Soft Set and Fuzzy Set Approaches in Sustainable Supplier Selection in the Textile Industry

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Abstract

The industry of textiles is experiencing a harness shift to sustainability with the growing environmental issues, limited resources, and strict regulatory policies. The choice of suppliers and the preference of materials have thus emerged as important elements in sustainable and green supply chain management. In order to solve the uncertainty, vagueness and the complexity of multiple criteria involved in sustainable selection of suppliers to the textile industry within the framework of soft set theory and fuzzy set theory, this paper suggests an integrated decision-support framework. The primary data was obtained through 300 stakeholders in Indian textile industry, descriptive statistics, exploratory factor analysis and multiple linear regression were used to validate the key decision criteria such as cost efficiency, quality, delivery time, sustainability and reliability. The parameter based supplier evaluation and ranking model was built using soft set theory and had no strict membership functions as the model was made flexible, and fuzzy set theory was used to process linguistic and subjective evaluations using membership functions. The comparative analysis shows that soft set-based approach offers more flexibility and strength in dealing with incomplete and uncertain information as opposed to the fuzzy set approach which makes easy to capture human judgment and imprecision. The findings support the fact that reliability, cost efficiency and availability time play a significant role in the general satisfaction of suppliers. The suggested hybrid framework will increase the accuracy of the decision, facilitate sustainable material preference, and improve the process of supplier evaluation in the textile sector, leading to the long-term environmental, economic, and social sustainability.

Keywords:

Sustainable Supplier Selection; Soft Set Theory; Fuzzy Set Theory; Textile Industry; Multi-Criteria Decision Making

The textile industry is in a critical change since it is experiencing pressure to be sustainable due to the growing environmental degradation, scarcity of resources, climate change issues and more strict regulations. Textiles being one of the resource consuming and pollution generating industries, they have a huge impact on the consumption of water, chemical release, carbon emission, and solid waste. This has led to the sustainable selection of suppliers becoming a central element of the green supply chain management, which has direct impacts on environmental performances, social responsibility and economic viability in the long term. The decisions of the suppliers in the modern world go much further than the rather universal cost-based approach and entail the combination of economic performance, environmental friendliness, social accountability, and the oncubature of the supply chain (Govindan et al. 2017; Badi et al. 2023).

Selecting suppliers in the textile business is a multi-criteria decision-making (MCDM) problem that is ambiguous, subjective and not complete in information. When it comes to such sustainability limitations as quality of eco-materials, ethical business behavior, ability to reduce waste and dependability of suppliers, decision-makers face problems with gauging a qualitative and uncertain parameter. The traditional deterministic approaches to decision making that are based on the accurate numerical performance cannot reflect the vagueness of such criteria. Consequently, sophisticated decision-support methodologies that can be used to model uncertainty have received growing interest in sustainable supply chain research (Kannan 2020; Mishra et al. 2022).

Supplier selection problems have been highly subjected to the use of the fuzzy set theory that was initially developed to cope with imprecise and linguistic data. The fuzzy based models enable the decision-makers to declare the subjective judgments in the language and transform them into numeric values by using membership functions. The fuzzy multi-criteria methods that have been widely used in the textile and garment sector to evaluate suppliers in terms of sustainability, quality, delivery reliability, and environmental performance include fuzzy AHP, fuzzy TOPSIS, and hybrid fuzzy models (Rouyendegh et al. 2016; Mao et al. 2017; Dey et al. 2022; Chithambaram et al. 2022). These methods have been especially successful when it comes to addressing sustainability based decision situations in which precise performance data does not exist or cannot be measured.

Although fuzzy set-based approaches are popular, they can be quite reliant on pre-programmed membership functions, which can be prone to subjectivity and lack of consistency, particularly when there is discrepancy in opinions among experts, or when there are limitations in the availability of data. Soft set theory has developed as an alternative to soft deterministic decision-making in order to overcome these constraints and provide a more suitable and resilient decision-making tool. Soft set theory offers a parametric structure, which removes the concept of inflexible membership functions and gives decision-makers the opportunity to directly couple the parameters with the decision options. This aspect renders soft sets especially appropriate when considering difficult sustainability-related standards of waste reduction, adoption of environment-friendly materials, flexibility of the supplier, and resilience in the textile supply chain over a long period (Chakraborty et al. 2019; Abedi et al. 2021).

