**A THREE-PHASE FUZZY GROUP DECISION APPROACH FOR TRAINING ASSIGNMENT: A CASE STUDY IN A DISTRIBUTION BUSINESS**

Fatih Yiğit[[1]](#footnote-1)\*

Istanbul Altinbas University, Department of Industrial Engineering

Istanbul, TURKEY

[fatih.yigit@altinbas.edu.tr](mailto:fatih.yigit@altinbas.edu.tr)

https://orcid.org/0000-0002-7919-544X

**ABSTRACT**

Proper and effective training of the employee is vital for the success of a company. The choice of the right person is a difficult task due to many variables in decision-making. Proper training, when assigned to the right people, would increase the performance of a company. This study proposes an integrated model that uses Fuzzy Decision Making, AHP and K-Means for the assessment of candidates. Use of novel approaches are important in the application of the proposed model. Flexibility of the proposed methodology is also essential when there is a constraint limiting the number of assignments.

This study aims to solve a common problem encountered in a real business case. Companies benefits from training such as financial management, team management, project management. The trainings both contribute to professional development and increase motivation and commitment of the employee.

The proposed Multi-Criteria Decision Making (MCDM) process focuses on deciding the correct number and right employee for training assignments. In addition, the model can be used to define the possible number of people to be assigned when needed, such as budgeting for the following year.

The result of the study shows that the proposed methodology can be used to not only for assignment but also the decision about the number of assigned staffs. Feedback from the decision makers are received. The positive feedback contributed to the validation of the proposed methodology.

Keywords: Analytic Hierarchy Process, K-Means Algorithm, Multi-Criteria Decision Making, Human Resources, Training Management

# Introduction

Training of the staff for a company is vital. Trainings contribute to the success of the companies. Both improvements in the skills and motivation of the employee will be beneficial for any company. The decision among the possible candidates can be challenging as multiple criteria and candidates are involved in the decision. Accurate assignment of the employee is vital for an efficient training management. Somebody inferior in one or more criteria, may demotivate other candidates. Such allocation of resources would be ineffective as well.

Volatile, uncertain, complex, and ambiguous (VUCA) is a managerial acronym used to define the current business environment. Employees are considered one of the main assets of a successful company in a demanding environment (Dobre, 2013). Training and eventual investment for an employee will increase the motivation. This motivation is partly because of the company's long-term expectations and skills acquired by the employee. The motivational increase and improvement in the skill set will contribute to the success of the company. The decision inherits constraints. One of the main constraints is the number of people to be trained.

In this study, a three-stage approach is proposed. In the first stage, the group fuzzy decision making is used to define criteria that influence the decision. In the second stage, expert opinions are used to analyze the weights of the specified criteria by employing Analytic Hierarchy Process (AHP). The weights are used as inputs to assess the alternative employees suitable for the trainings.

Finally, K-Means is used to cluster the employees based on their global ratings. Global ratings are calculated based on the weights of the criteria and values per employee per each criterion. Clusters represents the priority of each group for training assignments. K-Means allows the grouping of people based on their global ranking. The first group shows the candidates that need to be assigned. When the number of people is higher than the constraint, i.e., budget, reassignment is possible due to membership values. Multiple criteria decision-making (MCDM) methodologies can solve the selection of people for training. Our study uses a three-step approach to solve that problem.

The rest of this paper is as follows: In Section 2, our study's literature review and contribution are given. Section 2 provides a literature review on Group Decision Making Method, Analytic Hierarchy Process (AHP), K-Means, and general MCDM. In Section 3, the theoretical foundation of the proposed methodology is given. The proposed methodology's steps and workflow are also provided in the same section. The proposed methodology aims to solve a real-life problem. The relevant problem and solution with the proposed methodology are given in Section 4. Finally, in section 5 and 6, results and findings are discussed.

# Literature Review

The level of competition in today's business world underlines the importance of human resources. VUCA environment is prevalent in today's business world. For adaptation to such an environment, human resources quality is essential. Training of human resources plays a vital role in the needed adaptation. Parallel with this assumption, training of employees has broad research in literature.

