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AN INTEGRATED FUZZY AHP-TOPSIS APPROACH FOR SUSTAINABLE SUPPLIER SELECTION

Tural Gojayev

Azerbaijan University, Baku, Azerbaijan
e-mail: tural.gojayev@au.edu.az

Abstract. This study proposes an integrated Fuzzy AHP-TOPSIS model for sustainable supplier selection. The model uses Fuzzy AHP to weigh economic, environmental and social criteria under uncertainty and TOPSIS to rank suppliers. An Azerbaijani manufacturing case study demonstrates its applicability. Results confirm the approach as a robust and effective tool for sustainable procurement.

Keywords: Supplier selection, sustainability, multi-criteria decision making, Fuzzy AHP, TOPSIS.

DAVAMLI TƏCHİZATÇI SEÇİMİ ÜÇÜN İNTEQRASİYA OLUNMUŞ QEYRİ-SƏLİS AHP-TOPSIS YANAŞMASI

Tural Qocayev
Azərbaycan Universiteti, Bakı, Azərbaycan

Xülasə. Məqalədə dayanıqlı təchizatçı seçimi üçün iqtisadi, ekoloji və sosial meyarları birləşdirən qeyri-səlis AHP-TOPSIS modeli təklif edilmişdir. Model qeyri-müəyyənlik şəraitində meyar çəkilərini müəyyənləşdirmək üçün qeyri-səlis AHP-dən, təchizatçıların sıralanması üçün isə TOPSIS-dən istifadə edir. Azərbaycan sənaye sektorundakı tətbiqi modelin praktik tətbiqini nümayiş etdirir. Nəticələr inteqrasiya olunmuş yanaşmanın davamlı tender üçün etibarlı vasitə olduğunu təsdiqləyir.
Açar sözlər: Təchizatçı seçimi, dayanıqlılıq, çoxmeyarlı qərar qəbul etmə, qeyri-səlis AHP, TOPSIS.

1. Introduction

In the evolving global marketplace, the paradigm of supply chain management has shifted decisively from a singular focus on cost efficiency to a holistic imperative of creating sustainable value. Modern enterprises recognize that long-term competitiveness is inextricably linked to their ability to operate responsibly, making sustainable supply chain management not merely a compliance issue but a core strategic differentiator [3]. Within this framework, the decision of supplier selection is fundamentally critical, as a firm's environmental footprint and social impact are predominantly determined upstream in its supply chain. Consequently, sustainable supplier selection (SSS) has emerged as a paramount research area, demanding methodologies that can evaluate and integrate the often-conflicting dimensions of the triple bottom line: economic performance, environmental responsibility and social equity [6].

Traditional supplier evaluation models, heavily reliant on quantitative economic metrics, are demonstrably inadequate for this multi-faceted challenge. The process inherently involves intangible factors, subjective expert judgments and imperfect information, all operating under conditions of significant uncertainty. Multi-Criteria Decision-Making (MCDM) techniques provide the necessary structured framework to navigate this complexity.

The Analytic Hierarchy Process (AHP) is particularly renowned for decomposing complex problems into a hierarchical structure and deriving priority weights through systematic pairwise comparisons [6]. However, its classical form depends on precise numerical ratings, which are ill-suited to capture the ambiguity and linguistic nuance of human decision-making, especially when assessing nascent sustainability criteria.

This limitation is effectively addressed by the integration of fuzzy set theory with AHP. Fuzzy AHP allows decision-makers to express comparative judgments using linguistic terms (e.g., “moderately more important”) mapped to Triangular Fuzzy Numbers (TFNs), thereby incorporating the inherent vagueness of expert opinion into a rigorous mathematical model [1]. While Fuzzy AHP excels at determining the relative importance of criteria, an effective ranking mechanism for alternatives is still required. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a powerful and intuitively appealing MCDM method that ranks alternatives based on their simultaneous geometric distance from a positively ideal solution and a negatively ideal solution [4]. Its logic is straightforward: the optimal alternative is the one closest to the ideal and farthest from the anti-ideal [2].

The principal contribution of this paper lies in synthesizing these two robust methodologies into a cohesive, two-phase hybrid model. This integrated approach leverages the strength of Fuzzy AHP to reliably ascertain the weights of sustainability criteria under uncertainty in the first phase and then employs the computational efficiency and clarity of TOPSIS to generate a definitive ranking of supplier alternatives in the second phase. To validate its practical utility and procedural transparency, the proposed model is applied to a real-world case study involving the selection of a raw material supplier within Azerbaijan's growing manufacturing sector. This application serves to demonstrate the model's effectiveness in delivering a defensible and actionable decision for sustainable procurement.

