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A Signed Distance for (γ, δ) Interval-Valued Fuzzy Numbers to Solve Multi Objective Assignment Problems with Fuzzy Parameters

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Abstract

In this paper, a multi-objective assignment problem with fuzzy parameters (FMOASP) is introduced. These fuzzy parameters are characterized by an (γ, δ) interval-valued fuzzy numbers instead of fuzzy numbers. The signed distance ranking of (γ, δ) interval- valued fuzzy numbers of the parameters are not random but bear well-defined relationship to one another. A new approach namely, optimal flowing method is proposed to obtain the ideal and the set of all fuzzy efficient solutions for the problem. A numerical example is given to demonstrate the computational efficiency of the proposed approach.

Keywords: Multiobjective assignment problem, (γ, δ) interval-valued fuzzy numbers, Signed distance ranking, Optimal fuzzy assignment, Optimal flowing approach.

1 | Introduction

Assignment Problem (ASP) [6] is a problem to find an optimal assignment in which" n " jobs are allocated to " n" workers and each worker accepts exactly one job so that the total assignment cost must be minimum. Many authors have introduced approaches for solving the ASP problem (for instance, [11], [14]-[17], [19]).

In many scientific areas, such as system analysis and operators research, a model has to be setup-using data, which is only approximately known. Fuzzy sets theory, introduced by Zadeh [20] makes this possible. Fuzzy numerical data can be represented by means of fuzzy subsets of the real line, known as fuzzy numbers. Dubois [4] extended the use of algebraic operations on real numbers to fuzzy numbers by use of a fuzzification principle. In spite of having a vast decision making experience, the decision maker cannot always articulate the goals precisely. Decision-making in a fuzzy environment, developed by Bellman and Zadeh [2] improved and a great help in the management decision problems.

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Zimmermann [21] proposed the fuzzy set theory and its applications. Neuromas approaches have applied for solving MOASP in uncertainty environment (see, [5], [7], [9], [12], [13], [18]). Bao et al. [1] solved MOASP problem by converting it into a single objective ASP based on the $0-1$ programming method. Jayalakshmi and Sujatha [10] solved the MOASP using the optimal flowing method obtaining the set of all efficient solutions of the problem.

In this paper, a new approach for solving an (γ,δ) interval- valued fuzzy multiobjective assignment problem is proposed. This approach is based on the Hungarian method. The advantages of this approach is easy for applying and solving, and it helps the decision maker who are handling the MOASP in the real life situation.

The rest of the paper is outlined as follows:

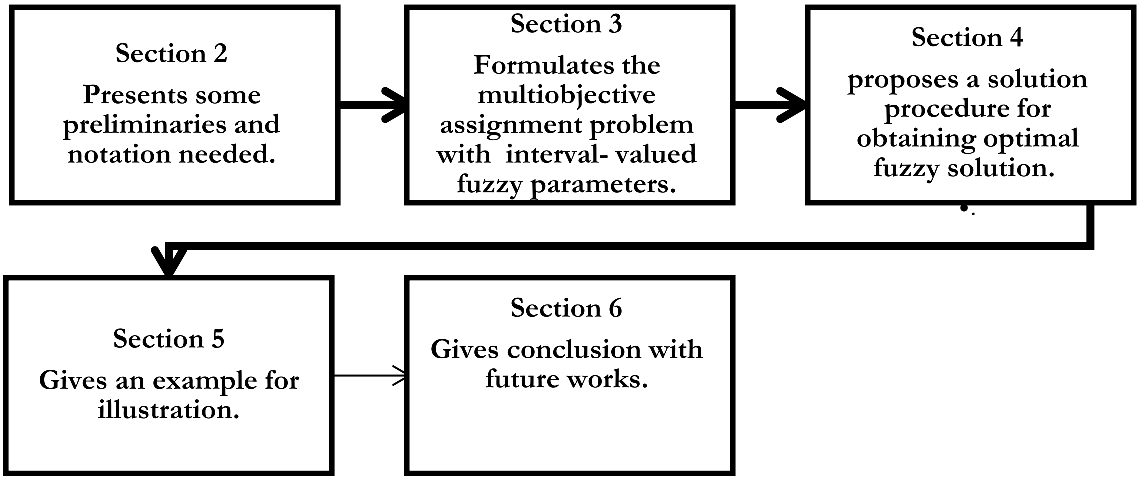

Fig. 1. Layout of remaining paper.

