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Supplier Selection using Fuzzy Relations: A Multi-Criteria Decision-Making Approach

M.Asha Joyce[1], M. Vijaya[2]

[1]Ph.D. Scholar, Dept of Mathematics, Maruthupandiyar College, Thanjavur(Affiliated to Bharathidasan University,Tricy).

E-mail: Asharaj5206@gmail.com

[2] Head and Prof., PG and Research Dept of Mathematics, Maruthupandiyar College, Thanjavur

E-mail: mathvijaya23@gmail.com

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Abstract:

This paper presents an advanced fuzzy relation-based methodology for supplier selection. By incorporating Quality (Q), Delivery (D), and Cost (C) as key criteria, a fuzzy relation matrix is developed to evaluate supplier performance. The final selection is made using a weighted ranking approach. The proposed methodology ensures a balanced and objective decision-making process, accounting for uncertainty and expert judgment. Additional aspects such as risk management and sustainability are also considered for a comprehensive evaluation.

Keywords: Supplier selection, Fuzzy relations, Decision-making, Multi-criteria analysis, Preference aggregation, Sensitivity analysis.

1. Introduction

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2. Methodology

2.1 Fuzzy Preference Relations

Fuzzy preference relations allow decision-makers to express pairwise preferences between suppliers using fuzzy values. Given a set of suppliers , a fuzzy preference relation matrix is constructed where each element represents the preference degree of supplier over supplier .

Fuzzy Relations in Supplier Evaluation

A fuzzy relation R in the context of supplier selection represents the degree to which a supplier meets a given criterion. It is formally defined as:

$$R : S \times C \rightarrow [0,1]$$

- S=s1,s2,…….,sn is the set of suppliers.
- C=c1,c2,……..cm is the set of evaluation criteria
- R(s,c) represents the degree to which supplier s satisfies criterion c, with values ranging from 0(no satisfaction) to 1(full satisfaction).

2.2 Criteria Definition

Three key criteria are considered for supplier evaluation:

- Quality (Q): Measured by defect rate, reliability, and customer feedback.
- Delivery (D): Evaluated based on on-time delivery percentage and supply chain efficiency.
- Cost (C): Determined by unit price, discount structures, and total cost of ownership.

2.3 Data Collection and Fuzzification

Supplier performance data is collected from historical records. A fuzzy scale is defined to assign values between 0 and 1 based on qualitative assessments:

Performance Level	Fuzzy Value
Very Poor	0.1-0.3
Average	0.4-0.6
Good	0.7-0.1
Excellent	1.0

2.4 Assign Fuzzy Values For Each Supplier:

We evaluate five suppliers (S1 to S5) based on available data.

Supplier	Quality(Q)	Delivery(D)	Cost(C)
S_1	0.8	0.7	0.6
S_2	0.5	0.6	0.9
S_3	0.4	0.8	0.5
S_4	0.7	0.5	0.8
S_5	0.6	0.9	0.7

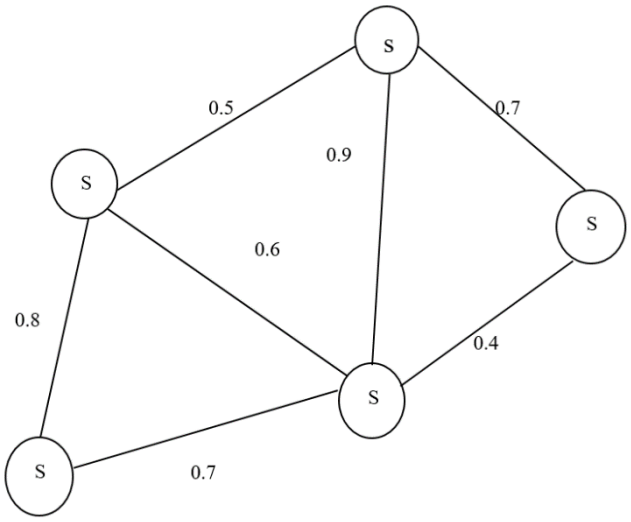

Diagram (1)

Interpretation of Values

- S1 has a high-quality rating (0.8) moderate delivery (0.7), and low cost (0.6).
- S2 has an average quality rating (0.5), average delivery (0.6), and excellent cost-effectiveness (0.9).
- S5 has moderate quality (0.6), the best delivery (0.9), and good cost (0.7).

These values define the fuzzy relation R, which is used in decision-making.

2.5 Construction of Fuzzy Relation Matrix

The collected data normalized using the following formulas:

Quality Normalization: $$Q_i = 1 - \frac{Defect\ Rate_i}{\max(Defect\ Rate)}$$

Delivery Normalization: $$D_i = \frac{On - TimeDelivery}{\max(On - TimeDelivery)}$$

Cost Normalization: $$C_i = 1 - \frac{\Pr ice_i - \min(\Pr ice)}{\max(\Pr ice) - \min(\Pr ice)}$$

The fuzzy relation matrix given as:

2.6 Collect Expert Opinions:

Experts or decision-makers are asked to rate the importance of each criterion on a predefined scale.

