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Enhancing Recruitment Efficiency: Leveraging Fuzzy Linear Programming for Effective Skill Management in Human Resources

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A B S T R A C T

The application of fuzzy linear programming and optimization techniques has a rich history in various domains. In recent years, the rise in layoffs within large companies has underscored the significance of employee performance and its impact on organizational progress. To address this issue, it is crucial to determine the appropriate number of employees required to effectively execute company projects, considering employee performance and organizational needs. Additionally, it is essential to identify an optimal employee count as a benchmark prior to hiring. This optimal value can be achieved through the utilization of optimization methodologies, such as fuzzy linear programming. This research paper presents a solution to the employee hiring problem in a hypothetical factory by utilizing the fuzzy linear programming method and simplex algorithm. The findings of this paper reveal that increasing the number of hires does not necessarily correlate with enhanced performance and the provided solution decreases the number of hires by 25% while reaching the peak performance. The outcome of this research enables organizations to make informed decisions regarding employee recruitment and enhance overall operational efficiency considering the required skillset of different workers.

1. Introduction

The process of hiring employees encompasses a multitude of influential factors, including the organization's specific needs, applicant attitudes and skills, individual aspirations, budgetary considerations, and desired salary levels. To make the most informed decision, it is essential to comprehensively evaluate all relevant parameters, ensuring the selection of the most suitable candidates for the required tasks, free from biases and discrimination. In this context, the interview process plays a crucial role in practically assessing an individual's qualifications.

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This article aims to address the challenge of determining the optimal number of employees to be hired for a hypothetical company, considering various hiring constraints. Specifically, the selection process focuses on individuals from a factory setting, utilizing available data to identify the most suitable candidates. Importantly, critical parameters such as employee performance and operational methodologies have been taken into account during the selection process. The factory has classified its employees into five distinct work categories, with the goal of selecting a balanced and high-performing team, ensuring fairness, and avoiding any form of discrimination. Consequently, the task at hand involves selecting a total of 50 individuals, with the objective of attaining an optimal solution that optimizes the number of employees to be hired for each team while maximizing overall performance.

By leveraging advanced techniques such as fuzzy linear programming [6, 10, 11, 15, 18] and optimization methodologies, this research aims to provide valuable insights and recommendations for organizations facing similar challenges in their recruitment processes. The application of these methodologies enables the identification of the ideal number of hires for each team, taking into consideration performance indicators and specific operational requirements. The ultimate goal is to achieve a well-balanced and high-performing workforce that aligns with the company's objectives.

The significance of this research lies in its potential to enhance the recruitment process by mitigating biases and promoting fairness. By employing objective and data-driven approaches, organizations can optimize their hiring decisions, leading to improved performance, employee satisfaction, and overall organizational success. The findings and recommendations presented in this article contribute to the advancement of skill management strategies, fostering an environment that promotes equal opportunities and harnesses the full potential of the workforce.

2. Related works

In [12], while previous works have explored optimization problems and decision-making processes, there is a clear lack of research on HFLP problems with hesitant cost coefficients. This paper contributes to the existing body of literature by proposing a solution methodology based on the simplex method and providing a practical demonstration of its effectiveness through illustrative examples. The findings of this study shed light on the applicability of the proposed method in real-world scenarios and highlight its potential for assisting decision-makers faced with optimization problems involving hesitant fuzzy information.

Yuan et al. [17] contribute to the field of IFPRs by introducing an optimization model that considers both cardinal and ordinal consistencies. The model improves the reliability of estimated preferences by effectively managing both types of consistencies and minimizing necessary modifications. This paper presents an optimization model that considers both cardinal consistency and ordinal consistency to estimate unknown preferences in IFPRs. The authors propose a model specifically designed to optimize consensus in large-scale group decision-making problems utilizing IFPRs.

The proposed model explicitly controls ordinal consistency, minimizes necessary preference modifications, and ensures effective management of both cardinal and ordinal consistencies. This approach outperforms prevailing methods in estimating unknown preferences while achieving a predefined level of consensus. The experimental results highlight the superiority of the proposed model compared to current methods, emphasizing its potential for enhancing decision-making processes involving incomplete preferences.