In order to discuss our problem conveniently, basic concepts and results related to fuzzy number,(α,β) interval- valued fuzzy number and its arithmetic operations are recalled.

Definition 1 ([20]). A fuzzy set $\tilde{A}$ defined on the set of real numbers $\mathbb{R}$ is said to be fuzzy numbers if its membership function

$\mu_{\tilde{A}}(x)$: $\mathbb{R} \rightarrow [0,1]$, have the following properties:

- *$\mu_{\tilde{A}}(x)$ is an upper semi- continuous membership function.*
- *$\tilde{A}$ is convex fuzzy set, i.e., $\mu_{\tilde{A}}(w\,x + (1-w)\,y) \geq min\{\mu_{\tilde{A}}(x), \mu_{\tilde{A}}(y)\}$ for all $x, y \in \Re; 0 \leq w \leq 1$.*
- *$\tilde{A}$ is normal, i.e., $\exists\ x_0 \in \Re$ for which $\mu_{\tilde{A}}(x_0) = 1$.*
- *$Supp\left(\tilde{A}\right) = \{x \in \Re: \mu_{\tilde{A}}(x) > 0\}$ is the support of $\tilde{A}$, and the closure $cl(Supp(\tilde{A}))$ is compact set.*

Definition 2 ([8]). If the membership function of the fuzzy set $\tilde{A}$ on $\Re$ is

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{\gamma\,(x-r)}{(s-r)}, & r < x \leq s \\ \dfrac{\gamma\,(t-x)}{(t-s)}, & s \leq x < t \\ 0, & \text{otherwise} \end{cases}$$

where $0 < \gamma \leq 1$ then $\tilde{A}$ is called a level α fuzzy number and it is denoted as $\tilde{A} = (r, s, t; \gamma)$.

Definition 3 ([8]). An interval- valued fuzzy set $\tilde{A}$ on $\Re$ is given by:

$\tilde{A} \triangleq \{(x, [\mu_{A^-}(x), \mu_{A^+}(x)]): x \in \Re\}$, where $\mu_{\tilde{A}^-}(x), \mu_{\tilde{A}^+}(x) \in [0, 1]$, and $\mu_{\tilde{A}^-}(x) \leq \mu_{\tilde{A}^+}(x);$ *for all* $x \in \Re$ and is denoted as $\tilde{A} = [\tilde{A}^-, \tilde{A}^+]$. Let

$$\mu_{\tilde{A}^-}(x) = \begin{cases} \frac{\gamma\,(x-r)}{(s-r)}, & r < x \leq s \\ \frac{\gamma\,(t-x)}{(t-s)}, & s \leq x < t \\ 0, \text{otherwise} \end{cases} \qquad \mu_{\tilde{A}^+}(x) = \begin{cases} \frac{\delta\,(x-a)}{(s-a)}, & a < x \leq s \\ \frac{\delta\,(b-x)}{(b-s)}, & s \leq x < c \\ 0, \text{otherwise} \end{cases}$$

Then $\tilde{A}^- = (r, s, t; \gamma)$, and $\tilde{A}^+ = (a, s, b;\ \delta)$.

It is clear that $0 < \gamma \leq \delta \leq 1$, and $a < r < s < t < b$. Then the (γ, δ) interval-valued fuzzy set is defined as:

$\tilde{A} \triangleq \{(x, [\mu_{A^-}(x), \mu_{A^+}(x)]): x \in \Re\}$, is denoted as $\tilde{A} = [(r, s, t; \gamma), (a, s, b; \delta)] = [\tilde{A}^-, \tilde{A}^+]$.

$\tilde{A}$ is called a level (γ, δ) interval-valued fuzzy number as shown in the following *Fig.1* ([8]).

