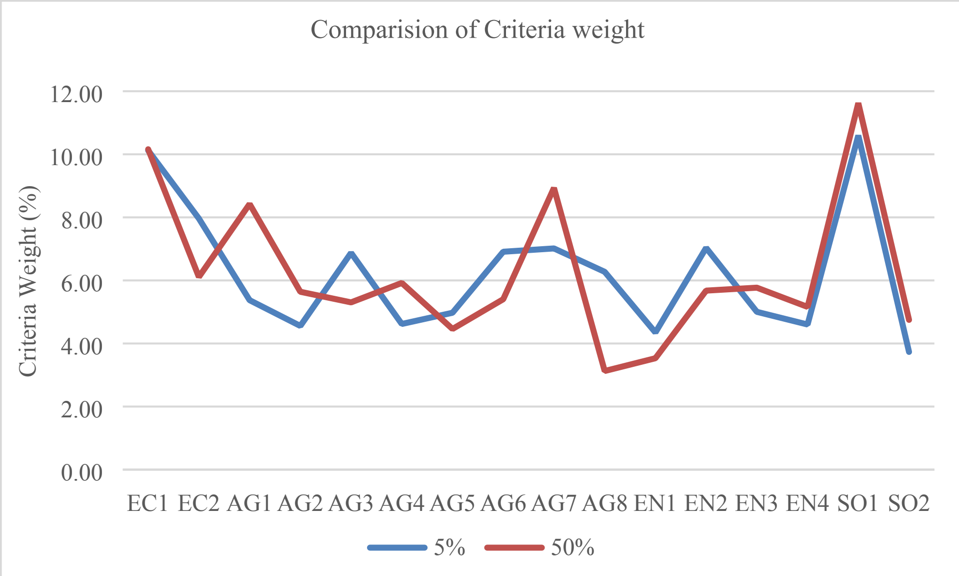

Figure 4: Comparison of Criteria Weight at Significance level 5% (by SF-CRITIC) and F-CRITIC

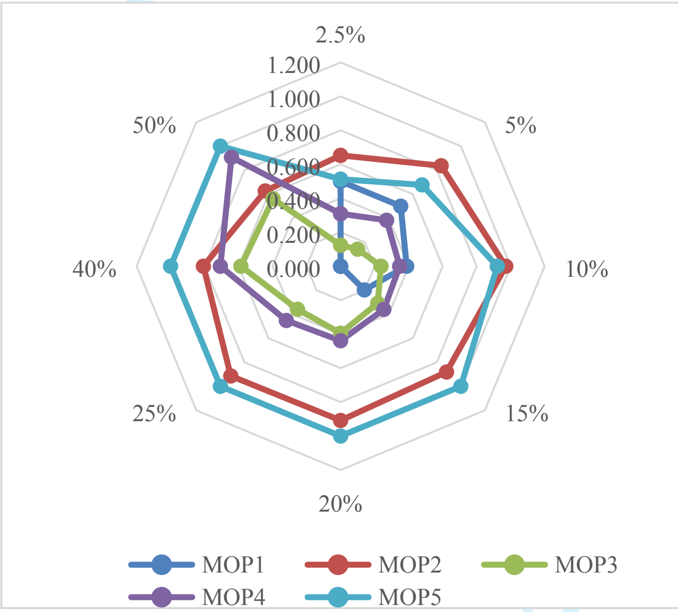

Figure 5: Sensitivity Analysis: MOP Rank with change of Significance level (α)

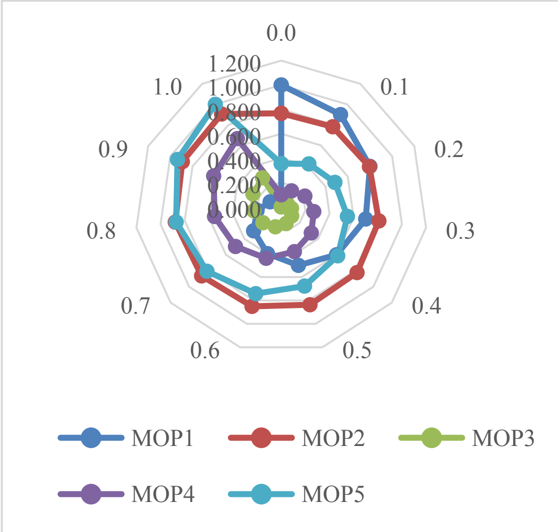

Figure 6: Sensitivity Analysis: MOP Rank with change of Strategy Weight (*V*) @ α=5%