Recent studies underline the usefulness of applying soft set theory to complement fuzzy logic in order to improve the strength and the certainty of decisions. Hybrid Hybrid soft-fuzzy models combine the linguistic power of fuzzy sets and structural flexibility of soft sets to achieve better uncertainty and incomplete information management. These combined solutions have been effectively implemented to assessments of textile suppliers, textile dyeing processes, and sustainable sourcing strategies, in particular, when operating in such a context as fluctuating prices of raw materials and disruptions of the chain of delivery due to global disasters, including the COVID-19 pandemic (Zavadskas et al. 2021; Li et al. 2024). Comparative research also indicates that the soft set-based and hybrid models are more effective than the conventional MCDM methods such as AHP and TOPSIS in regards to flexibility, computational speed, and consistency of decision-making (Yazdani et al. 2023).

Within the framework of sustainable textile supply chains, a hybrid solution, consisting of soft set and fuzzy sets, provides a holistic and flexible model of selecting suppliers and the preference of materials. These approaches allow the incorporation of quantitative performance measurements as well as qualitative expertise views as well as dealing with the uncertainty and vagueness. The soft set and fuzzy set theories can be used to enhance the sustainability goals, supplier relations, and competitiveness of textile supply chains in general, as they can improve decision accuracy and resilience. Consequently, the current research aims to use the soft set and fuzzy set methods to establish a powerful decision support model in the selection of sustainable suppliers and choice of materials in the textile sector.

Review of literature

Soft set and fuzzy set methods can well deal with unpredictability and lack of transparency in the decision-making process of suppliers and material choice in the textile industry. Multi-criteria decision-making (MCDM) techniques are used extensively because supplier evaluation is a complex process that requires numerous contradictory criteria, including: economical, environmental and social. Fuzzy logic can be used to manipulate the imprecise linguistic judgments, and soft set theory can be used to provide other forms of parameterization without rigid membership requirements. The combination of these strategies helps the green supply chain management in the textile industry greatly. The literature indicates that such applications have been steadily growing since the beginning of the 2010s, with more focus on hybrid fuzzy-soft models to evaluate suppliers and resilience (Buyukozkan and Govindarajan, 2018; Govindan et al., 2023).

Fuzzy Approaches in Supplier Selection

Zadeh (1965) developed the Fuzzy set theory that has been widely applied to deal with vagueness in the evaluation criterion of suppliers of textile; quality, delivery reliability, price stability, and sustainability compliance. The Mamdani-type fuzzy inference systems have been used in the Indian textile industry to evaluate the suppliers based on their inputs (cost efficiency, product quality, and service responsiveness) to give a graded acceptance decision (Goswami and Kumar, 2011).

The most notable hybrid fuzzy MCDM methods include fuzzy AHP-TOPSIS in the selection of sustainable garment suppliers. These models bring together the triple bottom line (TBL) model, which has balanced the economic viability, environmental responsibility, and social compliance (Kannan et al., 2014; Luthra et al., 2017). Ranking of yarn and fabric suppliers to produce shirts has also been provided by fuzzy TOPSIS with addition of flexibility and quality uncertainty (Buyuokozkan and Cifci, 2012; Singh et al., 2016).

Soft Set Applications

One proposal to hold uncertainty is soft set theory, which was introduced by Molodtsov (1999) and can be used where the parameters of the decision are subjective or context dependent. Fuzzy soft sets and rough fuzzy soft approximations enable the incorporation of more than two stakeholder views in supplier selection problems without having strict membership functions (Çağman and Enginoğlu, 2010; Alcantud et al., 2018).

Soft set applications are also being developed in textile-related studies, especially in smart and functional textiles fabric and material selection. The focus of these studies is the comfort, durability, thermal resistance, and functionality of these parameters, which in turn proves the versatility of the soft sets in the context of material preference modeling (Kumar et al., 2025; Ali et al., 2017).

Hybrid Fuzzy–Soft Models

The fuzzy and soft set theories have been hybridized to make it more robust and improve the sustainability of MCDM frameworks in choosing suppliers. Fuzzy soft sets are used in the confidence based supplier ranking systems which enhance stability of decisions made in the face of uncertainty (Roy and Maji, 2012). New, integrated frameworks are using fuzzy logic and soft computing with MCDM tools to promote resilience among suppliers in the case of a disruption like the COVID-19 pandemic (Govindan et al., 2023; Ivanov and Dolgui, 2020).

