Prioritization of Action Plans for Disaster Management using Hesitant Fuzzy Linguistic SAW-COPRAS Methods

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Abstract

Disaster management is vital, and it faces a variety of problems. It is a form of governance that aims to plan, direct, support, coordinate, and effectively implement the activities that should be done before and after the event to prevent disasters and reduce their damage. Disaster management has a multi-faceted, multi-actor, multi-disciplinary, dynamic, comprehensive, and complex structure. In this context, the study aims to propose an action plan evaluation framework for disaster management and to prioritize these action plans with Hesitant Fuzzy Linguistic (HFL) Simple Additive Weighting (SAW)-ComplexPRoportionalASsessment (COPRAS) methods. Considering the complex and uncertain nature of this multi-criteria decision-making (MCDM) problem, Hesitant Fuzzy Linguistic Terms Sets (HFLTS) is employed. This technique is applied to provide flexibility to experts using comparative linguistic expressions and obtain an evaluation environment closer to human thinking. The integrated HFL SAW-COPRAS methodology is practical, flexible, reliable, robust, adaptable to different fuzzy environments, and maximizing the benefit while minimizing the cost of alternatives. The evaluation factors and action plans are determined based on a literature review and experts' consulting. HFL SAW method is applied to find the weights of evaluation factors, and action plans are prioritized with the HFL COPRAS method. An illustrative application of disaster management is provided to illustrate the effectiveness of the proposed methodology. Finally, the results of this paper showed that the most appropriate factor is“Risk Planning and Control," and the first ranked action plan is "Planning & Organization".

Keywords
Action plan, COPRAS, Disaster management, Hesitant fuzzy linguistic, SAW.

1. Introduction
Disaster management has arisen as a perceptible global subject as disasters, both artificial or natural, might happen anytime, anywhere with tremendous results. By definition, disaster is an environmental, technological, or artificial event that causes physical, social, and financial losses intersects regular life and human activities for the society. Disaster management has four main functions: planning, operation, logistics, financial and administrative affairs. In this paper, we have focused on logistics functions in disaster management.

Logistics, an inseparable part of life, has great importance in effectively sustaining all business activities in different sectors. Logistics is an indispensable activity in disaster management operations, whose primary purpose is to save human life and overcome the crisis process with the least material and moral damage. The uncertainty of disaster logistics and the possibility that the slightest malfunction and error in the process may cost human life reveals the necessity of error-free management of this process (Karatop 2017). Therefore, it is challenging to manage logistics processes in disaster management.

The main objective of disaster management is the provision of search, rescue, medical first aid and treatment, and similar emergency services and needs in case of disasters. A practical action plan is necessary to meet the needs of vulnerable people in time. However, prioritizing action plans for disaster management problems has a multi-faceted, multi-actor, multi-disciplinary, dynamic, comprehensive, and complex structure. Therefore, in this paper, this problem is considered a Multi-Criteria Decision Making (MCDM) problem.

The purpose of the paper is to propose an action plan evaluation framework for disaster management and to prioritize these action plans using Hesitant Fuzzy Linguistic (HFL) Simple Additive Weighting (SAW)-

COmplexPRoportionalASsessment (COPRAS) methods. Hesitant Fuzzy Linguistic Term Sets (HFLTS) technique is preferred to handle the hesitation of experts while they express their thoughts on the MCDM problem. In HFLTS, experts can express themselves by using expressions such as "At least," "Between," "At most," which provides flexibility to them. Therefore, with the utilization of comparative linguistic expressions in the HFLTS technique, an evaluation environment closer to the way of human thinking is obtained (Rodriguez et al. 2012).

The proposed evaluation framework for disaster management is determined grounded on a literature review, industry reports, and discussing the experts. There are four main evaluation factors in our proposed evaluation framework, twenty evaluation factors in total, and five action plans. HFL SAW method is used to find the weights of evaluation factors, and the HFL COPRAS method is used to prioritize the action plans.

The originality of this paper stems from an extension of SAW-COPRAS methods in a hesitant fuzzy environment and integration of these methods for the first time in the disaster management area. The integrated HFL SAW-COPRAS methodology has many advantages (Zavadskas et al. 1994; Chou et al. 2008):

- it is practical, flexible, reliable, robust,
- it is adaptable to different fuzzy environments,
- it maximizes the benefit while minimizing the cost of alternatives.