Similarly, a recent study concluded that education is the primary mechanism to overcome companies’ difficulties. (Piñol *et al.*, 2017). Mahmud et al. (2019) investigated the impact of training needs assessment (TNA) on the performance of employees in the telecommunication sector in Bangladesh. TNA is a methodology used to assess the needs of training. The study showed that besides conducting TNA, providing financial incentives and training positively impacted the employee's performance.

The goals of the research are various in studies. The study conducted by Wahyuni et al. (2020)) focused on Vocational High Schools (VHS) education system. It is concluded that the main gaps are in six topics, including entrepreneurship, networking, and collaboration between relevant industries. Another study different in nature identifies the multimorbidity training needs of primary care professionals ((Leiva-Fernández *et al.*, 2021). The study underlined the importance of training needs analysis and healthcare professionals and patients.

To the best of our research, the focus on the decision about the number of people and selection is an under-investigated area. Choosing a set of people among alternatives is an MCDM problem. MCDM is a branch of decision-making involving choice among alternatives based on different criteria (Wang, Luo and Hua, 2008). Selection of criteria for decision is an essential aspect of MCDM. Choice of criteria and elimination play an essential role.

After the selection of criteria, the selection among alternatives is an essential part of MCDM. There are multiple methods employed for MCDM. Some well-known approaches are AHP, the technique for order of preference by similarity (TOPSIS), Elimination of Choice Translation Reality (ELECTRE).

AHP is a method used for MCDM developed by Saaty (1987)). The main advantage of the AHP methodology is flexibility. AHP can be applied to different needs. Many applications used AHP. Mathew et al. (2020)applied AHP and TOPSIS for advanced manufacturing system selection, to name a recent few.

The choice and clustering of alternatives is a stage of MCDM. The clustering is used to classify different applications. One of the applications of clustering is a combined decision-making approach. Supplier selection (Boran *et al.*, 2009), multi-criteria inventory classification (İsen and Boran, 2018), brain image segmentation (Huang *et al.*, 2019) are some applications. K-Means is a method used for clustering.

Our approach combines Fuzzy Group Decision Making, AHP, and K-Means to create a consensus and choice of people and the number of people to be trained. To the best of our research, the focus of our study is a new area for subjects associated with training and for MCDM problems. The combination of the Fuzzy Group Decision making Method, AHP, and K-Means is also a new contribution to the literature.

Based on our review of the literature, this paper makes the following contributions.

This research aims to develop a new multi-stage approach for the solution of the selection of people to be trained.

In this research, the proposed model implements multiple different methods as a part of multiple criteria decision-making. Fuzzy group decision making method is used to generate and analyze the factors that affect the need for training. The second stage covers the use of AHP to define weights.

After defining weights, expert opinions are used to assess different alternatives based on expert opinions. Relevant MCDM literature is given in Table 1. There are a vast number of studies with the mentioned methods in literature.

Table 1 Summary of MCDM Studies

(Boran *et al.*, 2009; Su *et al.*, 2011; Rouyendegh, 2014; Büyüközkan and Güleryüz, 2016; Veskovic *et al.*, 2018; İsen and Boran, 2018; Watson *et al.*, 2019; Huang *et al.*, 2019; Tiberius and Hirth, 2019; Mathew, Chakrabortty and Ryan, 2020; Abdulkareem *et al.*, 2021; Solangi, Longsheng and Shah, 2021)

The third contribution is the use of K-Means for clustering of the people who are nominees for training. This way, people can be grouped based on needs. The proposed approach is flexible to accommodate constraints in the decision process. Some constraints inherent in the process can be the number of people to be assigned or budget constraints. The proposed methodology allows the solution to be finalized without complex optimization techniques. This aspect is essential, especially when the number of people should adhere to a predefined parameter, such as budget, number of vacant people.