These hybrid models are especially appropriate when it comes to the textile supply chain, which can be marked by the instability of demand, environmental questioning, and labour-consuming nature of its functioning. Fuzzy–soft methods contribute to the flexibility and openness of supplier assessment (Buyuozekan et al., 2021).

Textile Industry–Specific Applications

Fuzzy inference systems are applied more often in textile-oriented studies to evaluate suppliers modularly, reflecting opinions of subjective experts on the criteria of green and ethical standards (Çalik, 2022). The ranking of suppliers of yarn and dyeing is performed with the help of the Fuzzy TOPSIS and Fuzzy VIKOR, where the priorities are quality, cost, flexibility, and environmental impact (Yildiz and Yildiz, 2016; Ertuğrul and Karakaasoglu, 2009).

The water use, chemical toxicity, and carbon emissions are environmental weights used in the choice of a sustainable dyeing and finishing supplier based on fuzzy MCDM frameworks (Khandekar et al., 2021; Singh and Jain, 2022).

Research Gaps and Emerging Trends

Although fuzzy MCDM techniques have been widely used, little has been done to directly hybridize soft and fuzzy sets in order to derive textile material preference and eco-material choice. The majority of the current research is aimed at generalized supply chains, but not at the textile contextual (Alcantud et al., 2018; Büyuozkan et al., 2021).

There are emerging trends in research that combine resilience, risk, and pandemic-related factors based on fuzzy best- worst approaches and interval-valued fuzzy sets (Pamučar et al., 2023; Govindan et al., 2023). The next step in research should focus on textile-related fuzzy - soft hybrid systems that assess sustainable fibers, intelligent fabrics and circular textile materials.

Research Methodology

Research Design

The current research adheres to the quantitative and analytical research design to investigate sustainable selection of suppliers and material preference decision-making in the textile industry through the Soft Set Theory and Fuzzy Set Theory. The methodology combines statistical tools and mathematical decision making models to systematically resolve uncertainty, vagueness and multi-criteria complexity of supplier evaluation and multi-faceted decision-making processes that address sustainability.

Study Area and Population

It is carried out in the Indian textile industry among the major stakeholders of the industry such as the textile industries, the suppliers of the raw material, the procurement managers, the quality control professionals, and industry experts. These respondents will be directly engaged in the selection of suppliers, acquisition of materials, and operation-related decisions which will have sustainability-related implications, which will ensure the practicality of the study.

Data Collection

The primary data were gathered through the structured questionnaire that was developed on the five-point Likert scale of very low to very high. The questionnaire was used to record the assessment of key supplier selection requirements, i.e. cost efficiency, quality, delivery time, sustainability and reliability. The 300 valid responses obtained were by conducting online survey and face to face interaction such that there was sufficient representation and diversity of industry views.

Data Preparation and Preprocessing

The systematic preprocessing of the data was carried out after collection to make sure that the dataset was accurate and reliable. Outliers have been determined based on the use of boxplot analysis, and the missing values were filled in based on the mean imputation. The data was

tested against the normality of the data through the ShapiroWilk and KolmogorovSmirnov tests. In order to facilitate mathematical modeling and comparability across criteria, all the variables were normalized to a 01 scale.

Statistical Analysis

The data were statistically analyzed with the help of SPSS in order to prove the data and facilitate the development of the model. To provide a summary of the attributes of the dataset, descriptive statistics were used. Internal consistency of the measurement scales was checked by means of the reliability analysis involving Cronbach Alpha. The empirical background of the Results chapter was comprised of Exploratory Factor Analysis (e.g. determining the underlying dimensions of supplier selection criteria) and Multiple Linear Regression Analysis (e.g. analyzing the connections between the variables of the decisions and the overall supplier satisfaction).

Application of Soft Set Theory

Soft Set Theory has been used as the main decision-making model to provide uncertainty and incompleteness in decision-making without having the pre-determined membership functions. The methodology entailed finding alternatives of decision, determining the appropriate parameters of evaluation, building soft sets, assigning weight to the criterion attributes as per expert judgment and combining weighted scores, ranking suppliers and material options. The stability and strength of the soft set based decision model were also tested by sensitivity analysis to determine their stability.