Vasant et al. [14] employed a fuzzy linear programming approach to compute profits and satisfaction levels. Fuzzy linear programming enables decision-makers to incorporate fuzziness and uncertainty into the optimization process. By utilizing the S-curve membership function, the authors capture the gradual and smooth transition between different levels of membership within the fuzzy sets, enhancing the accuracy and flexibility of the model.

Given that multiple decisions need to be made in the context of fuzzy mix product selection, the authors define a performance measure to identify the decision that achieves a high level of profit while ensuring a high degree of satisfaction. This performance measure provides a quantitative assessment of the decision alternatives, enabling decision-makers to prioritize options that offer the most favorable trade-off between profitability and satisfaction.

Tripathi et al. [13] introduced the IF-CoCoSo method, a decision-making approach that utilizes a combined compromise solution (CoCoSo) under intuitionistic fuzzy sets (IFSs). The primary objective of this approach is to provide an effective solution for multi-criteria decision-making problems in the context of IFSs.

To achieve this goal, the study proposes novel divergence measures and a score function to derive the criteria weights. These measures and the score function are specifically designed for IFSs and exhibit interesting properties. By utilizing these tools, the presented approach computes the criteria weights, which play a crucial role in the decision-making process. The IF-CoCoSo method introduced in this study offers a promising decision-making approach for multi-criteria problems in the context of intuitionistic fuzzy sets. By incorporating novel divergence measures and a score function, the method enables effective criteria weighting and provides practical solutions. The application to medical decision-making problems highlights the approach's applicability, while comparative and sensitivity analyses validate its performance and robustness.

Wang et al. [16] highlighted the importance of effective energy management in maintaining the economical operation of FCVs. However, traditional FLC approaches have shown limitations, particularly due to their reliance on expert knowledge, which often results in insufficient energy split. To overcome the limitations of traditional FLC, recent research has focused on the integration of strategy optimization based on FLC with driving cycles recognition. This approach aims to achieve near-optimal fuel economy and stable battery charge sustenance by incorporating advanced optimization techniques. In this context, the use of genetic algorithms (GA) has been proposed to optimize the centers and widths of the fuzzy logic control membership functions. Although decision-making is out of the scope of this paper, the researchers involved fuzzy linear programming as a means of problem-solving and optimization.

Aviso et al. [3] addressed the crucial issue of workforce availability disruptions in industrial systems, which is often overlooked in the literature on climate change adaptation strategies. The authors highlight the significance of business decision-making models in providing rational support for managers and industry practitioners facing crisis conditions resulting from climatic disruptions.

While existing techniques mainly focus on disruptions in physical resources propagated through supply chain linkages, there remains a significant research gap in mitigating the impacts caused by disruptions in workforce availability. To address this gap, the authors develop a novel fuzzy input-output optimization model that effectively allocates scarce labor resources within a business enterprise or organization. By incorporating the input-output framework, the model accounts for the organizational interdependencies among workers or departmental units, ensuring minimal loss of vital services provided to external clients.

Many more studies have dived deep into the concept of decision-making [2] and optimization [1, 4, 7, 8, 9] by utilizing the fuzzy linear programming and simplex method with the objective of enhancing the solutions to various problems and choosing the best feasible one.

3. Dataset

The dataset utilized in this research paper is sourced from Kaggle, specifically the "factory workers' daily performance & attrition" dataset. This dataset offers comprehensive insights into the performance and impact of employees within a factory environment, encompassing both employees and supervisors. Spanning a duration of 18 months, the dataset comprises daily performance data for a total of 508 factory employees.

The dataset encompasses a diverse range of quantitative and qualitative features related to employees, including their name, age, gender, team affiliation, role, level of commitment, power, health status, agility, perception, intellect, and working style. And for the supervisors, commitment, perceptiveness, and goodness are the features contained in the dataset. Of particular significance is the dataset's ability to provide the necessary information to establish connections between individual traits, performance, and subsequent employment either within the same factory or elsewhere. With a substantial volume of 411,948 employee observations, the dataset's richness and diversity contribute to its overall value.