2. Methodology

The proposed integrated model consists of two main phases.

Phase 1: Determining criteria weights using Fuzzy AHP

First, sustainability criteria and sub-criteria are defined through a comprehensive literature review and expert consultation to ensure relevance and completeness. A hierarchical structure is then built, with the main criteria (economic, environmental, social) broken down into specific measurable sub-criteria, as illustrated in Table 1. This hierarchical framework allows decision-makers to systematically evaluate and prioritize each aspect of sustainability in a structured and transparent manner.

Table 1. Sustainability criteria hierarchy for supplier selection

Main Criteria	Sub-Criteria	Description
C1: Economic	C11: Cost	Unit price, total cost of ownership
	C12: Quality	Defect rate, compliance with specifications
	C13: Delivery	On-time delivery rate, flexibility
C2: Environmental	C21: Carbon Footprint	GHG emissions, energy efficiency
	C22: Waste Management	Recycling rate, hazardous waste handling
C3: Social	C31: Labor Standards	Working conditions, safety records, fair wages
	C32: Community Impact	Local employment, social responsibility projects

Table 2. Fuzzy AHP weights for main and sub-criteria

Criterion	Fuzzy Weight ($\tilde{w}$)	Crisp Weight (w)	Normalized Weight
C1	(0.35, 0.45, 0.55)	0.450	0.447
C2	(0.25, 0.35, 0.45)	0.350	0.347
C3	(0.15, 0.20, 0.25)	0.200	0.206
C11	(0.40, 0.50, 0.60)	0.500	0.512
C12	(0.25, 0.30, 0.35)	0.300	0.307
C13	(0.10, 0.20, 0.30)	0.200	0.181
C21	(0.55, 0.65, 0.75)	0.650	0.667
C22	(0.25, 0.35, 0.45)	0.350	0.333
C31	(0.60, 0.70, 0.80)	0.700	0.682
C32	(0.20, 0.30, 0.40)	0.300	0.318

Note: Sub-criteria weights are local within their main criterion. Global weights are calculated by multiplying main and sub-criteria weights

Experts compare criteria using Triangular Fuzzy Numbers (TFNs). Let a_{ij}=(l, m, u) be a TFN representing the relative importance of criterion *i* over *j*, where l, m and u denote the lower, most likely and upper bounds of the fuzzy judgment, respectively. These TFNs effectively capture the vagueness and linguistic uncertainty inherent in expert opinions, allowing evaluators to express preferences using natural terms such as “moderately more important” or “strongly more important”. The fuzzy comparison matrix A is then constructed, with each element a_{ij} reflecting the fuzzy preference between criteria i and j. The consistency of the pairwise judgments is checked using a fuzzy consistency ratio to ensure logical reliability. Subsequently, fuzzy weights w_i are derived from this matrix using the extent analysis method, which synthesizes the fuzzy judgments into aggregated priority values for each criterion [1]. These fuzzy weights are finally defuzzified using the centroid method to obtain crisp weights w_i as presented in Table 2, ensuring a clear and applicable weighting scheme for the subsequent TOPSIS ranking phase.

Phase 2: Ranking Suppliers Using TOPSIS method

Let there be “m” suppliers (A1...Am) and “n” criteria with global weights wj from Phase 1.

1. **Building the decision matrix:** Matrix $X=[x_{ij}]_{m\times n}$ is constructed with performance ratings. A performance table (matrix) is created where each row represents a supplier and each column represents a sustainability criterion. The cells contain the suppliers' scores for each criterion, usually on a numerical scale.

2. **Normalization and weighting:** Matrix is normalized to R, then weighted to $V=[v_{ij}]$, where $v_{ij}=w_j\cdot r_{ij}$. To make scores comparable across different criteria, each column is normalized so that all values fall within a common scale. Then, each normalized score is multiplied by its corresponding criterion weight from Fuzzy AHP, giving more importance to the criteria deemed more significant.

3. **Determine ideal solutions:** Identify FPIS ($A+A+$) and FNIS ($A-A-$). Two theoretical reference points are defined: the Positive Ideal Solution (the best possible score for each criterion) and the Negative Ideal Solution (the worst possible score for each criterion). These are not real suppliers but benchmarks for comparison.

4. **Calculate distances and closeness coefficient:** Compute D_i+Di+, $Di-Di-$ and $CC_i=D_i-/(D_i++D_i-)$. For each supplier, the distance to the Positive Ideal and the distance to the Negative Ideal are calculated. The Closeness Coefficient (CC) is then determined as the ratio of the distance to the Negative Ideal divided by the sum of both distances. A higher CC means the supplier is closer to the best case and further from the worst case.

