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*Original Article*

# On Solving the Fuzzy Assignment Problem with Restrictions using the Fuzzy DEMATEL approach

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***Abstract*** - *The fuzzy assignment problem represents a significant optimization methodology employed for the distribution of finite resources to various tasks within uncertain contexts. In real-world decision-making scenarios, the assignment process frequently encounters a multitude of constraints and ambiguous data, thereby rendering traditional optimization techniques less effective. The proposed framework utilizes triangular fuzzy numbers to encapsulate uncertainty in decision-making parameters and assesses the inter-dependencies among restriction criteria via fuzzy DEMATEL analysis. By elucidating the causal relationships and the extent of influence among constraints, the model facilitates more informed assignment decisions in the face of imprecise conditions. The methodology empowers decision-makers to prioritize pivotal constraints and enhance allocation efficiency while taking into account the inter-dependencies among criteria. A numerical example is provided to illustrate the applicability and efficacy of the proposed approach. The results indicate that the integration of fuzzy DEMATEL with fuzzy assignment with restrictions modeling yields a systematic and dependable decision-support framework for addressing intricate assignment challenges in uncertain environments.*

***Keywords*** - *Assignment Problem With Restrictions, Fuzzy Assignment Problem, Fuzzy DEMATEL, Multi-Criteria Decision Making(MCDM), Triangular Fuzzy Number(TFN).*

## 1. Introduction

Decision-making is an essential process that involves selecting the most appropriate alternative by considering multiple influencing factors. Multi-Criteria Decision-Making (MCDM) has emerged as an effective approach for evaluating alternatives based on multiple criteria. Various MCDM methods have been developed over time, differing in their weighting procedures, uncertainty handling, and decision structures. These methods include the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), VIKOR, Complex Proportional Assessment (COPRAS), etc. Researchers have explored various fields, including logistics and inventory management, healthcare, engineering and manufacturing, environmental management, and human resource management, using these MCDM techniques to facilitate decision making.

Among the MCDM techniques, the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method, introduced by Gabus and Fontela, during 1973–1976 at the Geneva Research Centre of the Battelle Memorial Institute, widely used to analyse interrelationships among criteria. Unlike other methods that are used for ranking, DEMATEL identifies cause–and–effect relationships and determines influential criteria within a system. Uncertainty is handled by Fuzzy DEMATEL, which integrates Fuzzy Set Theory with the DEMATEL method. By representing imprecise information through fuzzy numbers, it enables a more flexible and robust analysis of relationships among criteria in uncertain environments.

In an optimization process, the objective lies in minimizing cost or time based on the decision-maker's preferences while considering the allocation of resources, workers and machine to perform a given task. The assignment problem has been discussed in recent years, and its application is widespread in domains such as information technology, manufacturing and administration. The fuzzy assignment problem with restrictions extends the classical assignment problem by incorporating uncertainty and additional constraints such as skill compatibility, equipment limitations, and operational requirements, thereby limiting assignment feasibility.

Although fuzzy assignment problems and fuzzy DEMATEL have been widely explored, limited research has integrated these approaches. The objective of the assignment model is to optimize cost or time under constraints, importance of machines is often assumed by excluding systematic evaluation. Fuzzy DEMATEL has been used to analyze relationships among criteria, with limited efforts to incorporate weights into assignment models. In addition, practical restrictions such as access, skill, and capacity constraints have received limited attention. Therefore, a research gap exists, and there is a need for a methodology that combines Fuzzy DEMATEL with a fuzzy assignment model with restrictions to improve the quality and practicality of assignment decisions.

An illustrative example is discussed in section 4, where machines are considered as the evaluation criteria, and their weights are determined using the Fuzzy DEMATEL approach. These weights are incorporated into a fuzzy assignment model with restrictions, where the restrictions include access restrictions, skill restrictions, and capacity restrictions.