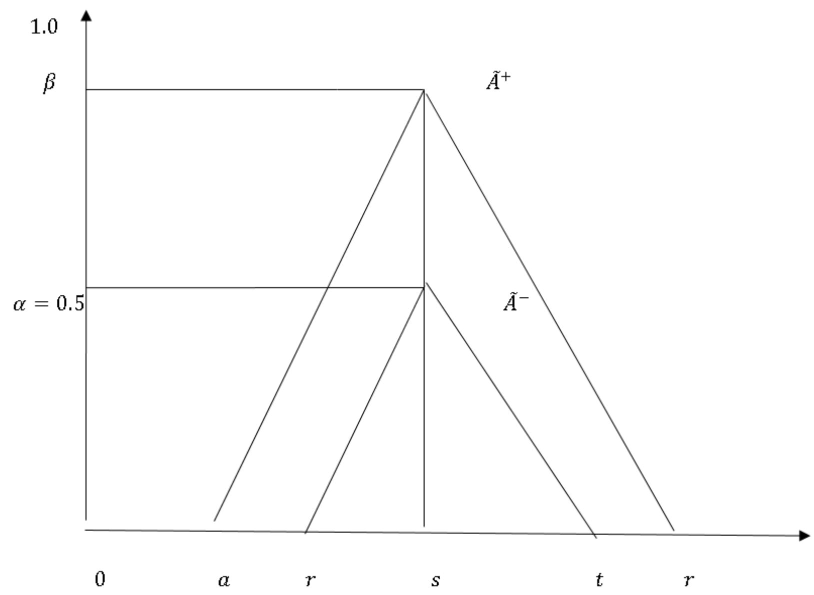

Fig. 2. Level (γ, δ) interval- valued fuzzy number.

Property 1 ([8]). Let, $F_{IVF}(\gamma, \delta) = \{[(r, s, t; \gamma), (a, s, b;\ \delta)]: \textit{for all}\ \ a < r < s < t < b\}, 0 < \gamma \leq \delta \leq 1$ be the family of $(\boldsymbol{\gamma}, \boldsymbol{\delta})$ interval- valued fuzzy numbers.

Let, $\widetilde{P} = [(r, s, t; \alpha), (a, s, b; \gamma)] \in F_{IVF}(\gamma, \delta)$, and $\widetilde{Q} = [(r_1, s_1, t_1; \gamma), (a_1, s_1, b_1; \delta)] \in F_{IVF}(\gamma, \delta)$. Then:

- $\tilde{P}(+)\widetilde{Q} = [(r + r_1, s + s_1, t + t_1; \gamma), (a + a_1, s + s_1, b + b; \delta)]$.
- $\tilde{P}(-)\widetilde{Q} = [(r - t_1, s - s_1, t - r_1; \gamma), (a - b_1, s - s_1, b - a_1; \delta)]$.
- $k.\tilde{P} = \begin{cases} [(kr, ks, kt; \gamma), (ka, ks, k\,b; \delta)], & k > 0, \\ [(kt, ks, kr; \gamma), (kb, ks, k\,a; \delta)], & k < 0, \\ [(0,0,0; \gamma), (0,0,0\,; \delta)], & k = 0. \end{cases}$

Definition 4 ([8]). Let $\widetilde{P} = [(r, s, t; \gamma), (a, s, b; \delta)] \in F_{IVF}(\gamma, \delta), 0 < \gamma \leq \delta \leq 1$. The signed distance ranking of $\tilde{P}$ from $\tilde{0}$ is given as

$$d_0(\widetilde{P}, \tilde{0}) = \frac{1}{8}\left[6s + r + t + 4a + 4b + 3(2s - a - b)\frac{\gamma}{\delta}\right].$$

Remark 1. $\widetilde{P} = [(a,a,a;\gamma),(a,a,a;\delta)]$, then $d_0(\widetilde{P},\widetilde{0}) = 2a$.