# Proposed Methodology for the Selection of People to be Trained

Traditional AHP has a significant drawback. The bias inherent in human judgment may cause bias in comparisons. Combining Fuzzy Sets and AHP can overcome this problem. Besides, having a group consensus among decision makers will allow the accurate representation of human behavior in decision-making. The proposed model for the solution of training candidates’ assessment and selection involves multiple phases The first phase consists of the decision of the criteria for evaluation. Criteria for some known problems such as financial ratio, multi-criteria inventory classification (MCIC) already exist in the literature (Ertuǧrul and Karakaşoǧlu, 2009; Aydin Keskin and Ozkan, 2013) .

To the best of our research, the criteria for the evaluation of candidates for training are not thoroughly studied. A method to employ criteria to define is to use expert opinions. Group Consensus approach proposed by Hsu and Chen (1996)).Group consensus approach allows effective integration of different approaches

## Details and Selection of Criteria – Fuzzy Group Decision Making

In complex environments involving multiple disciplines and opinions, it is essential to combine different opinions efficiently and fairly. The study involved fuzzy opinions under group decision-making in the first phase to apply this approach. Hsu and Chen (1996) propose the approach. The authors underlined the importance of aggregating the estimated ratings to a common opinion in the mentioned study. The study proposed a similarity aggregation method (SAM) to combine individual subjective estimates. Subjective estimates are vital in the current decision-making study as both importance and probability are subjective values in nature.

The existence of fuzziness is also a principle that lies behind fuzzy logic. An aggregation procedure is applied to apply fuzzy sets in group decision-making. The proposed model is developed using the aggregation method. The details of the approach are given as follows (Hsu and Chen, 1996).

Step 1. Suppose different opinions are shown as where n is the number of experts. The agreement degree is represented with S( and i≠j. The proportion of the consistent area to the total area represents the agreement degree.

The minimum area represents the intersection of two fuzzy sets, and the maximum area represents the union of different fuzzy sets. Eq. (1) represents the agreement degree.

(1)

is also called as similarity measure function. The number of cross-comparisons increases with the increased number of experts.

Step 2. The agreement degrees between two experts will be used for the agreement matrix (AM) .

Where Sij = , if i≠j and Sij = 1, if i=j. Based on AM, average agreement degree of expert is calculated according to Eq. (2).

where i≠j (2)

The number of agreement degrees of experts will be equal to the number of experts. The relative degree of experts is calculated according to Eq. (3), ensuring that the total relative degree of experts will be equal to 1. The relative degree of expert (RADi) will be Eq. (3).

i=(1,2,…n) (3)

In some cases, the importance of different experts can be categorized differently. In our case, the weights are equal. The experience and position of the experts are similar.

Step 3. The study uses trapezoidal fuzzy numbers as the outputs of group decision making. The output of the first phase will be global rankings of each risk. The output of the global rating will be calculated according to the multiplication of Impact (IMx) and Probability (PRx). x represents the set of risks, and s is the number of real risks. Eq. (4) represents the calculation of Global Rating (GRx).

GRx = IMx \* PRx where x = 1,2,…s (4)

## Criteria Assessment and Defining Weights – AHP

AHP is used to transform the experience of decision-makers to the weights of the criteria. AHP is a methodology used to convert decision makers' knowledge to each criterion's weight. Decision-makers compare two criteria based on their importance. Based on the AHP method, outputs are the weights of each criterion. The sum of all weights of each criterion is 1. The original AHP is crisp in nature (Saaty, 1987).

AHP is a well-known method used for MCDM. The application of the method is straightforward and there are multiple applications of the method in literature. The details of the application of the study is given by Saaty ( 1987).

#### Clustering of Candidates – K-Means

The objective of the k-means algorithm is J(z, A) with updating equations for cluster centers and memberships, respectively. The objective is to minimize the following Eq. 5. In Eq. 6, where is the Euclidean distance between the data point and the cluster center . Details of the model is given in the study of Sinaga and Yang (2020).