This integrated approach is then applied to an empirical study for a logistics company in Turkey to illustrate the potential of the proposed methodology. The contributions of this paper are offering a new evaluation framework for action plan prioritization of disaster management, presenting an integrated HFL SAW - HFL COPRAS methods in this area, and providing an empirical study about prioritization of disaster logistics action plans.

The organization of this paper is as the following. In the next section, the conceptual background of the subject is presented briefly. Then, the technical background of the study is provided to explain HFLTS, SAW and COPRAS approaches. The fourth section shows the proposed methodology, and the empirical study is provided in the fifth section. Finally, the last section concludes the paper.

2. Conceptual Background for Disaster Management

Disaster management is developing as a promising area of interest for researchers and practitioners (Mishra et al. 2019). Unfortunately, many countries globally, including Turkey, face the reality of the disaster. Every country has a wealth of knowledge stemming from their experiences. Collaboration and dialogue, which includes sharing information about the lessons learned from the events experienced, gain importance in reducing the disaster risk. Local and regional authorities and other relevant experts should take an active role in sharing experiences. For this reason, administrators, institutions, non-governmental organizations, and universities have duties to prevent natural events from turning into disasters (Karatop 2017).

To understand the importance of disaster management is necessary to examine the disaster logistics processes, which consist of 3 stages: pre-disaster, during the disaster, and post-disaster. Before the disaster, planning should be made to ensure that one or more of these activities are in the proper place at the exact time. During a disaster, any malfunction or inaccuracy in logistics operations negatively affects the success of emergency management. After the disaster, it is crucial to shorten the return to everyday life and heal the wounds. In disaster management literature, the majority of the papers have studied the relief phase, that is followed by the preparation phase, and just a few papers studied the recovery phase (Mishra et al. 2019; Manyaga et al. 2020).

In disaster management literature, a variety of MCDM techniques are employed. Merad et al. (2004) used the ELECTRE-TRI method for mining induced hazards, while Opricovic and Tzeng (2003) employed a fuzzy multi-criteria model for earthquakes. AHP, VIKOR, ANP, ELECTRE, TOPSIS, and TODIM are the most frequently used MCDM techniques (Opricovic and Tzeng 2003; Merad et al. 2004; Jun et al. 2013; Khosraviet al. 2014; Manyaga et al. 2020). Jena et al. (2020) recently integrated AHP-VIKOR methods for flood disasters. It is important to emphasize that the publications are focused on the regions where disasters are frequent such as Indonesia, Thailand, China, Brazil, India, Turkey, Iran, Columbia, USA, Netherlands, South Korea, Australia, and China (Manyaga et al. 2020).

Disaster management emergency scenarios are intensely affected by uncertainty. Generally, the relief demand assets and the equipment situations delivered by public and private actors pose uncertainty. Integration, optimization, and coordination are very crucial to provide mutual profit and creating value for each actor (Cao and He 2020). In the related literature, optimization and simulation approaches are addressed for disaster management (Mishra et al. 2019; Cao and He 2020; Liu et al. 2020). Precisely, the system dynamics approach, Monte Carlo simulation, agent-based simulation, discrete event simulation models are preferred for resolving problems about disaster management (Mishra et al. 2019). A hesitant fuzzy environment is also preferred for overcoming the uncertainty in a few papers. Ding et al. (2021) used the interval-valued hesitant fuzzy TODIM method to solve the dynamic emergency decision-making problem. Liu et al. (2018) used the hesitant fuzzy technique with unknown weight information for emergency decision-making. Zhang et al. (2020) used continuous hesitant fuzzy information for evaluating water resources emergency management plans.

The proposed HFL SAW-COPRAS methodology has the merits that separate itself from other publications. Primarily, the experts' judgments are based on HFLTS, and they are aggregated by using the fuzzy envelope technique proposed by Liu and Rodriguez (2014). Secondly, to the best of our knowledge, this paper is the first paper that integrates HFL SAW-COPRAS methods for the disaster management area.

3. Technical Background

This section provides the technical background with preliminaries of HFLTS. In addition, SAW-COPRAS methods are explained in detail.