Given the extensive number of features available, a focused approach has been adopted for the purposes of this paper. Specifically, a limited selection of features has been chosen for assessment, prioritizing those with the highest impact on employee and supervisor performance and subsequent employment. Key features identified as crucial in determining employee suitability for various roles include work style, power, health, commitment, and performance. While these features possess a qualitative nature, a precise measurement for meaningful analysis requires the consideration of relative numerical values. Consequently, numerical values ranging from 0 to 4.1 have been assigned to performance, while the remaining features are denoted within the 0 to 1 range. Moreover, employee work styles have been classified into five distinct categories, designated as Team A through Team E. Despite its richness, the dataset doesn't contain any negative features, which in this case is necessary for problem definition. To reach the needed pattern for the linear fuzzy problem, instead of using the strength feature for the employees and the perceptiveness for the supervisors, the lack of strength and the lack of perceptiveness were calculated by subtracting the original features from one. Consequently, the set of features used in the constraint definition part of the problem are health, commitment, and weakness for the employees, and commitment, goodness, and obliviousness for the supervisors.

The meticulous curation and inclusion of these essential features in the dataset enable a comprehensive assessment of the factors influencing employee/ supervisor performance and subsequent employment decisions. By leveraging this dataset, the research aims to gain valuable insights into the relationships between individual traits and performance, providing organizations with actionable intelligence for effective skill management and optimal recruitment strategies.

4. Methodology

The first step in addressing the problem at hand is to define the necessary coefficients for the linear programming model. This involves calculating the average values of the desired features, namely weakness, health, commitment, and performance, for employees and commitment, obliviousness, and goodness for the supervisors for each team individually. These coefficients serve as crucial inputs for the subsequent analysis.

The objective of this problem is to determine the optimal number of employees required for recruitment, taking into account the unique conditions of the factory. Consequently, the variables in this problem are the number of employees to be hired for each team to separate them by their unique skills. It is important to note that at least one individual from each team must be employed, as all the different skills are needed.

The output of this problem, along with the objective function, is utilized to assess the performance level. The coefficients for the constraints are derived from the average values of the various features. The next step is to define the needs of the company by setting some requirements for each feature and forming constraints. It's obvious that any company would like to have strong, healthy, and committed employees, not weak and oblivious ones. Some logical thresholds are set as the requirements of this problem, in which the company requires the overall commitment and health of the employees to be higher than 20, and their weakness less than 10. The constraints of the qualified supervisors require them to have an overall commitment of at least 20, more than 10 as the threshold for goodness, and a threshold of less than 10 when it comes to obliviousness.

Table 1 provides a comprehensive overview of the average features of the employees of each team, and Table 2 represents the coefficients of supervisors' features for each team, in addition to the requirements and the average performance, offering insights into the distinctive characteristics and capabilities of the different teams within the factory.

By incorporating these coefficients and employing the linear programming model, this research aims to determine the optimal number of employees to be hired for each team, thereby maximizing overall performance and ensuring that the factory's requirements are met in terms of expertise and skillsets.

Table 1. Average features of employees for each Team

Team (work style)	Weakness (average)	Commitment (average)	Health (average)	Performance (average)
A	0.262399432	0.723606356	0.737041517	1.109482317
B	0.262360972	0.739077414	0.715954913	1.278519779
C	0.262383999	0.747653344	0.771131777	0.926157499
D	0.262425592	0.742491299	0.75674884	0.778422274
E	0.262425272	0.753338434	0.705765077	1.085328533
Requirements	$10 \geq$	≥ 20	≥ 20	

Table 2. Average features of supervisors for each Team

Team (work style)	Commitment (average)	Obliviousness (average)	Goodness (average)	Performance (average)
A	0.747313611	0.269456527	0.705751279	1.109482317
B	0.747208002	0.269708435	0.705512011	1.278519779
C	0.747295743	0.269473564	0.705746045	0.926157499
D	0.747279764	0.269514488	0.705709606	0.778422274
E	0.747231945	0.269606285	0.705586359	1.085328533
Requirements	≥ 20	$10 \geq$	≥ 10	