(5)

(6)

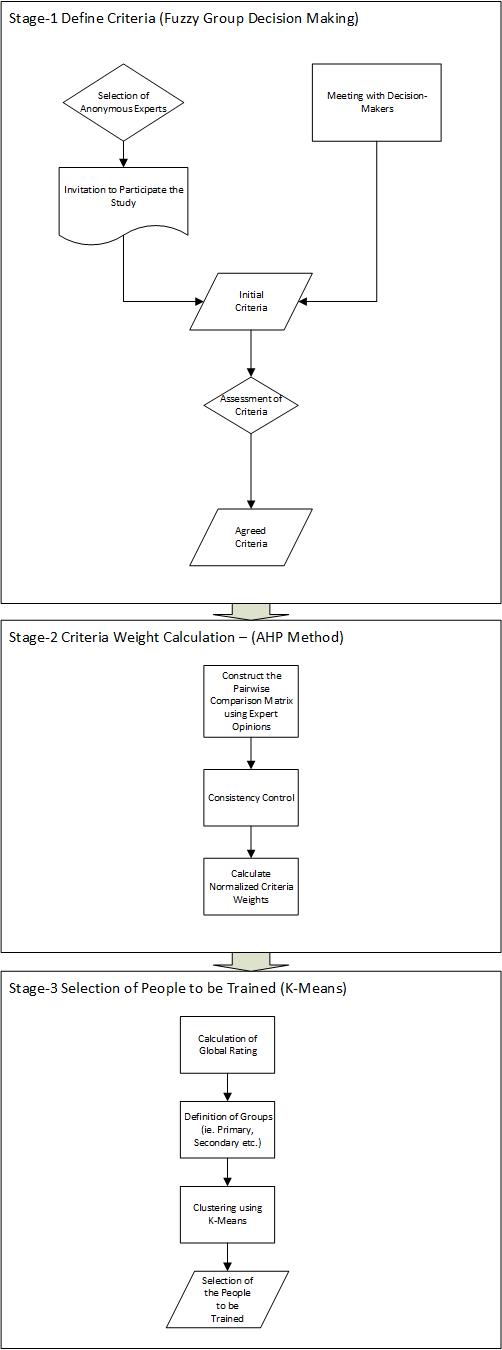


Figure 1 Workflow of the Proposed Methodology

# Numerical Application for a Distribution Company

In this section, the proposed methodology is applied in a real case. The study aims to find an integrated solution for the selection of candidates. The clustering also allows the decision about the number of people to be assigned. Due to the extensive coverage and contribution to the relevant candidates, training is in high demand. As a result, the application of the proposed model is conducted in a real-life case. The details of the application are given in the following sections.

## Decision on Criteria for Training Assignment Assessment

The first phase's goal is to define the criteria that will be used for the assessment of candidates. The goal of the first phase is to define criteria used for the rest of the study. A list of criteria received after an interview with the human resources department. The input of the first phase is the expert opinions.

A pool of 16 people working in human resources, and academics are chosen as decision makers for the first phase. A cover letter showing the reason for the study is shared. Fuzzy group decision making allowed the integration of different experts’ opinion. The participants fulfill the importance of criteria based on a five-scale importance list. The scale is given in Table 1.

Table 1 Number Scale of the first Phase



The criteria used for the Group Decision Making are summarized as follows;

New Process: This criterion covers when there is a new process is implemented. Order-To-Cash (OTC), Purchase-To-Pay (PTP), new financial controls are some examples of such new processes. The degree of the complexity of the processes are correlated with the assessment of the candidate’s grade received from the criterion.

Key Position: Key position reflects a position of a person that is vital for the company's success. The possibility of fulfilling that position may be challenging or highly costly. As a result, a candidate covering a key position is likely to take a training. Increased, motivation would play a beneficial factor for the retention of the employee.

New Regulation: A new regulation may be in place. This regulation may need additional certificates or official training.

Key Employee: The staff shows high performance among other employees. This high performance and potential may increase the value of the employee in a company.