Application of Fuzzy Set Theory

The Fuzzy Set Theory had been utilized in order to offer comparative analysis with the soft set approach. The linguistic data acquired out of the respondents were converted to fuzzy numeric numbers by using membership functions. Fuzzy scores were then aggregated (using weight) to rank the suppliers and material preferences to allow the calculation of subjective and imprecise decision criteria in the fuzzy environments.

Model Validation and Comparison

The reliability testing, factor structure validation, sensitivity analysis, expert judgment, and the comparison with historical performance data were used to determine the validity of the developed decision-making models. A methodological analysis of the approaches of Soft Set

and Fuzzy Set was carried out in comparison to evaluate their effectiveness in terms of flexibility, ease of computation and capability to deal with incomplete, qualitative and uncertain information.

Tools and Software

Statistical analysis was conducted in SPSS and mathematical modeling was applied in the implementation of Soft Set and Fuzzy Set frameworks.

Ethical Considerations

The study was voluntary and the respondents were guaranteed confidentiality and anonymity. Collected data were all applied towards academic and research purposes.

Results

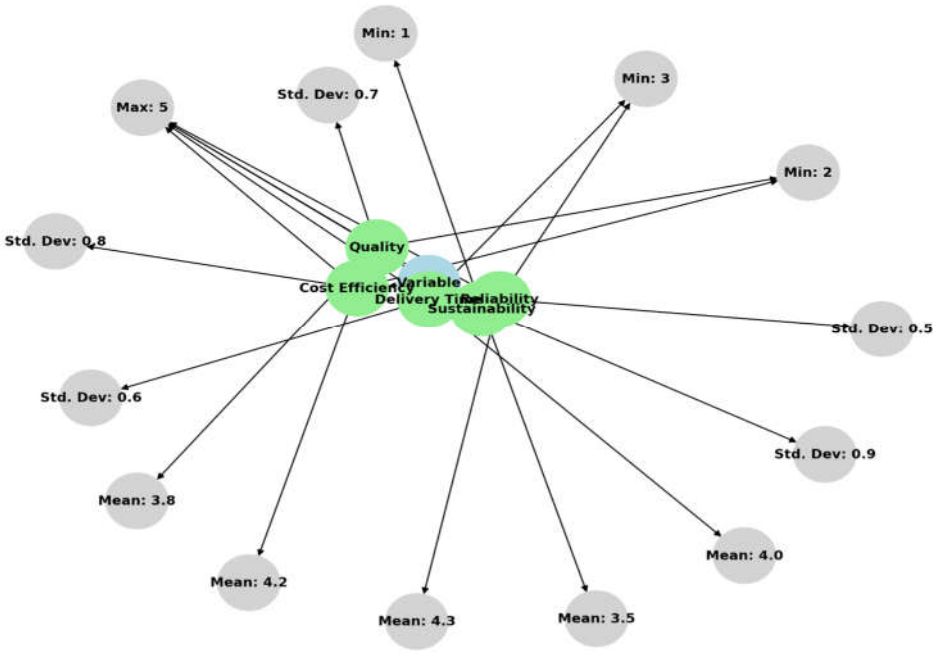
Descriptive Statistics

Table 1 shows the descriptive statistics of the major decision variables such as Cost Efficiency, Quality, Delivery Time, Sustainability and Reliability. These descriptive statistics are presented graphically in Figure 1, which illustrates the mean distribution and variability of each of the parameters among the textile suppliers sampled.

Table 5: Descriptive Statistics of Key Decision Variables for Textile Supplier Evaluation

Variable	Mean	Std. Dev	Min	Max
Cost Efficiency	4.2	0.8	2	5
Quality	3.8	0.7	2	5
Delivery Time	4	0.6	3	5
Sustainability	3.5	0.9	1	5
Reliability	4.3	0.5	3	5

