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Research Article

A Fuzzy Soft Set Theoretic Approach in Decision Making of Covid-19 Risk in Different Regions

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Abstract. In the present paper, we apply the theory of fuzzy soft sets to solve a decision making problem related to Covid-19. We give an example which shows that the method can be successfully applied to the burning problem of Covid-19 that contains uncertainties and find result regarding to the risk of Covid-19 in particular region.

Keywords. Soft set; Fuzzy soft set; Weighted fuzzy soft matrix; Decision making; Covid-19

Mathematics Subject Classification (2020). 03E72; 90B50; 91B06; 94D05

1. Introduction

Most of the concept, we observe in daily life are not clear and accurate. Now-a-days mathematical modeling of such problems involving uncertainties is of great importance. To deal with such problems some theories are given e.g. theory of probability, fuzzy set theory [16], theory of rough sets [15], intuitionistic fuzzy set theory [2], theory of vague sets [6] etc. But in recent times these theories are found to be inadequate. Infact, the inadequacy of the parametrization tool in these theories do not allow them to handle vagueness properly. Consequently in 1999 Molodtsov [13] introduced the concept of soft sets and established the fundamental results and successfully applied this theory into several directions such as game theory, generalised Riemann integration, theory of measurement etc. This theory is free from above difficulties.

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In 2001 Maji [9] studied this new theory and initiated some new results. Neog and Sut [14] further redefined complement of soft set and showed that soft sets also satisfy the axioms of exclusion and contradiction. Maji *et al*. [10] [11] gave first practical application of soft sets in decision making problems They have also introduced the concept of fuzzy soft set [12], a more generalized concept, which is a combination of fuzzy set and soft set and also studied some of its properties. Borah and Neog [3] gave an application of fuzzy soft sets in decision making problem. Whole world is facing the Covid-19 pandemic currently, which is the infectious disease caused by the most recently discovered corona virus. People can catch it from others who have the virus. The disease spread from person to person through small droplets from nose or mouth which are spread when an infected person coughs or exhales. These droplets land on surfaces around the person. Other people then catch it by touching these objects or surfaces, then touching their eyes, nose or mouth. There are some precautions for reducing the chance of infection such as staying aware of the latest information on Covid-19 outbreak, social distancing, using mask, sanitizer etc, staying at home, avoiding market products as well as possible or using them carefully, healthy routine and avoiding travel to hotspot areas of pandemic. In present paper we apply fuzzy soft set theory and construct a weighted matrix [8] of fuzzy soft set for decision making in ranking the risk of Covid-19 in different regions.

2. Preliminaries

Definition 1 ([13])**.** A pair (F,E) is called a soft set (over U) if and only if F is a mapping of E into the set of all subsets of the set U.
In other words, a soft set over U is a parameterized family of subsets of the universe U. Every set $F(e), e \in E$, from this family may be considered as the set of e-approximate elements of the soft set (F,E) or as the set of e-elements of the soft set (F,E).

Definition 2 ([12])**.** A pair (F,A) is called fuzzy soft set over U where $F : A \to \widetilde{P}(U)$ is a function from A into $\widetilde{P}(U)$, $\widetilde{P}(U)$ denotes fuzzy power set of U.

Definition 3 ([1])**.** Let U be a universal set and E be the set of attributes. Then (U,E), the set of all fuzzy soft sets on U with attributes from E, is called fuzzy soft class.

Definition 4 ([12])**.** For two fuzzy soft sets (F,A) and (G,B) in a fuzzy soft class (U,E), (F,A) is said to be fuzzy soft subset of (G,B), if

(i) $A \subseteq B$;

(ii) $e \in A \Rightarrow F(e) \subseteq G(e)$ and is written as $(F,A)\widetilde{\subseteq}(G,B)$.

Definition 5 ([1])**.** Let (F,A) and (G,B) be two fuzzy soft sets in a soft class (U,E) with $A \cap B \neq \phi$. Then intersection of these two fuzzy soft sets in fuzzy soft class (U,E) is a fuzzy soft set (H,C) where $C = A \cap B$ and $\forall\ e \in C$, $H(e) = F(e) \cap G(e)$ and is written as $(F,A)\widetilde{\cap}(G,B) = (H,C)$.

Definition 6 ([5]). The fuzzy soft set (R,C) of (F_i,A_i) is called an n-ary fuzzy soft relation. Here, $C \subset A_1 \times A_2 \times \ldots \times A_n$ $\forall$ $(x_1,x_2,\ldots,x_n) \in A_1 \times A_2 \times \ldots \times A_n$, $R(x_1,x_2,\ldots,x_n) \subset F_1(x_1) \cap F_2(x_2) \cap \ldots \cap F_n(x_n)$.

Definition 7 ([9]). Let $E = \{e_1,e_2,\ldots,e_k\}$ be a set if parameters. The "*not set of* E" denoted by $\neg E = \{\neg e_1, \neg e_2, \ldots, \neg e_k\}$, where $\neg e_j$ means not e_j $\forall$ $i = 1,2,\ldots,k$.