New Equipment: There may be new equipment, and training is mandatory. Necessary training would be essential for effective and safe operation.

New Safety Procedures: Due to an accident or an improvement, new procedures may need to be implemented. Training will be given to relevant staff for proper implementation and execution.

New Assignment: The employee is assigned to a new position. Therefore, receiving formal training is essential to acquire the necessary skills for the new assignment.

Poor Performance in a Specific Skill: The employee needs to improve a specific skill, such as soft skills in terms of communication or time management. Such training may help the employee to overcome the problems encountered or will encounter in the future.

Career Enhancement Plan: The employee is considered to have a potential. As a result, alternative career paths may be investigated. Relevant training may be suitable for the possible career paths. Formal training and appreciation by management also increases the motivation of the employee.

Managerial Competency Assessment: Regular assessments are made in companies. Managers or potential managers may be inferior in some skills. Relevant training is suitable for improvements.

Suitability of the Training Topic: Training has topics. Relevant training may be suitable for some specific employees. This criterion shows the degree of relevancy.

Request from Employee: Employee may ask for the training. In that case, the criteria would have a high ranking. Such request would also increase the efficiency of the training due to the motivation of the employee.

Individual Motivation: The motivation of the employee is vital for the success of the training. The high motivation will likely contribute to the success of the training.

Managerial Request: Request from the manager of the employee may be received. This criterion represents such a request.

New Promotion: The candidate may have been promoted recently. Due to new promotion, some specific skills may be needed to be improved. Training is an effective alternative to improve such skills.

Time to Retirement: Time to retirement may influence the training. Costly training may be unnecessary for an employee when retirement is short due to a lack of motivation and time to work in the future.

The study applied the fuzzy group decision making approach for the first phase. The goal is to have a consensus among participants. Feedbacks received by e-mail are stored in a separate file. Average values are calculated after each round.

The file including relevant participant’s assessment and average values are shared for the second and subsequent rounds. The cover letter also clarified the option to stick to the former decision or revise their initial assessment.

Average values after the first phase are shown in Table 2.

Table 2 Criteria Selection Results after Phase -1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Membership Values** | | |  |  |  |
| **A** | **B** | **C** | **Assigned Cluster** | **Criteria Descripion** | **Criteria No** |
| 0.99 | 0.01 | 0.00 | A | Key Employee | C1 |
| 0.88 | 0.10 | 0.01 | A | Key Position | C2 |
| 0.03 | 0.08 | 0.89 | C | Managerial Request |  |
| 0.00 | 1.00 | 0.00 | B | Managerial Competency Assessment |  |
| 0.75 | 0.22 | 0.03 | A | Poor Performance (Individual in a Specific Area) | C3 |
| 0.90 | 0.08 | 0.02 | A | New Equipment | C4 |
| 0.99 | 0.01 | 0.00 | A | New Process | C5 |
| 0.94 | 0.05 | 0.01 | A | New Regulation | C6 |
| 1.00 | 0.00 | 0.00 | A | New Safety Procedures | C7 |
| 0.05 | 0.28 | 0.67 | C | Individual Motivation |  |
| 0.03 | 0.96 | 0.01 | B | New Assignment |  |
| 0.01 | 0.04 | 0.96 | C | New Promotion |  |
| 0.02 | 0.97 | 0.02 | B | Request from Employee |  |
| 0.07 | 0.91 | 0.02 | B | Suitability of the Trainihg Topic |  |
| 0.56 | 0.40 | 0.04 | B | Career Enhancement Plan |  |
| 0.03 | 0.91 | 0.05 | B | Time to Retirement |  |

The initial number of criteria is 16. Because the criteria with the highest global rating are chosen. Using the outputs of the first phase, 7 criteria are chosen as the outputs of the first phase. 7 is the number of criteria proposed for AHP (Saaty, 1987). The increase in the number of criteria for AHP also causes complexity and possible inconsistency in the AHP Phase.