Figure 1



Regression Analysis

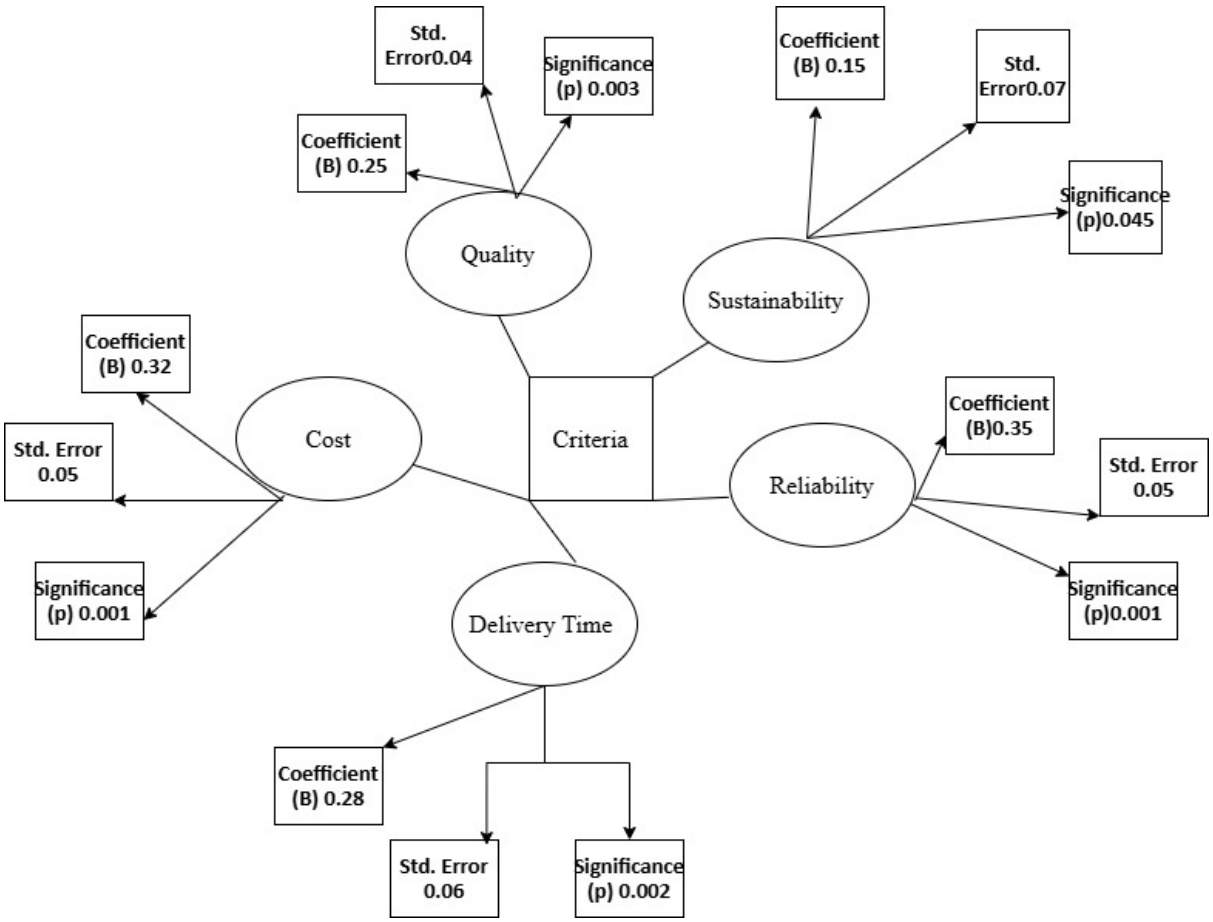
The multiple linear regression results examining the influence of Cost Efficiency, Quality, Delivery Time, Sustainability, and Reliability on Overall Supplier Satisfaction are summarized in Table 2. The graphical output of the regression model, depicting the strength and direction of predictor relationships, is presented in Figure 2 .

Table 2: Multiple Linear Regression Results for Factors Influencing Overall Supplier Satisfaction

Predictor	Coefficient (B)	Std. Error	Significance (p)
Cost Efficiency	0.32	0.05	0.001
Quality	0.25	0.04	0.003

Delivery Time	0.28	0.06	0.002
Sustainability	0.15	0.07	0.045
Reliability	0.35	0.05	0.001

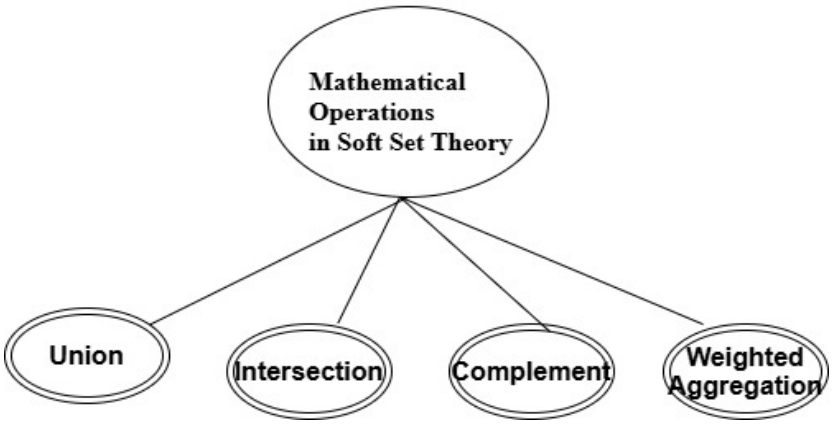
Figure 2 .