## 2. Literature Review

Kumar and Gupta [1] proposed Mehar's methods for solving fuzzy assignment with restrictions with LR flat fuzzy numbers and Yager's ranking index. Emrouznejad et al. [2] developed a Data Envelopment Analysis method to solve the assignment problems with fuzzy costs or fuzzy profits. Gomathi and Jayalakshmi [3] developed a one's orientation algorithm to solve distinct symmetric fuzzy assignment problems. Henry [4] used a triangular fuzzy number as cost coefficients to solve the assignment problem, defuzzified and Hungarian method was adopted. Kumar et al. [5] demonstrated the effectiveness of ranking techniques for solving fuzzy assignment problems. Adak et al. [6] proposed a framework for solving Pythagorean fuzzy assignment problems using spherical distance measures and a scoring method. Gurukumaresan et al. [7] employed the centroid defuzification method, and an optimal solution was obtained for the fuzzy assignment problem. In addition to fuzzy assignment models, researchers have also investigated constrained assignment problems. Hu et al. [8] proposed two combinatorial algorithms for solving the constrained assignment problem with bounds and penalties. Mim et al. [9] proposed a branch-and-bound algorithm for solving assignment problems. Khelifa et al. [10] presented a fuzzy approach for task assignment in heterogeneous distributed multi-robot systems.

Srinivas and Prabakaran [11] presented a triangular fuzzy neutrosophic assignment model. Several studies have applied fuzzy DEMATEL methods to analyse relationships among criteria in uncertain environments. Arjomandi et al. [12] integrated a hybrid fuzzy DEMATEL–ANP–VIKOR model for maintenance strategy selection.DEMATEL–ANP was used to determine the weights of the evaluation criteria, while VIKOR was applied to rank the maintenance strategies under an interval type-2 fuzzy environment. Deva and Felix [13] developed a bipolar fuzzy DEMATEL method for analysing causal relationships among decision criteria. The use of bipolar fuzzy information enabled both positive and negative preferences to be considered during the evaluation process. Shahvar and Marsella [14] used a modified fuzzy DEMATEL approach to examine the relationships among factors influencing coastal management. In healthcare decision-making, Khan et al. [15] used the fuzzy DEMATEL method to study the barriers to telemedicine adoption. Karaşan and Kahraman [16] developed an intuitionistic fuzzy DEMATEL–ANP–TOPSIS integrated methodology for freight village location selection. Fakhrzad et al. [17] applied the fuzzy DEMATEL method to evaluate risk factors in the Instruction Center of Iran's National Oil Company. Similarly, Abdullah et al. [18] developed an intuitionistic fuzzy decision-making framework for subcontractor selection by determining the relationships among selection criteria. In recent fuzzy-based MCDM studies, Fujita [19] introduced Hyperfuzzy VIKOR and Hyperfuzzy DEMATEL methods to handle complex uncertainty in decision-making problems.

However, most existing studies mainly focus on finding the optimal assignment solution while giving negligible focus to the influence and importance of the criteria involved in the assignment process. On the other hand, DEMATEL is widely used to analyse relationships among criteria and determine their relative importance, but its application with fuzzy assignment models involving restrictions is inadequately addressed. Therefore, this study aims to combine Fuzzy DEMATEL with a fuzzy assignment model with restrictions to consider both criterion importance and assignment constraints for improving decision-making.

## 3. Preliminaries and Definition

**Definition 3.1**

A *Fuzzy set* $\tilde{A}$ in a universe of disclosure X is defined by $\tilde{A}=\{(x, \mu_{\tilde{A}}(x)) | x \in X\}$ where $\mu_{\tilde{A}}: X \to [0,1]$ is called the membership function of $\tilde{A}$, and $\mu_{\tilde{A}}$ represents the degree of membership to which $x \in \tilde{A}$.

**Definition 3.2**

A *Fuzzy set* $\tilde{A}$ along with its membership grade $\mu_{\tilde{A}}(x)$ in [0,1], a fuzzy number is called a *Fuzzy number* if it satisfies the following

1. $\tilde{\tilde{A}}_{\alpha}$ is a closed set for $0 < \alpha \leq 1$.
2. $\tilde{\tilde{A}}$ is normal, i.e, $\tilde{\tilde{A}} = 1$.
3. $\tilde{\tilde{A}}$ is convex, i.e., $\tilde{\tilde{A}}$ is a convex subset for $0 < \alpha \leq 1$.