## Weights Determination of Criteria

The second phase includes the expert’s opinions responsible for the training problem. The experts are responsible for the final decision of the training assignment. Two experts working in the distribution company participated in the second phase. Fuzziness is inherent in decision-making. Vagueness is a part of the decisions. IVN-AHP Method is therefore selected to represent this inherent vagueness. Experts working in the human resources (HR) department fulfilled the Excel file. Excel files allow cross-comparison of 7 criteria. The list of the 7 criteria is given in Table 3. Table 4, represents the feedback received from the expert for the second stage.

Table 3 Criteria Selected After Phase-1

|  |  |
| --- | --- |
| **Criteria Number** | **Criteria** |
| Key Employee | C1 |
| Key Position | C2 |
| Poor Performance (Individual in a Specific Area) | C3 |
| New Equipment | C4 |
| New Process | C5 |
| New Regulation | C6 |
| New Safety Procedures | C7 |

Table 4 Cross-comparison of Criteria by Expert

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Criteria** | **C1** | **C2** | **C3** | **C4** | **C5** | **C6** | **C7** |
| C1 | EI | EI | SI | SI | MIc | EI | EI |
| C2 | EI | EI | VSI | VSI | EI | EI | EI |
| C3 | SIc | VSIc | EI | MI | MIc | MIc | SIc |
| C4 | SIc | VSIc | MIc | EI | EI | MIc | SIc |
| C5 | MI | EI | MI | EI | EI | EI | MIc |
| C6 | EI | EI | MI | MI | EI | EI | MIc |
| C7 | EI | EI | SI | SI | MI | MI | EI |

MATLAB 2021b program is used for the calculation of each weight. Table 5 represents the weights of each criterion according to Buckley's Method (Buckley, 1985).

Table 5 Criteria Weights after Phase-2

|  |  |  |  |
| --- | --- | --- | --- |
| **Criteria** | **Description** | **Priority** | **Rank** |
| C7 | New Safety Procedures | 16.89% | 1 |
| C2 | Key Position | 16.28% | 2 |
| C1 | Key Employee | 15.43% | 3 |
| C5 | New Process | 14.86% | 4 |
| C6 | New Regulation | 14.86% | 5 |
| C3 | Poor Performance (Individual in a Specific Area) | 11.02% | 6 |
| C4 | New Equipment | 10.64% | 7 |

## Candidates Selection

The third and last phase involves the assessment of candidates based on agreed criteria. Each candidate has different values for each criterion. An expert working as a human resources manager shared opinion. 30 candidates are working in the company who are eligible for the costly trainings. Duration of the working period is one of such conditions. The employees nominated for the training work for the company at least 1 year. All of the candidates meet requirements such as foreign language or required experience for the trainings.

Each candidate’s global rating is calculated using the result of the valuation is given in Eq 7. In Eq. 7, OVi represents the global rating of candidate I, Wj represents the weight of criterion j, and Vij represents the value of criterion j for candidate i.

(7)

The decision will be to assign or not to assign to the training. This research used 3 clusters for the assignment. The first cluster is used for the leading candidates, and the second cluster will be used for possible additional trainings or backup. The third cluster represents the candidates not assigned for trainings opportunities. The decision-maker defined the number of groups. The importance of the clusters are given as ABC, according to ABC analysis.

Matlab code is used for clustering. Relevant theoretical information is given in Section 3.3. A computer with 16GB RAM running on Windows 10 with i5 Gen 10 CPU is used for calculations. All calculations are performed using Matlab 2021b code. Table 6 and figure 2 represent the outputs of K-Means As seen from the table, the number of candidates assigned to each cluster are different.