3.1 Hesitant Fuzzy Linguistic Approach

Uncertain environments often make complex the decision-making challenges faced in the real world. In this context, linguistic information might help manage the uncertainty. Hesitant fuzzy sets were presented in 2010 by Torra. HFLTS was proposed by Rodriguez et al. (2012). HFLTS indicates a technique proposing linguistic expressions through a set. It is a strong and helpful technique to overcome uncertainty and hesitancy. It provides flexibility with linguistic expressions e.g. "at most (atm)", "at least (atl)", "between (bet), "greater than (grt), "lower than (lwt)". It ensures experts express their thoughts simply with words instead of numbers. Therefore, MCDM based on HFLTS gives a more realistic result.

To transform comparative linguistic term sets into HFLTS, E_{GH}function is utilized.

The superior bound $H_{s+}$and inferior bound H_{s-} are defined as (Torra 2010; Rodriguez et al. 2012):

$$H_{s+} = max(s_i) = s_j\ ,\ si \in H_S\ et\ s_i \leq s_j\ \forall_i \quad (1)$$

$$H_{s-} = min(s_i) = s_j\ ,\ s_i \in H_S\ et\ s_i \leq s_j\ \forall_i \quad (2)$$

The envelope for HFLTS, $env(H_S)$, is a linguistic interval with the superior bound, and the inferior bound is presented by Liu and Rodriguez (2014):

$$env(H_S) = [H_s^-, H_s^+],\ H_s^- \leq H_s^+ \quad (3)$$

3.2 Hesitant Fuzzy Linguistic SAW-COPRAS Methods

The SAW method was proposed by Hwang and Yoon (1981).It is a well-known, practical technique in the literature. Fuzzy SAW is proposed for facility location selection by Chou and his colleagues (2008). Thus, it is possible to extend this method under the HFL environment.

In SAW literature, there are many different application areas such as facility location, technology, logistics, transportation, agriculture (Chou et al. 2008; Zolfaniet al. 2012; Orojlooet al. 2018;Büyüközkan and Güler 2020). The HFL extension of the SAW method is used for the first time in the literature in the smartwatch evaluation, and it is integrated with the HFL ARAS method (Büyüközkan and Güler 2020). In this paper, the HFL SAW method is applied to calculate the factors' weights, combined with HFL COPRAS.

The COPRAS (Zavadskas et al. 1994) is a method of evaluating alternatives according to the importance and utility ratings. It allows the evaluation of both qualitative and quantitative criteria. It can be used for maximum and also minimum criterion values in MCDM. The COPRAS method's extension in a hesitant fuzzy environment allows decision-makers (DMs) to assess quantitative and qualitative criteria, necessitating limited individual information from DMs. COPRAS has a simple approach, and it needs less calculation time.

In the literature, the HFL COPRAS method is applied for the renewable energy MCDM problem and combined with the HFL AHP method (Büyüközkan et al. 2018). Also, HFL COPRAS is used for the severity of the chronic obstructive pulmonary disease patients' evaluation (Zheng et al. 2018), personnel selection (Yalçin and Pehlivan 2019), sustainable supplier selection (Rani et al. 2020). This study applies the HFL COPRAS method to prioritize the action plans.

4. Proposed Methodology

The proposed methodology is given in this section, including the proposed evaluation factors and action plans and proposed HFL SAW-COPRAS methods.

4.1 Proposed Evaluation Factors and Action Plans

This study defines evaluation factors by conducting a literature review, investigating industrial reports, and taking the experts' views. The determined evaluation factors are as in Table 1 (Karatop 2017; Mishra et al. 2019; Ferreira et al. 2019; Cao and He 2020; Shang et al. 2020).

Table 1. Evaluation factors

Main Factors	**Sub-Factors**
F1. Information & Communication Management	F11. Communication and Information Systems
	F12. Telecommunication Capacity
	F13. Early Warning and Surveillance
	F14. Monitoring and Reporting
	F15. Effective Use of Social Media
F2. Resource Management	F21. Essential Medicines, Supplies, and Medical Devices
	F22. Logistics and Emergency Delivery Systems
	F23. Local Workforce Capacities
	F24. Food, Water, Shelter, and Sanitation
	F25. Relief Logistics Agreements of Organizations
F3. Social & Cultural Management	F31. Transparency
	F32. Experience with Disasters
	F33. Recovery Planning and Coordination
	F34. Role of Civil Societies
	F35. Transportation Restrictions
F4. Risk Management	F41. Risk Planning and Control
	F42. Public Safety
	F43. Crisis Management
	F44. Contingency Plan
	F45. Capacity for Risk Management Efforts

Action plans to be prioritized for disaster management are as follows (Ferreira et al., 2019; Shang et al., 2020):

Action Plan1-Planning & Organization: In efficient disaster management, planning, employment, and organization of activities are essential to confirm that products, materials, and relevant information are ensured for vulnerable people.