Definition 5 ([8]). Let $\widetilde{P},\widetilde{Q} \in F_{IVF}(\gamma,\delta)$, the ranking of level$(\gamma,\delta)$ interval- valued fuzzy numbers in $F_{IVF}(\gamma,\delta)$ using the distance function d_0 is defined as

$$\widetilde{Q} < \widetilde{P} \Longleftrightarrow d_0(\widetilde{Q},\widetilde{0}) < d_0(\widetilde{P},0),$$

$$\widetilde{Q} \approx \widetilde{P} \Longleftrightarrow (\widetilde{Q},\widetilde{0}\ ) = d_0(\widetilde{P},0).$$

Property 2 ([8]). Let $\widetilde{P} = \left[[(r,s,t;\gamma),(a,s,b;\delta)]\right]$ and $\widetilde{Q} = [(r_1,s_1,t_1;\gamma),(a_1,s_1,b_1;\delta)]$ be (γ,δ) interval-valued fuzzy numbers in $F_{IVF}(\alpha,\beta)$. Then

- $d_0(\widetilde{P} \oplus \widetilde{Q},\widetilde{0}) = d_0(\widetilde{P},\widetilde{0}) + d_0(\widetilde{Q},\widetilde{0})$,
- $d_0(k\,\widetilde{P},\widetilde{0}) = k\,d_0(\widetilde{P},\widetilde{0}), k > 0.$

2 | Problem Formulation and Solution Concepts

2.1 | Assumptions, Index and Notation

2.1.1 | Assumptions

Assume that there are n jobs must be performed by and n persons, where the costs depend on the specific assignments. Each job must be assigned to one and only one person and each person has to perform one and only one job.

2.1.2 | Index

i: Persons.

j: Jobs.

2.1.3 | Notation

$\tilde{c}_{ij}^{k}$: (γ,δ) Interval- valued fuzzy numbers of ith person assigned to jth job.

x_{ij}: Number of jth jobs assigned to ith person.

A multiobjective assignment problem with costs represented by (γ,δ) interval- valued fuzzy numbers can be formulated as follows:

$$\text{(FMOASP)}\ \min \tilde{Z}^k(x) = \sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{c}_{ij}^{k}x_{ij},\ k = \overline{1,K}.$$

Subject to

$$\sum_{I=1}^{n} x_{ij} = 1, j = \overline{1,n} \text{ (Only one person would be assigned the jth job).} \quad (1)$$

$$\sum_{j=1}^{n} x_{ij} = 1, i = \overline{1,n} \text{ (Only one job selected by ith person).}$$

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ person is assigned } j^{th} \text{ work} \\ 0, \text{otherwise} \end{cases}$$

Where $\tilde{Z}^k(x) = \{\tilde{Z}^1(x), \tilde{Z}^2(x), \dots, \tilde{Z}^K(x)\}$ is a vector of K objective functions. It is assumed that all the objective functions fuzzy coefficients $\tilde{c}_{ij}^k$ are characterized by (γ, δ) Interval- valued fuzzy numbers (i.e. $\tilde{c}_{ij}^k = \left[\left(c_{ij}^k - \Psi_{3ij}^k, c_{ij}^k, c_{ij}^k + \Psi_{4ij}^k ; \gamma\right), \left(c_{ij}^k - \Psi_{1ij}^k, c_{ij}^k, c_{ij}^k + \Psi_{2ij}^k ; \delta\right)\right], 0 < \Psi_{3ij}^k < \Psi_{1ij}^k < c_{ij}^k, 0 < \Psi_{4ij}^k < \Psi_{2ij}^k, i, j = \overline{1, n}; k = \overline{1, K}. \tilde{1} = [(1,1,1; \gamma), (1,1,1; \delta)]$.

Definition 6. A point $\bar{x} \in X = \{\bar{x}_{ij}: i, j = \overline{1, n}\}$ is said to be fuzzy feasible solution to *FMOASP* (1) if $\bar{x}$ satisfies the constraints in it.

Definition 7 ([3]). A fuzzy feasible point $\bar{x} = \{\bar{x}_{ij}: i, j = \overline{1, n}\}$ is said to be a fuzzy efficient solution to *FMOASP* if there is no $x \in X$ such that $\tilde{Z}^k(x) \leq \tilde{Z}^k(\bar{x})$ for all $k = \overline{1, K}$ with strict inequality holds for at least one k.