Factor Analysis Results

Exploratory Factor Analysis revealed that there are two strong factors that explain supplier selection behavior. Figure 3 shows the graphical representation of factor structure and variable loading in support of grouping and dimensional reduction of decision criteria.

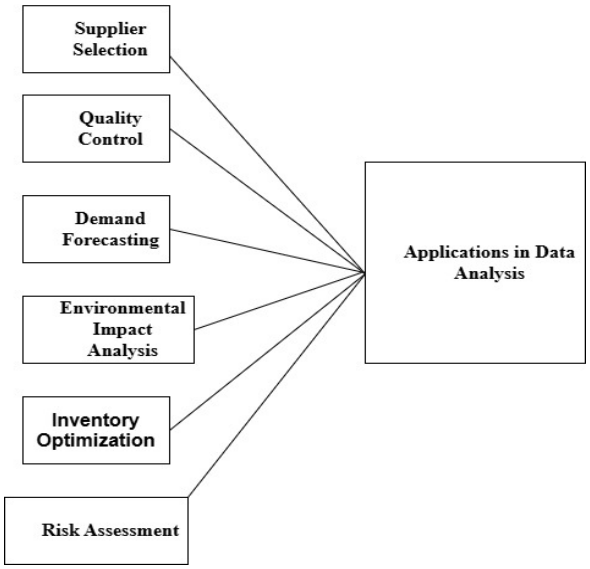
Figure-3



Applications of Soft Set Theory

Figure 4 is a visual representation of the conceptual and operational structure of the soft set theory and the mathematical operations of the soft set theory such as union, intersection, complement, and weighted aggregation. This value can be explained by the fact that soft set-based decision modelling is used in the decision to select suppliers, control quality, predict demand, evaluate sustainability, optimize inventory, and analyze risks.

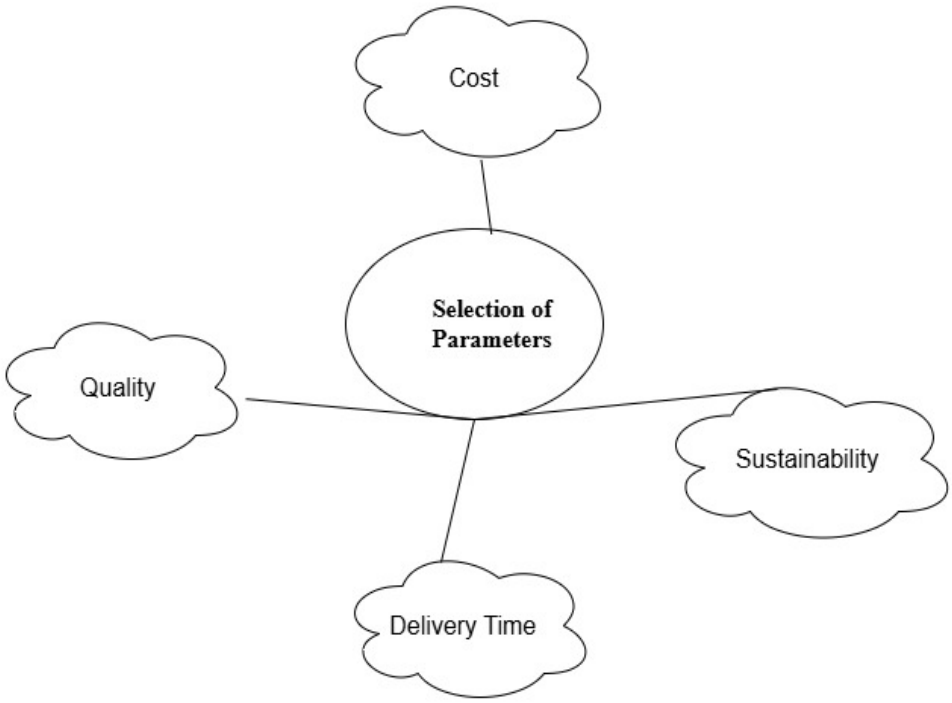
Figure -4



Decision-Making Model Development

The identification of the parameters in the soft set-based decision-making structure is depicted in Figure 5 that depicts the correlation between the criteria of the decisions and the supplier options. This metric aids graphically in the development of the process of the soft set and mapping parameters.