5. **Rank suppliers:** Rank by CC_i descending. Suppliers are ranked from highest to lowest based on their CC value. The supplier with the highest CC is identified as the most sustainable choice.

3. Supplier evaluation in the ındustry of Azerbaijan

The model was applied to select a sustainable raw material supplier for an industrial plant in Sumgait. Challenges related to sustainable supplier selection in Azerbaijan's industrial sector have also been highlighted in previous research [5]. Five potential suppliers (S1-S5) were evaluated based on field audits, historical performance records and expert scoring. Performance data were collected on a scale of 1-10 (10 being the best) for each sub-criterion, ensuring both quantitative and qualitative aspects of sustainability were captured. The global weighted decision matrix (a fragment) and final TOPSIS results are shown in Table 3, offering a transparent view of how each supplier performed under the weighted criteria.

Table 3. TOPSIS results for supplier ranking

Supplier	D+	D-	CC	Rank
S1	0.0452	0.0321	0.415	3
S2	0.0218	0.0587	**0.729**	**1**
S3	0.0623	0.0189	0.233	5
S4	0.0511	0.0244	0.323	4
S5	0.0385	0.0416	0.519	2

Supplier S2, with a closeness coefficient (CC) of 0.729, emerges as the highest-ranked alternative, indicating it is the most balanced and sustainable choice according to the integrated Fuzzy AHP-TOPSIS model. The CC value reflects that S2 is simultaneously closest to the Fuzzy Positive Ideal Solution (FPIS) and farthest from the Fuzzy Negative Ideal Solution (FNIS). Further analysis of the weighted decision matrix reveals that S2 demonstrated strong performance across multiple sub-criteria, particularly in the environmental (C2) and social (C3) dimensions. For instance, it received the highest scores in *Carbon Footprint (C21)* and *Labor Standards (C31)*, which carried significant global weights as determined in the Fuzzy AHP phase.

In order to test the reliability of this ranking, a sensitivity analysis [7] was conducted by systematically varying the main criterion weights (C1, C2, C3) within a ±10% range and observing the impact on the final supplier ranks. In all tested scenarios, Supplier S2 consistently retained its first-place position and the overall ranking order (S2 > S5 > S1 > S4 > S3) remained stable. This indicates that the proposed model’s outcome is robust and not overly sensitive to minor changes in decision-makers’ preferences or uncertainties in the weighting process. Such stability is crucial for practical decision-making, as it enhances confidence in the recommendation and supports its adoption in real procurement processes.

Conclusion. This study has successfully developed, articulated and applied a comprehensive two-stage integrated model for sustainable supplier selection, combining the fuzzy analytical hierarchy process (Fuzzy AHP) with the technique for order of preference by similarity to ideal solution (TOPSIS). The model directly addresses a central challenge in sustainable procurement: the need to make informed, balanced decisions amidst multiple conflicting objectives, incomplete data and subjective human judgment. In its first phase, Fuzzy AHP provided a mathematically sound mechanism to translate imprecise expert linguistic assessments into definitive, reliable weights for economic, environmental and social criteria. This step is crucial for grounding the sustainability evaluation in a transparent and justifiable weighting scheme that reflects real-world uncertainty.

The subsequent application of TOPSIS in the second phase offered a geometrically intuitive and computationally efficient method to synthesize the weighted performance data into a clear, actionable ranking of supplier alternatives. The case study in the Azerbaijani manufacturing sector served as a robust validation, demonstrating the model's practical applicability and its ability to produce a definitive, logically sound recommendation - in this instance, selecting Supplier S2. The structured tables presenting the criteria hierarchy, derived weights and final results enhance the model's transparency, allowing decision-makers to trace and verify the entire analytical process from initial judgment to final rank.

The integrated Fuzzy AHP-TOPSIS approach thus provides supply chain managers and procurement professionals with a powerful, structured decision-support tool. It moves sustainable supplier selection from a potentially ambiguous, qualitative exercise to a quantitative, auditable and defensible process. By facilitating a holistic assessment, it enables organizations to align their procurement strategies with overarching corporate sustainability goals, potentially mitigating risk, enhancing brand reputation and creating long-term resilient supply chains. For future research, the model's framework is highly adaptable. Potential extensions include employing other fuzzy set variants (e.g., intuitionistic or neutrosophic sets) to model higher levels of hesitancy, integrating the model with Life Cycle Assessment (LCA) data for more objective environmental scoring or adapting it for large-scale group decision-making settings in global supply chains. Applying and testing the model across diverse industrial and cultural contexts will further establish its generalizability and refine its practical utility.

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