Action Plan2-Coordination & Integration: In disaster management, coordination can be challenging. Various stakeholders such as public actors, private actors, and associations should be integrated and coordinated.

Action Plan3-Mobility: The type of transport to the affected areas must be defined in case of a disaster. Corporations expected to entry to the warehouses should be contracted.

Action Plan4-Security & Privacy: Preparing different emergency scenarios and practicing these scenarios are essential to prevent the security problem in panic in case of a disaster.

Action Plan5-Communication & Network Strategy: In disaster management, information and communication technologies provide interaction between all stakeholders in the disaster network.

4.2 Proposed HFL SAW-COPRAS Methods

The following are the HFL SAW steps:

Step 1. Experts evaluate the factors by using linguistic terms. The linguistics scale used in this study is provided in Table 2.

Table 2. Linguistic scale for HFL SAW and HFL COPRAS (Beg and Rashid, 2013)

Linguistic term	**Fuzzy Numbers**
None (N)	(0,0,0.17)
Low (L)	(0.17,0.33,0.5)
Very Low (VL)	(0,0.17,0.33)
Medium (M)	(0.33,0.5,0.67)
High (H)	(0.5,0.67,0.83)
Very High (VH)	(0.67,0.83,1)
Perfect (P)	(0.83,1,1)

Step 2. The envelope for HFLTS, *env(HS),* is developed as given in (3) since its practicality and usability (Liu and Rodriguez, 2014) to obtain fuzzy numbers from HFLTS.

Step 3. The DM weights are not equal, reflecting the relevance levels of each DM. The importance degrees of DMs (I_t) are computed where the fuzzy weights of the DMs are symbolized by the $\widetilde{\omega_t}$:

$$I_t = \frac{d(\widetilde{w_t})}{\sum_{t=1}^{k} d(\widetilde{w_t})}, t = 1,2, \dots, k \tag{4}$$

In this case, $d(\widetilde{w_t})$ signifies the defuzzified value of fuzzy weights.
Step 4. The fuzzy weights of $C_j$which symbolized by$\widetilde{W_j} = (a_j, b_j, c_j, d_j)$, are aggregated as:

$$\widetilde{W_j} = (I_1 \otimes \widetilde{W_{j1}}) \oplus (I_2 \otimes \widetilde{W_{j2}}) \oplus \dots \oplus (I_k \otimes \widetilde{W_{k1}}) \tag{5}$$

where $a_j = \sum_{t=1}^{k} I_t a_{jt}$, $b_j = \sum_{t=1}^{k} I_t b_{jt}$, $c_j = \sum_{t=1}^{k} I_t c_{jt}$, $d_j = \sum_{t=1}^{k} I_t d_{jt}$.

Step 5. The fuzzy weights' defuzzification is realized where the weight is symbolized by $\widetilde{W_j}$, and the defuzzified weight is symbolized by $d(\widetilde{W_j})$as:

$$d(\widetilde{W_j}) = \frac{1}{4}(a_j + b_j + c_j + d_j), where\ j = 1,2,\dots,n \tag{6}$$

Step 6. The normalization is realized to obtain the normalized weights (W_j) as:

$$W_j = \frac{d(\widetilde{w_j})}{\sum_{j=1}^{n} d(\widetilde{w_j})}, j = 1,2,\dots,n \tag{7}$$

where $\sum_{j=1}^{n} W_j = 1$.

The weight vector W=($W_1, W_2, \dots, W_n$) is obtained.