**Definition 3.3**
A Fuzzy number $\tilde{\tilde{A}} = (l_1, m_1, u_1)$ is called a Triangular Fuzzy Number (*TFNs)* if its membership function is given by

$$\mu_{\tilde{\tilde{A}}}(x) = \begin{cases} 0 & x < l_1; \\ \dfrac{x - l_1}{m_1 - l_1} & l_1 \leq x \leq m_1; \\ \dfrac{u_1 - x}{u_1 - m_1} & m_1 \leq x \leq u_1; \\ 0 & x > u_1 \end{cases}$$

**Definition 3.4**
Defuzzification is the process that involves the conversion of fuzzy output values into a single crisp value. The centroid method is the most widely used defuzzification technique. It involves finding the center of gravity of the area under the curve defined by the fuzzy output. Defuzziciation of a triangular fuzzy number, $\tilde{\tilde{A}} = (l_1, m_1, u_1)$ is given by

$$D = \frac{l_1 + m_1 + u_1}{3}$$

## 4. Materials and Methods

### *4.1. Problem Definition*

The Objective of worker–machine assignment is to allocate workers to machines in order to obtain the minimum assignment cost while satisfying all operational constraints. The workers possess different skill levels, and machines require specific competencies, making the assignment process a complex decision-making problem. Furthermore, certain worker–machine combinations may be infeasible because of operational policies, safety requirements and skill incompatibilities. In this study, five workers say $W_1, W_2, W_3, W_4$ and $W_5$ are assigned to five machines: $M_1, M_2, M_3, M_4$ and $M_5$. The assignment costs are represented using TFNs to account for uncertainty in expert judgments. To improve the reliability of the assignment problem, the evaluation criteria are analyzed using the DEMATEL method to determine their relative importance and causal relationships. The normalized criterion weights obtained from DEMATEL are then incorporated into the fuzzy assignment model. Finally, the weighted fuzzy costs are defuzzified, and the assignment problem with restrictions is formulated as a binary integer programming model to obtain the optimal worker–machine allocation. The operational restrictions considered in this study are as follows:

- $R_1$ : $W_1$ cannot be assigned to $M_2$.
- $R_2$ : $W_3$ cannot be assigned to $M_1$.
- $R_3$ : $W_5$ can be assigned only to $M_1$ or $M_5$.

The proposed methodology has the following steps:

***Phase 1: Fuzzy DEMATEL Approach***

Step 1**:** Define the Criteria.

The machines in the worker–machine assignment problem are defined as the evaluation criteria, namely. $M_1$, $M_2$, $M_3$, $M_4$, and $M_5$. These criteria form the basis for the DEMATEL analysis. Expert judgments are obtained using a triangular fuzzy linguistic scale as presented in table 3, to identify the influence of each machine on the others within the environment.

Step 2: Construction of the Initial-Direct influence matrix $\tilde{Z}$.

The initial direct influence matrix $\tilde{Z}$ is constructed to represent the direct relationships among the evaluation criteria. It forms the basis for analyzing the inter-dependencies and causal relationships among the criteria in the DEMATEL method.

$$\tilde{Z} = \begin{bmatrix} (0,0,0) & \tilde{z}_{12} & \tilde{z}_{13} & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & (0,0,0) & \tilde{z}_{23} & \cdots & \tilde{z}_{2n} \\ \tilde{z}_{31} & \tilde{z}_{32} & (0,0,0) & \cdots & \tilde{z}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1} & \tilde{z}_{n2} & \tilde{z}_{n3} & \cdots & (0,0,0) \end{bmatrix}$$

where,

$\tilde{z}_{\mathrm{ij}}$: represents TFN $\tilde{z}_{\mathrm{ij}} = (l_{ij}, m_{ij}, u_{ij})$,

$n$: represents the total number of evaluation criteria.

Step 3: Normalization of Initial-Direct-Relation Matrix $\tilde{Z}$.