Linear programming is a powerful technique widely used in optimization problems to maximize or minimize an objective function subject to a set of linear constraints. One of the most popular algorithms for solving linear programming problems is the simplex method. The simplex method iteratively moves from one feasible solution to another in order to approach the optimal solution. The fuzzy linear problem model is shown in Model (1):

$$
\begin{aligned}
&M\tilde{a}x\ \ \tilde{C}_1x_1 \oplus \tilde{C}_2x_2 \oplus \ldots \oplus \tilde{C}_nx_n \\
&s.t. \\
&\quad \tilde{A}_{i1}x_1 \oplus \tilde{A}_{i2}x_2 \oplus \ldots \oplus \tilde{A}_{in}x_n \lesssim \tilde{B}_i,\ \ i=1,\ldots,m \\
&\quad x_1, x_2, \ldots, x_n \geq 0.
\end{aligned}
\tag{1}
$$

In which

$$\tilde{A}_{ij}, \tilde{B}_i, \tilde{C}_j, i=1,\ldots,m; j=1,\ldots,n$$

Fuzzy sets are a part of real numbers, and the symbol $\oplus$ represents the extended addition. To solve the model using the simplex method, the problem is rewritten in the following form shown in formula (2):

$$
\begin{aligned}
&Max\,\tilde{Z} = \tilde{C}_Bx_B + \tilde{C}_Nx_N \\
&s.t. \\
&\quad Bx_B + Nx_N \leq b, \\
&\quad x_B \geq 0, x_N \geq 0
\end{aligned}
\tag{2}
$$

In which $\tilde{C}_B$ and $\tilde{C}_N$ are representatives of the objective function coefficients (the average of performance in our problem), and x_B and x_N show the decision variables (in this case the teams), B and N being the constraint coefficients (the average of various features of employees or supervisors), and b is the requirement that needs to be satisfied.

The decision variables, objective function coefficients, and constraint coefficients are already defined in Table 1 and Table 2. The objective is to find the values of the decision variables that optimize the objective function while satisfying all the given constraints.

The formulated form of the fuzzy linear problem model for the employees can be observed in formula (3):

$$\begin{aligned}
&\text{Max}\,1.109482317x_1 + 1.278519779x_2 + 0.926157499x_3 + 0.778422274x_4 + 1.085328533x_5 \\
&s.t. \\
&\quad 0.737041517x_1 + 0.715954913x_2 + 0.771131777x_3 + 0.75674884x_4 + 0.705765077x_5 \geq 20 \\
&\quad 0.755292414x_1 + 0.755481072x_2 + 0.744176494x_3 + 0.743358469x_4 + 0.755291629x_5 \geq 20 \\
&\quad 0.262399432x_1 + 0.262360972x_2 + 0.262383999x_3 + 0.262425592x_4 + 0.262425272x_5 \leq 10
\end{aligned} \tag{3}$$

The fuzzy linear problem model for the supervisors is shown in formula (4):

$$\begin{aligned}
&\text{Max}\,1.109482317x_1 + 1.278519779x_2 + 0.926157499x_3 + 0.778422274x_4 + 1.085328533x_5 \\
&s.t. \\
&\quad 0.747313611x_1 + 0.747208002x_2 + 0.747295743x_3 + 0.747279764x_4 + 0.747231945x_5 \geq 20 \\
&\quad 0.705751279x_1 + 0.705512011x_2 + 0.705746045x_3 + 0.705709606x_4 + 0.705586359x_5 \geq 10 \\
&\quad 0.269456527x_1 + 0.269708435x_2 + 0.269473564x_3 + 0.269514488x_4 + 0.269606285x_5 \leq 10
\end{aligned} \tag{4}$$

The solution to the simplex method will be briefly explained below.

From formula (2) we have formula (5):

$$x_B + B^{-1}Nx_N = B^{-1}b \tag{5}$$

Thus formula (5) is used in the objective function and formula (6) will be obtained:

$$\tilde{Z} + (\tilde{c}_B B^{-1}N - \tilde{c}_N)x_N = \tilde{c}_B B^{-1}b \tag{6}$$

And with considering some of the decision variables to be zero in formula (7):

$$x_N = 0 \tag{7}$$

Formula (8) will be obtained:

$$x_B = B^{-1}b = y_0 \tag{8}$$

And by utilizing the formula (8) in objective function formula (9) will appear:

$$\tilde{z} = \tilde{c}_B B^{-1}b \tag{9}$$

In conclusion, the linear programming problem above is rewritten in the simplex model form as shown in Table 3.