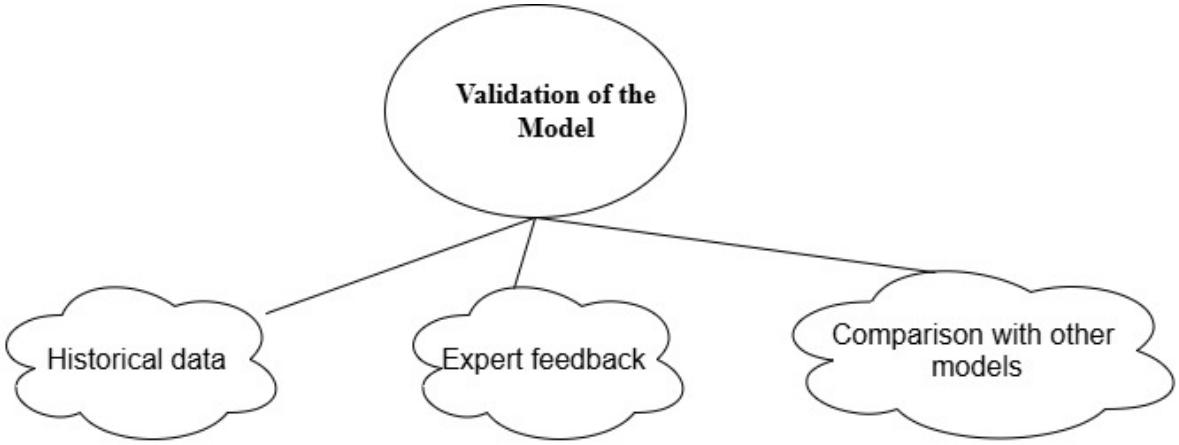
Figure -5



Model Validation

The validation mechanisms of the developed decision-making model—including historical data comparison, expert judgment, and model robustness—are depicted in Figure , 6reinforcing the credibility and applicability of the proposed approach.

Figure-6



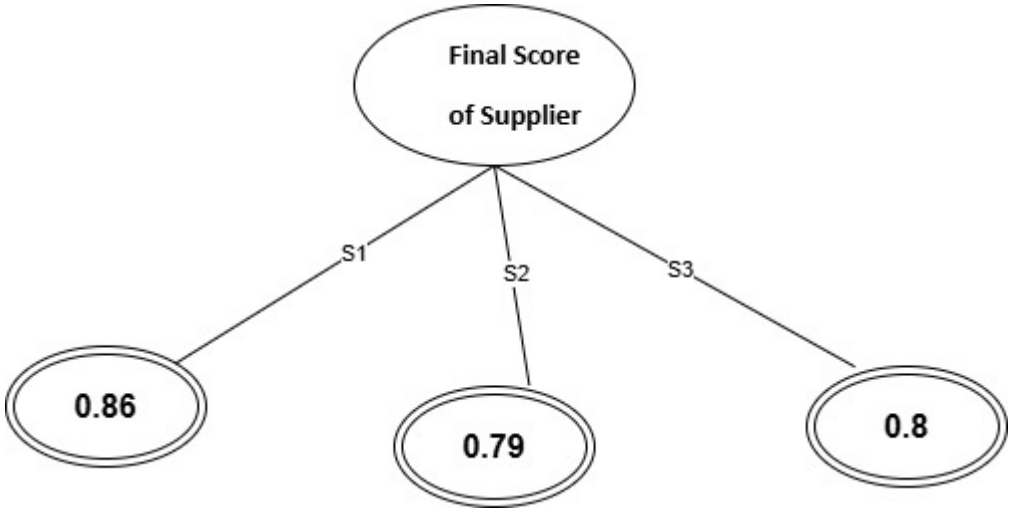
Evaluation and Interpretation of Results

The comparative performance of suppliers based on aggregated soft set scores is presented in Table 3, while the corresponding graphical comparison of final supplier scores is shown in Figure 10, enabling clear visualization of ranking outcomes.