The normalization process in DEMATEL is applied to standardize the data, ensuring it is comparable across various criteria. The normalized matrix $N$ preserves the relative influence among the machines while facilitating the computation of the total relation matrix.

$$\widetilde{N} = s\tilde{Z}$$

where

$$s = \left[\frac{1}{max(max_{\mathrm{i}} \sum_{j=1}^{n} \left|z_{ij}\right|, max_{\mathrm{j}} \sum_{i=1}^{n} \left|z_{ij}\right|)}\right]$$

Step 4: Calculation of Fuzzy Total-Relation Matrix $\tilde{T}$.

The fuzzy total-relation matrix is expressed as

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \tilde{t}_{13} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \tilde{t}_{23} & \cdots & \tilde{t}_{2n} \\ \tilde{t}_{31} & \tilde{t}_{32} & \tilde{t}_{33} & \cdots & \tilde{t}_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \tilde{t}_{n3} & \cdots & \tilde{t}_{nn} \end{bmatrix}$$

where

$\tilde{t}_{\mathrm{ij}}$: represents TFN $\tilde{t}_{\mathrm{ij}} = (l_{ij}, m_{ij}, u_{ij})$,

$n$: represents the total number of evaluation criteria.

The Fuzzy Total-Relation Matrix $\tilde{T}$ is calculated as;

$$\tilde{T} = \widetilde{N}(I - \widetilde{N})^{-1}$$

where

$\tilde{T}$: represents the total relation matrix,

$\widetilde{N}$: represents Normalized matrix,

$I$: represents Identity matrix.

Step 5: Defuzzification of the total relation matrix $\tilde{T}$.

The fuzzy total relation matrix is converted into a crisp total relation matrix using the centroid defuzzification method that transforms the fuzzy total-relation matrix. $\tilde{T}$ into the crisp total-relation matrix $T$. The defuzzified value of each triangular fuzzy number for this methodology is given below as;

$$t_{ij} = \frac{l_{ij} + m_{ij} + u_{ij}}{3}$$

Step 6: Calculation of the Prominence and Relation.

This step involves the process of summing up the rows. $D_i$ and columns $R_i$ of the defuzzified total relation matrix. These values are computed as

$$D_i = \left[\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{t}_{\mathrm{ij}}\right]$$

$$R_i = \left[\sum_{\mathrm{j}=1}^{\mathrm{n}} \mathrm{t}_{\mathrm{ji}}\right]$$

where

$D_i$: represents the total influence exerted by Machine i on the other machines,

$R_i$: represents the total influence received by Machine i from the other machines.

The Prominence ($P_i$) and Relation ($Q_i$) are determined using the following;

$$P_i = D_i + R_i$$
$$Q_i = D_i - R_i$$

where

$D_i + R_i$: indicates the overall importance of Machine i,
$D_i - R_i$: determine whether the machine belongs to the cause group $D_i - R_i > 0$ or the effect group

$$D_i - R_i < 0$$

Step 7: Calculation of criteria weights.

The weights of the evaluation criteria are calculated from the prominence values (D+R) obtained through the DEMATEL analysis. The weight of each criterion is given by

$$w_i = \frac{D_i + R_i}{\sum_{i=1}^{n}(D_i + R_i)}$$

where,

$w_i$: normalized weight of the $i^{th}$ criterion,
$D_i + R_i$: prominence of the $i^{th}$ criterion,
n: total number of criteria.

These weights are later incorporated into the fuzzy assignment model to prioritize worker-machine assignment according to their overall significance.

***Phase 2: Construction of a fuzzy assignment model.***

Step 8: Construction of Fuzzy Assignment matrix $\tilde{A}$

The fuzzy assignment model is formed by worker–machine assignment costs using TFNs based on expert evaluations. The fuzzy assignment cost matrix is represented as

$$\tilde{A} = \left[\tilde{A}_{ij}\right]_{h\times k}$$

where

$\tilde{A}_{ij}$: represents the triangular fuzzy assignment cost of assigning Worker i to Machine j,
$h$: represents the total number of workers,
$k$: represents the total number of machines.

***Phase 3: Integration of Fuzzy DEMATEL weights into the fuzzy assignment model.***

Step 9: Calculate the Weighted Cost matrix $\tilde{C}$.