The steps of HFL COPRAS are explained next:

Step 1. Experts evaluate the alternatives by using linguistic terms given in Table 2. Then, the envelope for HFLTS, *env(H_S),* is developed as provided in (3) (Liu and Rodriguez 2014). The defuzzification of decision matrices are realized with the center of area method, where the crisp value x_{ij} can be calculated as:

$$x_{ij} = \frac{[(U_{x_{ij}} - L_{x_{ij}}) + (M_{x_{ij}} - L_{x_{ij}})]}{3} + L_{x_{ij}} \tag{8}$$

Step 2. The normalization of decision matrix is realized by calculating each element of the matrix as:

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{9}$$

Step 3. The weighted normalized decision matrix is obtained by calculating each element of the matrix as:

$$d_{ij} = x_{ij}^{*}.w_j \tag{10}$$

Step 4.S_i^- and S_i^+ of weighted standardized values are computed as:

$$S_{i^+} = \sum_{j=1}^{k} d_{ij} \tag{11}$$
$$S_{i^-} = \sum_{j=k+1}^{n} d_{ij} \tag{12}$$

Step 5. Each alternative's relative importance values (Q_i) are computed as:

$$Q_i = S_{i^+} + \frac{\sum_{i=1}^{m} S_{i^-}}{S_{i^-*} \sum_{i=1}^{m} \frac{1}{S_{i^-}}} \tag{13}$$

The alternative with the highest relative importance value indicates the best alternative.

Step 6.Q_{max} value is calculated.

Step 7. Each alternative's performance index (P_i) is calculated as:

$$P_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \tag{14}$$

5. Empirical Study

The proposed methodology is demonstrated with an empirical study to verify its effectiveness. There is a company that wants to determine the most appropriate action plan for disaster management.

In this study, the opinions and knowledge of experienced experts in the field of disaster management were used. The company must decide on the most appropriate action plan regarding the four main criteria and twenty sub-criteria given in Table 1. There are five possible action plans: Planning & Organization (ACT1), Coordination & Integration (ACT2), Mobility (ACT3), Security & Privacy (ACT4), Communication & Network (ACT5).

5.1 Factors' Weight Calculation with HFL SAW Method

Firstly, DMs evaluated evaluation factors using comparative linguistic expressions (e.g., between, at least, at most) and the scale provided in Table 2. These evaluations are illustrated in Table 3.

Table 3. DMs' evaluations

Sub-Factors	**DM1**	**DM2**	**DM3**
F11	atl VH	bet VH and P	bet VH and P
F12	bet M and H	atl VH	atl VH
F13	bet H and VH	bet M and H	atl P
F14	atl P	bet M and H	bet L and M
F15	bet VH and P	bet VH and P	bet VH and P
F21	bet H and VH	atl VH	bet H and VH
F22	bet VH and P	bet M and H	bet VH and P
F23	bet M and H	atl P	bet H and VH
F24	atl VH	bet H and VH	bet M and H
F25	bet M and H	bet L and M	atl VH
F31	bet VH and P	bet N and VL	bet VL and L
F32	bet M and H	bet M and H	bet M and H
F33	atl VH	bet M and H	bet H and VH
F34	bet L and M	bet H and VH	bet VH and P
F35	bet M and H	bet N and VL	bet L and M
F41	atl P	atl P	bet H and VH
F42	bet VH and P	bet H and VH	atl P
F43	bet H and VH	bet H and VH	atl VH
F44	bet VH and P	bet L and M	bet VH and P
F45	atl VH	bet M and H	bet M and H

The linguistic expressions in Table 3 are converted to HFLTS using the EGH function. Then, the aggregated fuzzy numbers are computed using (5), and the defuzzified values are obtained (6). Then, they are normalized by using (7), and the final weights of the factors are achieved as provided in Table 4.

Table 4. Weights of the evaluation factors

Sub Factors	**Defuzzified Weights**	**Normalized Weights**	**Ranking**
F11	0.833	0.056	3
F12	0.778	0.052	9
F13	0.814	0.055	7
F14	0.703	0.047	16
F15	0.833	0.056	3
F21	0.833	0.056	3
F22	0.778	0.052	9
F23	0.814	0.055	7
F24	0.778	0.052	9
F25	0.667	0.045	17
F31	0.444	0.030	19
F32	0.667	0.045	17
F33	0.778	0.052	9
F34	0.722	0.048	13
F35	0.444	0.030	19

F41	0.907	0.061	1
F42	0.870	0.058	2
F43	0.833	0.056	3
F44	0.722	0.048	13
F45	0.722	0.048	15

The results show that the most appropriate factor is "F41.Risk Planning and Control," and the second factor is "F42. Public Safety". In the third place, there are four factors such as "F43. Crisis Management", "F11. Communication and Information Systems", "F15. Effective Use of Social Media", "F21. Essential Medicines, Supplies, and Medical Devices".