Table 3. Fuzzy simplex model table

Basis	x_B	x_N	R.H.S.
$\tilde{z}$	0	$\tilde{z}_N - \tilde{c}_N = \tilde{c}_B B^{-1} N - \tilde{c}_N$	$\tilde{y}_{00} = \tilde{c}_B B^{-1} b$
x_B	1	$Y = B^{-1} N$	$y_0 = B^{-1} b$

Table 3 contains all the needed information for solving the simplex problem. In order to solve it, it should be taken into consideration that the cost of this table is calculated from formula (10):

$$\tilde{y}_0^T = \tilde{c}_B B^{-1} A - \tilde{c} \tag{10}$$

With generalization, the formula (11) will be achieved:

$$\tilde{y}_{0j} = \tilde{c}_B B^{-1} a_j - \tilde{c}_j = \tilde{z}_j - \tilde{c}_j, 1 \le j \le n \tag{11}$$

Considering the formula (12):

$$\tilde{y}_{0j} = 0 \tag{12}$$

For the conditions in formula (13).

$$j = B_i, 1 \le i \le m \tag{13}$$

The optimal solution is obtained if the formula (14):

$$\tilde{y}_{0j} \ge 0 \tag{14}$$

Is applied for all the conditions in formula (15).

$$j \ne B_i, 1 \le i \le m \tag{15}$$

But if the formula (16) is true:

$$\tilde{y}_{0k} = \tilde{z}_k - \tilde{c}_k \prec 0 \tag{16}$$

And the conditions in formula (17) apply:

$$y_{ik} \le 0, i = 1, \dots, m \tag{17}$$

The solution space for the problem is infinite thus, no solution exists and the fuzzy linear programming problem is unbounded.

But if k exists such that formula (18) is true:

$$y_{0k} = \tilde{z}_k - \tilde{c}_k \prec 0 \tag{18}$$

And B_i exists such that formula (19) is true:

$$y_{ik} \succ 0 \tag{19}$$

Then a pivoting row of "r" can be found so that pivoting on y_{rk} yields a feasible tableau with a corresponding nondecreasing (increasing under nondegeneracy assumption) fuzzy objective value. In this case "r" can be chosen so that formula (20) is applied.

$$\frac{y_{r0}}{y_{rk}} = \min_{1\le i\le m}\{\frac{y_{i0}}{y_{ik}} \mid y_{ik} \succ 0\} \tag{20}$$

which is determinative for the next steps until the condition of the feasibility of the problem is satisfied. With reaching this step of the problem, the optimal solution is attainable.

For a better understanding of the simplex method, the pseudo-code for the simplex method from [5] can be observed in Figure 1.

```
SIMPLEX(A, b, c)
(N, B, A, b, c, v) = INITIALIZE-SIMPLEX(A, b, c)
let Δ be a new vector of length n
while some index j ∈ N has c_j > 0
    choose an index e ∈ N for which c_e > 0
    for each index i ∈ B
        if a_ie > 0
            Δ_i = b_i/a_ie
        else Δ_i = ∞
    choose an index l ∈ B that minimizes Δ_i
    if Δ_l == ∞
        return "unbounded"
    else (N, B, A, b, c, v) = PIVOT(N, B, A, b, c, v, l, e)
for i = 1 to n
    if i ∈ B
        x̄_i = b_i
    else x̄_i = 0
return (x̄_1, x̄_2, ..., x̄_n)
```

Figure 1. Pseudo-code for simplex method [5]

5. Findings

Both the employees' and supervisors' problems have been solved using the simplex method and in this section, the findings will be discussed. The solution to the employees' problem indicates that hiring ten employees from Team A, ten employees from Team B, seven employees from Team C, one employee from Team D, and finally ten employees from Team E, which all together form a Team of thirty-eight employees, can achieve the highest possible performance (42.09) considering the constraints that the hypothetical company necessitated. The obtained value for performance (objective function) has an abstract definition and only makes sense when compared to other problems so the solution to the supervisors' problem can help with the analogy. The solution to the supervisors' problem shows that hiring ten supervisors from each and every Team A, B, and E, 6 supervisors from Team C, and one supervisor from Team D reaches the peak performance for the supervisor's Team which is 41.16. Thus instead of hiring 50 supervisors, only thirty-seven supervisors would be enough to reach the highest performance possible. The results are also shown in Table 4.