The weighted cost matrix is calculated by integrating the normalized weights of criteria from DEMATEL analysis with the fuzzy worker-machine assignment cost. Each triangular fuzzy assignment cost is multiplied by the corresponding criterion weight, which reflects the relative importance of the evaluation criteria.

$$\tilde{C}_{ij} = \; w_j \tilde{A}_{\text{ij}}$$

where

$\tilde{C}_{ij}$: weighted triangular fuzzy assignment cost of assigning worker *i* to machine *j*,
$w_j$: normalized fuzzy DEMATEL weight associated with Machine *j*,
$\tilde{A}_{ij}$: triangular fuzzy cost of assigning worker *i* to machine *j*.

Step 10: Defuzzification of Weighted Cost Matrix.

The weighted fuzzy cost matrix $\tilde{\boldsymbol{C}}$ is converted into the crisp cost matrix *C* using the centroid defuzzification method. The defuzzified assignment cost is calculated for this study as

$$C_{ij} = \frac{\boldsymbol{l_{ij}} + \boldsymbol{m_{ij}} + \boldsymbol{u_{ij}}}{3}$$

Step 11: Solving the assignment with restrictions using binary integer programming.

# 5. Results and Discussion

## *5.1. DEMATEL Analysis Results*

The DEMATEL technique is used to determine the prominence and causal relationships among the five machines involved in the assignment problem. The total relation matrix is tabulated, the sum of the rows, which is called as prominence, indicates the overall importance of each machine within the system, and the sum of columns, which is called relation, distinguishes whether a machine is a part of the cause or effect group. The normalized weight represents the relative significance of each machine. The results are tabulated in the following table 1.

**Table 1. Prominence, Relation and Normalized Criterion Weights**

| | D | R | D+R | D-R | Weight |
|---|---|---|---|---|---|
| $M_1$ | 3.5909 | 4.4742 | 8.0651 | -0.8833 | 0.2001 |
| $M_2$ | 4.0646 | 3.6271 | 7.6917 | 0.4375 | 0.1908 |
| $M_3$ | 4.6273 | 3.752 | 8.3793 | 0.8753 | 0.2079 |
| $M_4$ | 4.3211 | 4.8139 | 9.135 | -0.4928 | 0.2267 |
| $M_5$ | 3.548 | 3.4846 | 7.0327 | 0.0634 | 0.1745 |

The prominence value shows that the Machine. $M_4$(9.1355) It is the most influential and highly connected machine within the assignment system. This is followed by Machine. $M_3$(8.3790), Machine $M_1$(8.0638), Machine $M_2$(7.6922), and Machine $M_5$(7.0333). Therefore, Machine $M_4$ plays the most significant role in the overall interaction among the machines.
The relation value classifies the machine into a cause group and an effect group.

- **Cause group:** Machine $M_2$(0.4366), Machine $M_3$(0.8760), and Machine $M_5$(0.0629) They are identified as cause machines, indicating that they exert greater influence on the other machines. Among them, Machine $M_3$ has the highest positive relation value, making it the strongest driving machine in the system.
- **Effect group:** Machine $M_1$(-0.8824)and Machine $M_4$(-0.4929) belong to the effect group, implying that they are more influenced by other machines than they influence others. Although Machine $M_4$ has the highest prominence; its negative relation value indicates that it primarily receives the effects of interactions generated by the cause machines.

The normalized weights further indicate the importance of the machines. Machine $M_4$ receives the highest weight (0.2267), followed by Machine $M_3$ (0.2079), Machine $M_1$ (0.2001), Machine $M_2$ (0.1909), and Machine $M_5$ (0.1745). The derived prominence, causal relationships, and weights provide a quantitative basis for improving decision-making in the subsequent fuzzy assignment optimization process.