5.2 Action Plans' Prioritization with HFL COPRAS Method

DMs assess the action plans by using the scale presented in Table 2. The evaluation matrix between factors and action plans is constructed as in Table 5.

Table 5. Evaluation matrix

	F11	**F12**	**F13**	**F14**	**F15**	**F21**	**F22**	**F23**	**F24**	**F25**
ACT1	bet VL and L	lwt M	lwt M	atl H	lwt M	atl H	atl H	bet M and VH	bet M and VH	bet L and M
ACT2	lwt M	atm L	lwt M	bet M and VH	bet L and M	bet M and VH	grt M	atl H	bet M and VH	bet M and VH
ACT3	bet M and VH	bet VL and L	bet L and M	lwt M	bet M and VH	lwt M	atl H	bet VL and L	bet M and VH	bet VL and L
ACT4	atl H	lwt M	atl H	lwt M	atl H	lwt M	bet VL and L	atm L	atm L	bet VL and L
ACT5	grt M	grt M	grt M	bet M and VH	grt M	At most L	bet VL and L	bet VL and L	atm L	bet L and M
	F31	**F32**	**F33**	**F34**	**F35**	**F41**	**F42**	**F43**	**F44**	**F45**
ACT1	lwt M	atl H	grt M	atl H	bet L and M	atl H	bet L and M	atl H	atl H	bet M and VH
ACT2	lwt M	atl H	atl H	atl H	bet L and M	bet M and VH	bet L and M	bet L and M	bet M and VH	bet M and VH
ACT3	bet L and M	lwt M	lwt M	bet L and M	bet M and VH	lwt M	lwt M	bet L and M	bet M and VH	lwt M
ACT4	atl H	lwt M	bet L and M	bet VL and L	lwt M	lwt M	grt M	lwt M	bet L and M	lwt M
ACT5	atl H	atl H	atl H	atl H	bet L and M	bet VL and L	lwt M	bet M and VH	atl H	lwt M

The linguistic expressions in Table 5 are converted to HFLTS by using the E_{GH} function. Then, these fuzzy numbers are defuzzified by using (8). The normalized matrix is obtained by using (9), and the weighted normalized matrix is obtained by using (10). The values of Q_i, S_{i+}, S_{i-}, P_i is calculated using (11)-(14). Finally, the ranking of alternatives is active, provided in Table 6.

Table 6. Final results

Action Plans	S_{i-}	S_{i+}	Q_i	P_i	Ranking
ACT1	0.200	4.608	4.799	100.000	**1**
ACT2	0.200	4.371	4.562	95.062	**2**
ACT3	0.267	3.045	3.188	66.436	**5**
ACT4	0.133	2.972	3.257	67.879	**4**
ACT5	0.200	4.004	4.194	87.402	**3**

According to the result in Table 6, the most appropriate action plan is "Planning & Organization (ACT1)". The second, third, fourth, and fifth action plans are ranked as ACT2, ACT5, ACT4, and ACT3, respectively.

6. Conclusion

This paper aimed to propose an action plan evaluation framework for disaster management and prioritize these action plans using an integrated HFL MCDM approach. The weights of the factors were obtained with the HFL SAW method, and the HFL COPRAS method was used to prioritize action plans.

An empirical study was shown to illustrate the methodology's efficacy, and the outcomes of this examination were presented. The most appropriate factor was found as "F41. Risk Planning and Control," and the first ranked action plan was determined as "ACT1. Planning & Organization". As mentioned in paper (Adiguzel, 2019), all management activities, including planning, organizing, coordinating, communicating, ordering, supervising/evaluation, and so on, are critical in disaster management.

For future investigation, different aggregation operators can be used to aggregate DMs' evaluations in group decision-making. On the other hand, other extensions (e.g. elicit information,pythagorean fuzzy sets, spherical fuzzy sets) of fuzzy sets may be implemented into the framework.

Acknowledgements

The authors would like to express their gratitude towards industry specialists. Galatasaray University's Scientific Research Projects Commission provided support for this work (FOA-2021-1059).

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