Table 4. The results of employees' and supervisors' problems

Team	#Employees	#Supervisors
A	10	10
B	10	10
C	7	6
D	1	1
E	10	10

The findings show that the performance of employees is higher than supervisors' and it's because the constraints for the employees were harder to satisfy and needed them to be at the top of their Teams. But the supervisors' Team requires one less person to reach the highest performance, so it's a trade-off between performance and the number of hires which is up to the organization's human resources management choice.

The results show that it is not necessary to hire more people in order to achieve the best performance, and in this problem, instead of focusing only on the number of hires without consideration of the skillset needed for the organization, we tried taking into account that the abilities play a huge role in the overall performance of the Teams, since some Teams have shown higher efficacy than the other ones in the dataset. Also, the results show that the different skillsets of employees and supervisors and the requirements set by the hiring company affect the results so by changing the number of hires or considering different skills and thresholds, the performance shows which scenario reaches the best possible results. Therefore the problem discussed in this paper helps human resources management Teams in organizations to make insightful decisions that prevent the wastage of the organization's resources.

6. Conclusion

In this study, we addressed the presence of uncertainty in real-world linear programming problems, where certain model parameters are subject to ambiguity expressed through probabilistic or fuzzy numbers. We employed fuzzy linear programming to tackle the hiring process and determine the required number of employees and supervisors for a hypothetical organization. While the study's output is subject to specific theoretical conditions, it is evident that the optimal performance and best solutions differ under varying conditions. Therefore, it is crucial to thoroughly investigate relevant factors before making decisions and subsequently apply them within optimization algorithms to achieve the best possible outcome.

The solution approach presented in this study holds practical value for human resources managers involved in the hiring process and employee requirement determination. Furthermore, considering the qualitative nature of the objective function, it can be concluded that simplex optimization proves useful not only for obtaining quantitative optimal solutions but also for qualitative problems. Importantly, the proposed approach yields outputs that are closer to reality due to its consideration of different factors and incorporation of probabilities, leading to solutions that align more closely with real-world scenarios compared to alternative methods.

In this paper, we utilized a real-world dataset and carefully selected relevant features to address the problem at hand. Additionally, we formed the fuzzy simplex model to solve the linear programming problem, offering a streamlined path to reach an accurate optimal solution. It is worth noting that this model is not limited to the specific dataset used in this study but is applicable to other qualitative or quantitative datasets. It can effectively address various types of linear programming problems, proving to be a versatile tool.

The results show that increasing the number of hires doesn't necessarily increase the overall performance achieved by the hired Team. The findings of this paper show that instead of hiring a Team of 100 total workers, only 75 workers can achieve the highest performance regarding the constraints of the hypothetical organization, so hiring more employees can lead to the wastage of money and resources considering the fact that not all the Teams have high performances and needed thresholds when it comes to skillsets.

In conclusion, our study highlights the importance of addressing uncertainty in linear programming problems and demonstrates the utility of fuzzy linear programming. By considering probabilities and incorporating relevant factors, our approach yields solutions that are both accurate and realistic. The model's application to a real-world dataset and its versatility in solving different types of linear programming problems further solidify its practical value. By adopting similar methodologies and approaches, decision-makers can enhance their decision-making processes and achieve optimal solutions in various domains.

Future interested researchers can add up to the findings of this paper by applying the same technique to other human resources decision-making problems in the real world and comparing the results with ours since the fuzzy linear programming approach hasn’t been discussed enough in the field of human resources management. Also, the practicality of this paper is only achievable through real-world practice, which requires following the footsteps of the discussed solution in this paper and comparing the results with another type of hiring technique used by human resources managers that are traditionally used in different organizations. With the obtained analogy, new techniques for efficiency optimization in the recruitment process can be defined.

Conflict of interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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