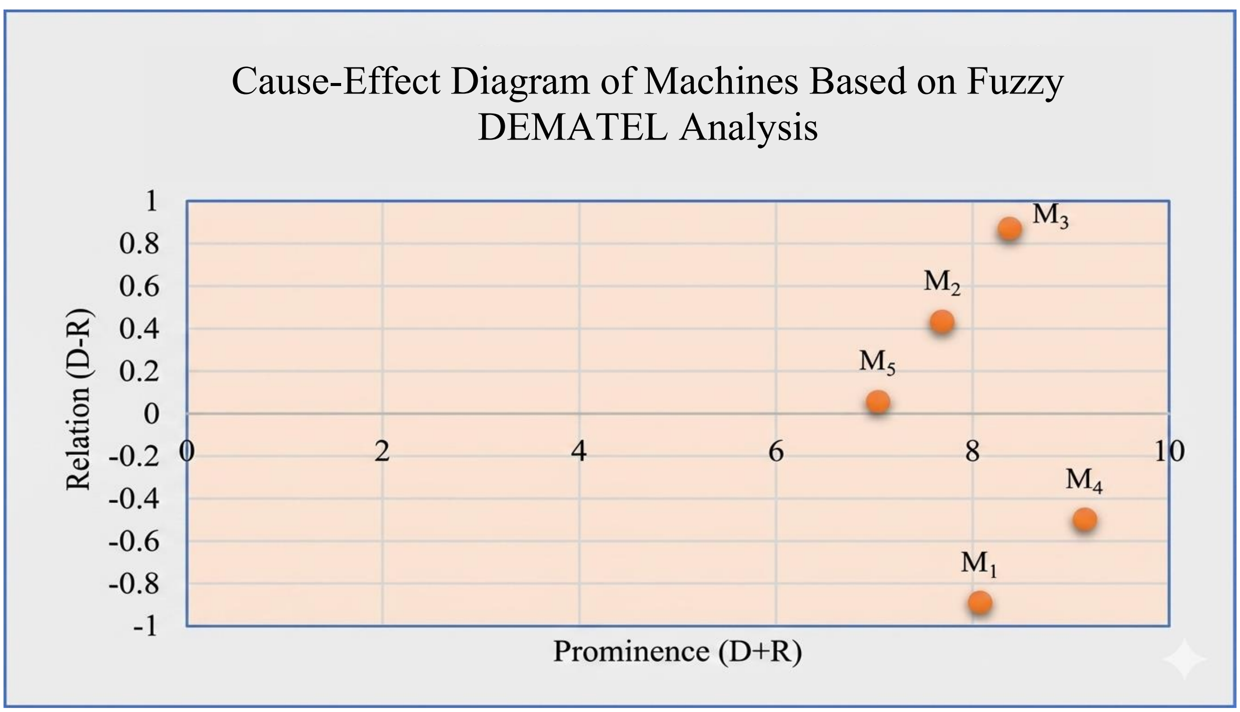


**Fig. 1 DEMATEL cause-effect diagram**

### 5.2. Assignment with Restrictions Results

Fuzzy assignment with restrictions was formulated using Integer Programming. The optimal solution is assigned with a worker to the corresponding machine as follows: Worker $W_1$ to Machine. $M_4$, Worker $W_2$ to Machine $M_3$, Worker $W_3$ to Machine $M_2$, Worker $W_4$ to Machine $M_1$, and Worker $W_5$ to Machine $M_5$. Therefore, the minimum total assignment cost is 5.7314**.** The obtained solution satisfies all assignment constraints, ensuring that each worker is assigned to exactly one machine and each machine is assigned to exactly one worker. Furthermore, all predefined assignment restrictions were satisfied, confirming the feasibility of the optimal solution.

**Table 2. Optimal Worker–Machine Assignment with Restrictions**

| Worker | Machine | Cost |
|---|---|---|
| $W_1$ | $M_4$ | 1.1335 |
| $W_2$ | $M_3$ | 1.2474 |
| $W_3$ | $M_2$ | 0.9545 |
| $W_4$ | $M_1$ | 1.0005 |
| $W_5$ | $M_5$ | 1.396 |

## 6. Conclusion

This study exhibited the effectiveness of integrating the DEMATEL method with an assignment model incorporating practical restrictions to support optimal decision-making. The DEMATEL analysis identified the interrelationships among the machines and measured their relative importance by providing meaningful weights for constructing the assignment cost matrix. By incorporating predefined worker–machine assignment restrictions, the proposed model accurately represented operational requirements while ensuring feasible and optimal assignment solutions.