Based on the signed distance ranking defined in Definition4, *FMOASP* is converted into the following crisp problem as

$$\text{(MOASP)} \ \min Z^k(x) = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}^k x_{ij}, k = \overline{1, K}.$$

Subject to

$$\sum_{I=1}^{n} x_{ij} = 1, j = \overline{1, n} \text{ (Only one person would be assigned the jth job).} \quad (2)$$

$$\sum_{j=1}^{n} x_{ij} = 1, i = \overline{1, n} \text{ (Only one job selected by ith person).}$$

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ person is assigned } j^{th} \text{ work} \\ 0, \text{otherwise} \end{cases}$$

3 | Solution Method

In this section, a new method for solving *FMOASP* is introduced as in the following steps:

Step 1. Consider *FMOASP*.

Step 2. Convert the *FMOASP* into the crisp *MOASP* based on the signed distance ranking of the (γ, δ) Interval-valued fuzzy numbers.

Step 3. Test whether the *MOASP* is balanced or not. If it balanced go to step 5, otherwise go to step 4.

Step 4. Add dummy row/ column with zero cost in the *MOASP*.

Step 5. Solve *MOASP* individually with respect to the given constraints to find the optimal assignment, say, $X_l^*, l = \overline{1, K}$ with minimum cost Z_l^*.

Step 6. Apply the optimal solution of the problem that is obtained from step 5 in the *MOASP*.

Step 7. Repeat the step 5 for all the problems in *MOASP* that is provides all the efficient solutions of the MOASP.

4 | Numerical Examples

Consider the following *FMOASP* as

$$\text{(FMOASP)} \min \tilde{Z}^k(x) = \sum_{i=1}^{3} \sum_{j=1}^{5} \tilde{c}_{ij}^k x_{ij}, k = 1, 2.$$

Subject to

$$\sum_{I=1}^{3} x_{ij} = 1, j = \overline{1,3}$$

$$\sum_{j=1}^{3} x_{ij} = 1, i = 1, 2, 3 \quad (3)$$

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ person is assigned } j^{th} \text{ work} \\ 0, \text{otherwise} \end{cases}$$

where the values of $\tilde{c}_{ij}^1$ for $i = 1, 2, 3,$ and $, j = \overline{1,3}$.

$\tilde{c}_{11}^1 = [(7,6,9; 0.6), (3,6,11; 0.9)], \tilde{c}_{12}^1 = [(2,3,4; 0.6), (1,3,13; 09)],$

$\tilde{c}_{13}^1 = [(6,7,8; 0.6), (5,7,17; 09)], \tilde{c}_{21}^1 = [(7,10,11; 0.6), (1,10,12; 09)],$

$\tilde{c}_{22}^1 = [(2,11,12; 0.6), (1,11,13; 09)], \tilde{c}_{23}^1 = [(2,4,8; 0.6), (1,4,10; 09)],$

$\tilde{c}_{31}^1 = [(3,7,13; 0.6), (2,7,15; 09)], \tilde{c}_{32}^1 = [(5,13,15; 0.6), (3,13,18; 09)],$

$\tilde{c}_{33}^1 = [(3,4,7; 0.6), (2,4,9; 09)], \tilde{c}_{11}^2 = [(4,6,8; 0.6), (2,6,14; 09)],$

$\tilde{c}_{12}^2 = [(3,7,13; 0.6), (2,7,15; 09)], \tilde{c}_{13}^2 = [(2,3,4; 0.6), (1,3,13; 09)],$

$\tilde{c}_{21}^2 = [(3,5,7; 0.6), (2,5,8; 09)], \tilde{c}_{22}^2 = [(9,10,11; 0.6), (8,10,12; 09)],$

$\tilde{c}_{23}^2 = [(4,5,8; 0.6), (3,5,14; 09)], \tilde{c}_{31}^2 = [(3,7,13; 0.6), (2,7,15; 09)],$

$\tilde{c}_{32}^2 = [(3,5,7; 0.6), (2,5,8; 09)], \tilde{c}_{33}^2 = [(5,6,7; 0.6), (3,6,9; 09)].$

The crisp model for problem *Eq. (3)* is

$$\min Z^1(x) = 13x_{11} + 8x_{12} + 16x_{13} + 18x_{21} + 19x_{22} + 9x_{23} + 15x_{31} + 24x_{32} + 9x_{33},$$

$$\min Z^2(x) = 13x_{11} + 15x_{12} + 8x_{13} + 10x_{21} + 20x_{22} + 12x_{23} + 15x_{31} + 10x_{32} + \quad +12x_{33},$$