Table Training Candidate Assignments

|  |  |
| --- | --- |
| **Classes** | **Number of Candidates** |
| A | 4 |
| B | 11 |
| C | 5 |
| Total | 20 |

Figure Training Assignment Groups

# Discussion

The study aims to provide a solution to an existing problem faced in a business company. The use of modern decision-making approaches embedded with the novel fuzzy approach provides beneficial results. The proposed approach converted expert opinions in separate areas namely criteria selection, weight assessment and candidate analysis data to quantitative values. The proposed approach as can be seen in the relevant outcomes provides solutions that can be used for the existing problem and possible future problems. Due to the nature of the problem, the study has limitation. The main limitation is the set of candidates. The goal of the study is to solve an existing problem of a distribution company using a novel MCDM method. As a result, the number of candidates is limited with the existing problem. Based on the feedback received, the proposed method can be applied to similar cases by changing criteria or candidate set such as recruitment, promotion or different areas such as customer classification.

This limitation is valid as a part of comparison phase. Similar concerns are also valid in the assessment of each candidate. Some of the criteria decided are hard to interpret into quantitative values. Namely, “key employee” refers that the candidate performs higher than the other employees. This assessment is based on subjective assessment of the decision makers. Future studies in this field will cover a larger set of data and experts from a variety of fields. The increase in the size of decision makers and a greater pool will be beneficial to overcome these limitations.

# Conclusion

The authors propose a training candidates’ assessment and selection model using integrated Fuzzy Group Decision Making, AHP, and K-Means. The goal of this study is to convert raw input of experts’ opinions to the assignment of candidates for training. Fair and transparent assessment and selection is an essential aspect of the process. The current practice is to receive candidates from separate departments and a random selection of people. The research allows a more effective and fair solution to this problem. Selection is performed on multiple criteria, and the author proposed an alternative selection model to this problem.

The main contributions of the study are;

* Use of group decision. This aspect is important, as the final decision should represent at least the majority and preferably consensus.
* The study is the first application to solve training assignments for candidates. This study aims to develop a model for the decision of the possible number of people to be trained and select among a pool of candidates. The model develops input data of the experts to the output representing the selected candidates.
* Selection of criteria as in the first phase. To the best of our research, the literature lacks the criteria involved for the assignment decision. Our study gathered data and developed a consensus among experts for the criteria selection. These data can be used for further studies.
* A combined model of Fuzzy Group Decision Making- AHP- K-Means first in literature. This combined methodology allows the combined decision of experts and quantitative conversion of decision makers' preference and clustering using a novel technique that will represent the selected people to be trained.

Further studies will also be investigated about implementing the proposed methodology in a decision support system (DSS) for human resources management. Using a broader set of data incorporating surveys may improve the application areas in human resources.

# References

Abdulkareem, K. H. *et al.* (2021) ‘A new standardisation and selection framework for real-time image dehazing algorithms from multi-foggy scenes based on fuzzy Delphi and hybrid multi-criteria decision analysis methods’, *Neural Computing and Applications*, 33(4), pp. 1029–1054. doi: 10.1007/s00521-020-05020-4.

Aydin Keskin, G. and Ozkan, C. (2013) ‘Multiple criteria ABC analysis with FCM clustering’, *Journal of Industrial Engineering*, 2013.

Boran, F. E. *et al.* (2009) ‘A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method’, *Expert Systems with Applications*, 36(8), pp. 11363–11368. doi: 10.1016/j.eswa.2009.03.039.

Buckley, J. J. (1985) ‘Fuzzy hierarchical analysis’, *Fuzzy sets and systems*, 17(3), pp. 233–247.

Büyüközkan, G. and Güleryüz, S. (2016) ‘A new integrated intuitionistic fuzzy group decision making approach for product development partner selection’, *Computers and Industrial Engineering*, 102, pp. 383–395. doi: 10.1016/j.cie.2016.05.038.

Dobre, O.-I. (2013) ‘Employee motivation and organizational performance’, *Review of applied socio-economic research*, 5(1).

Ertuǧrul, I. and Karakaşoǧlu, N. (2009) ‘Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods’, *Expert Systems with Applications*, 36(1), pp. 702–715. doi: 10.1016/j.eswa.2007.10.014.

Hsu, H. M. and Chen, C. T. (1996) ‘Aggregation of fuzzy opinions under group decision making’, *Fuzzy Sets and Systems*, 79(3), pp. 279–285. doi: 10.1016/0165-0114(95)00185-9.