The optimal assignment allocated Worker W1 to Machine. $M_4$, Worker W2 to Machine $M_3$, Worker W3 to Machine $M_2$, Worker W4 to Machine $M_1$, and Worker W5 to Machine $M_5$, resulting in a minimum total assignment cost of 5.7314. All assignment and restriction constraints were satisfied, demonstrating that the proposed approach can effectively balance optimality with operational feasibility.

The findings highlight that combining DEMATEL-based prioritization with a restricted assignment model provides a systematic and practical decision support for complex assignment problems. This approach improves the quality of assignment decisions by considering both the relative importance of resources and realistic operational constraints. Consequently, the proposed framework has potential applications in manufacturing systems, healthcare resource allocation, personnel scheduling, and other optimization problems where assignment decisions must satisfy practical restrictions. Overall, the integration of DEMATEL with the assignment model provides a systematic and reliable decision-support framework that enhances the quality and feasibility of assignment decisions in real-world applications.

Future work may include applying the proposed method to larger assignment problems. In addition, sensitivity analysis can be carried out to study the effect of changes in the DEMATEL-derived criterion weights and assignment costs on the optimal solution. The proposed framework may also be extended by incorporating intuitionistic fuzzy, Pythagorean fuzzy, or spherical fuzzy sets to represent uncertainty in complex decision-making environments.

## Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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## Appendix 1, etc.

**Table 3. Triangular Fuzzy Linguistic Scale Used for DEMATEL Analysis**

| Linguistic Term | TFN |
|---|---|
| No Influence(NI) | (0,0,0) |
| Very Low(VL) | (0,1,2) |
| Low(L) | (1,2,3) |
| Medium(M) | (2,3,4) |
| High(H) | (3,4,5) |
| Very High(VH) | (4,5,6) |
| Extreme Influence(EI) | (5,6,7) |

**Table 4. Fuzzy Direct Influence Matrix $\tilde{Z}$**

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $M_1$ | (0,0,0) | (1,2,3) | (3,4,5) | (4,5,6) | (0,1,2) |
| $M_2$ | (3,4,5) | (0,0,0) | (2,3,4) | (5,6,7) | (1,2,3) |
| $M_3$ | (5,6,7) | (4,5,6) | (0,0,0) | (2,3,4) | (4,5,6) |
| $M_4$ | (5,6,7) | (2,3,4) | (3,4,5) | (0,0,0) | (3,4,5) |
| $M_5$ | (0,1,2) | (2,3,4) | (1,2,3) | (5,6,7) | (0,0,0) |

**Table 5. Normalised Matrix Fuzzy direct relation matrix Ñ**

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $M_1$ | (0,0,0) | (0.0625,0.1,0.125) | (0.1875,0.2,0.2083) | (0.25,0.25,0.25) | (0,0.05,0.0833) |
| $M_2$ | (0.1875,0.2,0.2083) | (0,0,0) | (0.125,0.15,0.1667) | (0.3125,0.3,0.2917) | (0.0625,0.1,0.125) |
| $M_3$ | (0.3125,0.3,0.2917) | (0.25,0.25,0.25) | (0,0,0) | (0.125,0.15,0.1667) | (0.25,0.25,0.25) |
| $M_4$ | (0.3125,0.3,0.2917) | (0.125,0.15,0.1667) | (0.1875,0.2,0.2083) | (0,0,0) | (0.1875,0.2,0.2083) |
| $M_5$ | (0,0.05,0.0833) | (0.125,0.15,0.1667) | (0.0625,0.1,0.125) | (0.3125,0.3,0.2917) | (0,0,0) |