Subject to

$$\sum_{I=1}^{3} x_{ij} = 1, j = \overline{1,3}$$

$$\sum_{j=1}^{3} x_{ij} = 1, i = 1, 2, 3 \quad (4)$$

$$x_{ij} = \begin{cases} 1, \text{if } i^{th} \text{ person is assigned } j^{th} \text{ work} \\ 0, \text{otherwise} \end{cases}$$

Solve the$Z^1(x)$ and $Z^2(x)$ individually with respect to the constraints in *Eq. (4)* to obtain the optimal assignment as:

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Global optimal solution found.

Objective value: 9.000000.

Variable	Value	Reduced Cost
X11	0.000000	13.00000
X12	0.000000	0.000000
X13	0.000000	7.000000
X21	0.000000	9.000000
X22	0.000000	19.00000
X23	1.000000	0.000000
X31	0.000000	6.000000
X32	0.000000	16.00000
X33	0.000000	9.000000

$min\, Z^2(x) = 8.000000.$

Global optimal solution found.

Objective value: 8.000000.

Variable	Value	Reduced Cost
X11	0.000000	13.00000
X12	0.000000	5.000000
X13	1.000000	0.000000
X21	0.000000	2.000000
X22	0.000000	20.00000
X23	0.000000	4.000000
X31	0.000000	7.000000
X32	0.000000	0.000000
X33	0.000000	12.00000

$X_1^* = (0,0,0,0,0,1,0,0,0)$ with $Z^{1^*} = 9$, and $\tilde{Z}^{1^*} = [(2,4,8;0.6),(1,4,10;09)]$, and

$X_2^* = (0,0,1,0,0,0,0,0,0)$ with $Z^{2^*} = 8$, and $\tilde{Z}^{2^*} = [(2,3,4;0.6),(1,3,13;09)]$.

Using the optimal assignment of$Z^1(x)$ with given constraints in problem $Z^2(x)$ with the same constraints, its efficient solution is

$Z^1, Z^2 = (9,12)$, and $\tilde{Z}^1, \tilde{Z}^2 = ([(2,4,8;0.6),(1,4,10;09)],[(4,5,8;0.6),(3,5,14;09)]\,)$.

Using the optimal assignment of $Z^1(x)$ with given constraints in problem $Z^2(x)$ with the same constraints, its efficient solution is

$Z^1(x), Z^2 = (8,16)$, and $\tilde{Z}^1, \tilde{Z}^2 = ([(2,3,4;0.6),(1,3,13;09)],[(6,7,8;0.6),(5,7,17;09)]\,)$.

Hence, the ideal assignment is $Z^{1^*}, Z^{2^*} = (9,8)$, ideal fuzzy assignment is

$\tilde{Z}^{1^*}, \tilde{Z}^{2^*} = ([(2,4,8;0.6),(1,4,10;09)],[(2,3,4;0.6),(1,3,13;09)]\,)$, the set of all efficient solutions are $Z^1, Z^2 = (9,12)$ and $(8,16)$. In addition, the set of all fuzzy efficient solutions is $\tilde{Z}^1, \tilde{Z}^2 = ([(2,4,8;0.6),(1,4,10;09)],[(4,5,8;0.6),(3,5,14;09)]\,)$ and $([(2,3,4;0.6),(1,3,13;09)],[(6,7,8;0.6),(5,7,17;09)]\,)$.

It is obvious that the solution obtained by the proposed method is less than the obtained by Jayalakshmi and Sujatha [10].

5 | Conclusions and Future Works

In this paper, a new algorithm has proposed to solve the FMOASP based purely on the Hungarian method. The method yields the ideal solution and the set of all efficient solutions. The advantages of this method is easy to solve and apply to any problems in uncertain environment. In addition, with this method the decision maker able to handle the MOASP in the real world applications. In the future work might include the advance extension of this study to other fuzzy- similar structure (i. e. interval- valued fuzzy set, Neutrosophic set, Pythagorean fuzzy set, Spherical fuzzy set etc. with more discussion and suggestive comments.

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Conflicts of Interest

Authors do not have any conflicts of interest.

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