Huang, H. *et al.* (2019) ‘Brain Image Segmentation Based on FCM Clustering Algorithm and Rough Set’, *IEEE Access*, 7, pp. 12386–12396. doi: 10.1109/ACCESS.2019.2893063.

İsen, E. and Boran, S. (2018) ‘A Novel Approach Based on Combining ANFIS, Genetic Algorithm and Fuzzy c-Means Methods for Multiple Criteria Inventory Classification’, *Arabian Journal for Science and Engineering*, 43(6), pp. 3229–3239. doi: 10.1007/s13369-017-2987-z.

Leiva-Fernández, F. *et al.* (2021) ‘Identification of the multimorbidity training needs of primary care professionals: Protocol of a survey’, *Journal of Multimorbidity and Comorbidity*, 11(23), p. 263355652110247. doi: 10.1177/26335565211024791.

Mathew, M., Chakrabortty, R. K. and Ryan, M. J. (2020) ‘A novel approach integrating AHP and TOPSIS under spherical fuzzy sets for advanced manufacturing system selection’, *Engineering Applications of Artificial Intelligence*, 96(September), p. 103988. doi: 10.1016/j.engappai.2020.103988.

Piñol, T. C. *et al.* (2017) ‘Study of the training needs of industrial companies in the Barcelona Area and proposal of Training Courses and Methodologies to enhance further competitiveness.’, *Procedia Manufacturing*, 13, pp. 1426–1431. doi: 10.1016/j.promfg.2017.09.159.

Rouyendegh, B. D. (2014) ‘Developing an integrated ahp and intuitionistic fuzzytopsis methodology’, *Tehnički vjesnik*, 21(6), pp. 1313–1319.

Saaty, R. W. (1987) ‘The analytic hierarchy process-what it is and how it is used’, *Mathematical Modelling*, 9(3–5), pp. 161–176. doi: 10.1016/0270-0255(87)90473-8.

Sinaga, K. P. and Yang, M. (2020) ‘Unsupervised K-Means Clustering Algorithm’, 8. doi: 10.1109/ACCESS.2020.2988796.

Solangi, Y. A., Longsheng, C. and Shah, S. A. A. (2021) ‘Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach’, *Renewable Energy*, 173, pp. 209–222. doi: 10.1016/j.renene.2021.03.141.

Su, Z. X. *et al.* (2011) ‘An interactive method for dynamic intuitionistic fuzzy multi-attribute group decision making’, *Expert Systems with Applications*, 38(12), pp. 15286–15295. doi: 10.1016/j.eswa.2011.06.022.

Tiberius, V. and Hirth, S. (2019) ‘Impacts of digitization on auditing: A Delphi study for Germany’, *Journal of International Accounting, Auditing and Taxation*, 37, p. 100288. doi: 10.1016/j.intaccaudtax.2019.100288.

Veskovic, S. *et al.* (2018) ‘Evaluation of the railway management model by using a new integrated model delphi-swara-mabac’, *Decision Making: Applications in Management and Engineering*, 1(2), pp. 34–50. doi: 10.31181/dmame1802034v.

Wahyuni, D. S. *et al.* (2020) ‘Analysis on vocational high school teacher competency gaps: Implication for VHS teacher training needs’, *Journal of Physics: Conference Series*, 1516(1). doi: 10.1088/1742-6596/1516/1/012051.

Wang, Y. M., Luo, Y. and Hua, Z. (2008) ‘On the extent analysis method for fuzzy AHP and its applications’, *European Journal of Operational Research*, 186(2), pp. 735–747. doi: 10.1016/j.ejor.2007.01.050.

Watson, K. E. *et al.* (2019) ‘Defining pharmacists’ roles in disasters: A Delphi study’, *PLoS ONE*, 14(12), pp. 1–14. doi: 10.1371/journal.pone.0227132.

1. \* Corresponding Author [↑](#footnote-ref-1)