**Table 6. Fuzzy Total–relation Matrix T̃**

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $M_1$ | (1.3491,1.4865,1.6326) | (0.281,0.4511,0.6176) | (0.404,0.5464,0.6953) | (0.5445,0.7082,0.8699) | (0.2206,0.3977,0.5683) |
| $M_2$ | (0.5839,0.7342,0.8887) | (1.2664,1.4179,1.5721) | (0.417,0.5772,0.7377) | (0.6917,0.8429,0.9969) | (0.3131,0.4914,0.6627) |
| $M_3$ | (0.7388,0.8864,1.0382) | (0.5348,0.6973,0.8592) | (1.3641,1.5202,1.6779) | (0.6791,0.8586,1.0314) | (0.5018,0.6658,0.8283) |
| $M_4$ | (0.6962,0.8383,0.9868) | (0.4061,0.5835,0.7547) | (0.4885,0.6465,0.8056) | (1.4958,1.6597,1.822) | (0.428,0.5938,0.7576) |
| $M_5$ | (0.3367,0.5246,0.7017) | (0.3186,0.48,0.641) | (0.29,0.4599,0.6256) | (0.5963,0.7456,0.899) | (1.2042,1.3383,1.4823) |

**Table 7. Defuzzified Total Relation Matrix T**

| | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $M_1$ | 1.4894 | 0.4499 | 0.5486 | 0.7075 | 0.3955 |
| $M_2$ | 0.7356 | 1.4188 | 0.5773 | 0.8438 | 0.4891 |
| $M_3$ | 0.8878 | 0.6971 | 1.5207 | 0.8564 | 0.6653 |
| $M_4$ | 0.8404 | 0.5814 | 0.6469 | 1.6592 | 0.5931 |
| $M_5$ | 0.521 | 0.4799 | 0.4585 | 0.747 | 1.3416 |

**Table 8. Triangular Fuzzy Assignment Cost Matrix**

| Worker Machihne | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $W_1$ | (5,6,7) | (8,9,10) | (6,7,8) | (4,5,6) | (7,8,9) |
| $W_2$ | (7,8,9) | (6,7,8) | (5,6,7) | (8,9,10) | (5,6,7) |
| $W_3$ | (8,9,10) | (4,5,6) | (7,8,9) | (6,7,8) | (5,6,7) |
| $W_4$ | (4,5,6) | (7,8,9) | (6,7,8) | (5,6,7) | (8,9,10) |
| $W_5$ | (5,6,7) | (6,7,8) | (8,9,10) | (4,5,6) | (7,8,9) |

**Table 9. Weighted Assignment Cost Matrix C̃**

| Worker Machihne | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $W_1$ | (1.0005,1.2006,1.4007) | (1.5264,1.7172,1.908) | (1.2474,1.4553,1.6632) | (0.9068,1.1335,1.3602) | (1.2215,1.396,1.5705) |
| $W_2$ | (1.4007,1.6008,1.8009) | (1.1448,1.3356,1.5264) | (1.0395,1.2474,1.4553) | (1.8136,2.0403,2.267) | (0.8725,1.047,1.2215) |
| $W_3$ | (1.6008,1.8009,2.001) | (0.7632,0.954,1.1448) | (1.4553,1.6632,1.8711) | (1.3602,1.5869,1.8136) | (0.8725,1.047,1.2215) |
| $W_4$ | (0.8004,1.0005,1.2006) | (1.3356,1.5264,1.7172) | (1.2474,1.4553,1.6632) | (1.1335,1.3602,1.5869) | (1.396,1.5705,1.745) |
| $W_5$ | (1.0005,1.2006,1.4007) | (1.1448,1.3356,1.5264) | (1.6632,1.8711,2.079) | (0.9068,1.1335,1.3602) | (1.2215,1.396,1.5705) |

**Table 10. Defuzzified Weighted Assignment Cost Matrix C**

| Worker Machine | $M_1$ | $M_2$ | $M_3$ | $M_4$ | $M_5$ |
|---|---|---|---|---|---|
| $W_1$ | 1.2006 | 1.7181 | 1.4553 | 1.1335 | 1.396 |
| $W_2$ | 1.6008 | 1.3363 | 1.2474 | 2.0403 | 1.047 |
| $W_3$ | 1.8009 | 0.9545 | 1.6632 | 1.5869 | 1.047 |
| $W_4$ | 1.0005 | 1.5272 | 1.4553 | 1.3602 | 1.5705 |
| $W_5$ | 1.2006 | 1.3363 | 1.8711 | 1.1335 | 1.396 |