Table 3: Comparative Evaluation of Suppliers Based on Aggregated Soft Set Scores

Supplier	Cost (C)	Quality (Q)	Delivery Time (D)	Sustainability (S)	Final Score
S1	0.8	0.9	0.85	0.7	0.86
S2	0.7	0.8	0.75	0.85	0.79
S3	0.9	0.75	0.6	0.8	0.8

Figure-7



Discussion

The results of the current research are valuable to make the selection of suppliers and the decision on the choice of material in the textile industry as sustainable in terms of Soft Set and Fuzzy Set. The descriptive statistics demonstrate that reliability and cost-effectiveness have the largest mean values of all the considered criteria, which can be explained by the fact that textile companies remain focused on operational stability and economic viability as they shift to the concept of sustainability. Although slightly less in the mean value, sustainability is a very important factor, indicating the increasing awareness and the gradual realization of the environmental issues in the supplier evaluation practices.

Regression analysis also validates the claim that the overall satisfaction of suppliers is statistically significantly influenced by all the five decision variables, which are cost efficiency, quality, delivery time, sustainability, and reliability. Reliability has been the most influential predictor, then cost efficiency and delivery time. This observation is consistent with previous research that has highlighted the significance of reliable supply performance in the textile business, especially in the event of demand instability as well as supply chain failures. There is also a positive and significant effect of sustainability, which, however, supports the argument

that the competitiveness of suppliers in the environmentally responsible practice is becoming more and more significant.

The existence of two prevailing underlying dimensions of supplier selection behavior was found in the exploratory factor analysis, confirming the multidimensionality of sustainability-related decision-making. These findings are in line with the existing literature that textile industry supplier selection cannot be effectively done using single-criterion methods, or using only cost based methods.

The use of Soft Set Theory proves that it is able to deal with parameter based uncertainty without the need to use predefined membership functions. Such a level of flexibility comes in handy especially when assessing a complex and qualitative set of sustainability goals like waste reduction, use of eco-materials and supplier resilience in the long run. The aggregated soft set scores vividly contrast supplier performance and make it transparent to rank and this can be seen in the results of the comparative evaluation.

Conversely, the Fuzzy Set methodology is useful to encode linguistic judgments to quantitative values, which represents the expert opinions and subjective evaluations. Nevertheless, it has a subjective element because it depends on membership functionality particularly in cases where there is limited expert agreement. According to the comparative methodological discussion, fuzzy approaches are more effective at modeling human judgments, but soft set-based models are more flexible and computationally simpler in uncertain and data-constrained situations.

In general, the discussion reveals that the hybrid soft-fuzzy decision-making models are especially appropriate in the textile business where the sustainability, uncertainty, and complexity of operations are present. The article supports the increasing agreement that effective MCDM tools are needed to ensure stable and sustainable textile supply chains..

Conclusion

The current research was able to create and verify a comprehensive decision-making model based on Soft Set and Fuzzy Set theory to select sustainable suppliers and select materials in the textile industry. The research minimized the issue of uncertainty, vagueness and complexity of multi-criteria in supplier evaluation processes that was tackled by the integration of statistical validation techniques and mathematical decision models.

The empirical findings indicate that the critical aspects that influence overall supplier satisfaction include reliability, cost efficiency and delivery time whereas sustainability

contributes significantly and increasingly in the decision making process. The use of soft set-based evaluation model in managing the incomplete and qualitative information that is not subjected to rigid membership functions was particularly effective and therefore manufactured it quite appropriate in the sustainability-driven decisions. This was complemented by the fuzzy set approach which was able to capture lingual assessment and expert judgment and thus a broad comparison was made between decision-making approaches.

The results endorse the idea that the hybrid Soft Set and Fuzzy Set methods offer a sound, adaptable and transparent model of sustainable supplier selection in the textile industry. The suggested model contributes to green supply chain goal achievement by increasing the quality of decisions, the consistency of suppliers ranking, and environmentally friendly sourcing.

Practically, the study can be of great help to the textile managers, procurement professionals and policy makers to adjust to the sophisticated decision-support tools to manage suppliers in a sustainable way. Scholarly, it adds to the literature on the increasing number of hybrid MCDM approaches and methods of their implementation in industry-specific sustainability settings. The following research can build on this framework by adding circular economy indicators, real-time data analytics, and intelligent decision-support systems of next-generation textile supply chains.

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