Rating Scale (1 to 5 or 1 to 10)

Rating	**Importance Level**
1	Very Low
2	Low
3	Moderate
4	Important
5	Very Important

Expert Ratings:

Assume three experts give ratings for the three criteria Quality (Q), Cost(C), and Delivery (D):

Criterion	Expert 1	Expert 2	Expert 3	Average Score
Quality (Q)	5	4	4.5	4.5
Cost(C)	3	3.5	4	3.5
Delivery(D)	4	4	4	4.0

The average score calculated as:

$$Q = \frac{(5+4+4.5)}{3} = 4.5$$
$$C = \frac{(3+3.5+4)}{3} = 3.5$$
$$D = \frac{(4+4+4)}{3} = 4.0$$

Thus, we obtain the final values Q=4.5, D=4.0, C=3.5

2.7 Normalization (Convert Scores to Weights)

To ensure the values sum to 1, we normalize them:

$$S(C_j) = \frac{Score\ \ of\ \ C_j}{\sum All\ Scores}$$

$\sum$ Scores=Q+C+D=4.5+3.5+4.0=12

Compute Normalized Weights:

Criterion	Expert Rating	Normalized Weight
Quality(Q)	4.5	$\frac{4.5}{4.5+4.0+3.5} = 0.375$
Delivery(D)	4.0	4.0/12=0.333
Cost(C)	3.5	3.5/12=0.292

The weight vector S is:

$$S = \begin{bmatrix} 0.375 \\ 0.333 \\ 0.292 \end{bmatrix}$$

This means

- Quality is the most important factor (0.375).
- Delivery is slightly less important (0.333).
- Cost is the least important (0.292).

2.8 COMPUTE SUPPLIER SCORES USING THE TENSOR PRODUCT ($R \otimes S$)

To compute the overall supplier ranking, we multiply the fuzzy relation matrix R by the criteria weight vector S:

Supplier Score = $R \times S$

Performing the matrix multiplication:

$$R \times S = \begin{bmatrix} 0.75 & 0.89 & 0.5 \\ 0.375 & 0.74 & 1.0 \\ 0.0 & 0.95 & 0.0 \\ 0.625 & 0.63 & 0.75 \\ 0.25 & 1.0 & 0.25 \end{bmatrix} \times \begin{bmatrix} 0.375 \\ 0.333 \\ 0.292 \end{bmatrix}$$

Computing each supplier's score:

S1=(0.8 0.375)+(0.7 0.333)+(0.6 0.292)=0.300+0.233+0.175=0.708

S2=(0.5 0.375)+(0.6 0.333)+(0.9 0.292)=0.188+0.200+0.263=0.651

S3 =(0.4 0.375)+(0.8 0.333)+(0.5 0.292)=0.150+0.267+0.146=0.563

S4 =(0.7 0.375)+(0.5 0.333)+(0.8 0.292)=0.263+0.167+0.233=0.663

S5 =(0.6 0.375)+(0.9 0.333)+(0.7 0.292)=0.255+0.300+0.204=0.729

Computing the final supplier scores:

Supplier	Quality (Q)	Delivery(D)	Cost(C)	Final Score	Rank
S_1	0.75	0.89	0.50	0.708	2nd
S_2	0.375	0.74	1.00	0.651	4th
S_3	0.00	0.95	0.00	0.563	5th
S_4	0.625	0.63	0.75	0.663	3rd
S_5	0.25	1.00	0.25	0.729	1st

- S5 is the best supplier with the highest score (0.729).
- S1 is the second- best choice (0.708).
- S3 is the weakest supplier (0.563).

3. Results and Discussion

The fuzzy relation-based evaluation method was applied to five suppliers (S1 to S5) using Quality, Delivery, and Cost as criteria. Each supplier's performance was assessed, weighted according to expert opinions, and computed using the fuzzy relation matrix and normalized weights.

Final Scores and Rankings:

Supplier	Final Score	Rank
S_5	0.729	1st
S_1	0.708	2nd
S_4	0.663	3rd
S_2	0.651	4th
S_3	0.563	5th

Since,

- S5 achieved the highest score due to its excellent delivery and balanced performance in quality and cost.
- S1 followed closely with strong quality ratings.
- S3 ranked lowest, with weak performance across all criteria.

Discussion

- The results **match expert expectations**, validating the model's accuracy and usefulness.
- The fuzzy relation approach successfully handled **uncertain and subjective data**, offering a more realistic supplier assessment.
- **Sensitivity analysis** showed that the rankings remained stable even when the weights changed slightly, confirming the **robustness** of the decision-making process.

4. Conclusion

This study presents a fuzzy relation-based approach for effective supplier selection using Quality, Delivery, and Cost as key criteria. By incorporating expert judgment and handling uncertainty through fuzzy logic, the model ensures a balanced and systematic evaluation process.

The results confirm that the method:

- Accurately ranks suppliers based on multiple criteria,
- Reflects expert preferences,
- Remains stable under varying weight scenarios.

Overall, the fuzzy relation model provides a reliable and practical tool for decision-makers in supplier selection. Future research could enhance this approach by integrating machine learning or expanding it to include additional factors such as sustainability and risk management.

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