Definition 8 ([7]). The standard fuzzy complement, $\bar{A}$, of fuzzy set A with respect to the universal set X is defined for all $x \in X$ by the equation

$$\bar{A}(x) = 1 - A(x).$$

Since fuzzy complement is not unique, we can define a fuzzy compliment as follows:
Let A be the fuzzy set with respect to the universal set X s.t. $A(x) > 0$ $\forall$ $x \in X$ then complement A^c is given by

$$A^c(x) = \frac{\min\{A(x)\}}{A(x)} - \min\left\{\frac{\min\{A(x)\}}{A(x)}\right\}.$$

Definition 9 ([4]). Let U be a universe, E be a set of parameters with respect to U and $A \subset E$. Let (F_A,E) be a soft set over U. Then a subset R_A of $U \times E$, uniquely defined as $R_A = \{(u,e) : e \in A, u \in F_A(e)\}$, is called a relation form of the soft set (F_A,E).
The characteristic function $\chi_{R_A} : U \times E \to \{0,1\}$, where $\chi_{R_A} = 1$ if $(u,e) \in R_A$ otherwise 0.
Now, if $U = \{u_1,\ldots,u_k\}$ and $E = \{e_1,\ldots,e_m\}$ then the soft set (F_A,E) can be represented by a matrix $[a_{ij}]$ called $k \times m$ soft matrix of the soft set (F_A,E) over U, where $a_{ij} = \chi_{R_A}(u_i,e_j)$.

Definition 10 ([8]). Lin in 1996 defined a new theory of mathematical analysis which is "Theory of W-soft sets" which means weighted soft sets. Following Lin's style we define the weighted table of fuzzy soft set (F,E) which have entries $d_{ij} = c_{ij} \cdot w_j$ instead of c_{ij} = fuzzy membership grade of u_i in $F(e_j)$.

3. Application of Fuzzy Soft Sets in Ranking the Risk of Covid-19 in Diffrent Regions

Consider, $U = \{u_1,u_2,u_3,\ldots,u_m\}$ for some $m \in N$, as our universal set.
U being the set of m regions.
Also, consider the set of parameters

$$E = \{e_1,e_2,e_3,e_4,e_5,e_6,e_7\},$$

where

e_1 = transport density = transport/area,
e_2 = population density = population/area,
e_3 = dependence on market = sale/population,
e_4 = lack of awareness,
e_5 = active cases of Covid-19,
e_6 = low recovery rate,
e_7 = high death rate

We construct fuzzy soft sets $F(e_j)$ for $j = 1,2,\dots,7$. So, we require a membership function μ_j for each j. We denote the membership grade of u_i in $F(e_j)$ i.e. $\mu_j(u_i)$ by μ_{ij}.

For $j = 1$: We calculate transport density for each u_i, $i = 1,2,\dots,m$. Then membership μ_{i1} of u_i in $F(e_1)$ is given by

$$\mu_{i1} = \frac{\text{transport density in } u_i}{\max_i\{\text{transport density in } u_i\}}.$$

Thus, we have

$$F(e_1) = \{(u_i, \mu_{i1}) : i = 1,2,\dots,m\}.$$

For $j = 2$: We calculate population density for each u_i, $i = 1,2,\dots,m$. Then membership μ_{i2} of u_i in $F(e_2)$ is given by

$$\mu_{i2} = \frac{\text{population density in } u_i}{\max_i\{\text{population density in } u_i\}}.$$

Thus, we have

$$F(e_2) = \{(u_i, \mu_{i2}) : i = 1,2,\dots,m\}.$$

For $j = 3$: We calculate market dependence (sale/population) for each u_i, $i = 1,2,\dots,m$. Then membership μ_{i3} of u_i in $F(e_3)$ is given by

$$\mu_{i3} = \frac{\text{market dependence in } u_i}{\max_i\{\text{market dependence in } u_i\}}.$$

Thus, we have

$$F(e_3) = \{(u_i, \mu_{i3}) : i = 1,2,\dots,m\}.$$

For $j = 4$: first we find the membership function for awareness i.e. $\neg e_4$. For this we find r_{1i}, r_{2i}, r_{3i}, r_{4i} for each $i = 1,2,\dots,m$, defined as following

$$r_{1i} = \frac{\text{sale of news paper}}{\text{population}}, \qquad r_{2i} = \frac{\text{sale of mask, gloves}}{\text{population}}, \qquad r_{3i} = \frac{\text{sale of sanitizer}}{\text{population}},$$

$$r_{4i} = \frac{\text{internet data use}}{\text{population}}, \qquad r_{5i} = \text{litracy percentage}$$

for each u_i.

Let

$$\mu'_{r_{ki}} = \frac{r_{ki}}{\max_i\{r_{ki}\}}$$

then membership grade of u_i in $F(\neg e_4)$ (say μ'_{i4}) is given as

$$\mu'_{i4} = \frac{\sum\limits_{k=1}^{5} \mu'_{r_{ki}}}{5}$$

then membership of u_i in $F(e_4)$ is given by

$$\mu_{i4} = \frac{\min_i\{\mu'_{i4}\}}{\mu'_{i4}} - \min\left\{\frac{\min_i\{\mu'_{i4}\}}{\mu'_{i4}}\right\}.$$

The term $\min\left\{\frac{\min_i\{\mu'_{i4}\}}{\mu'_{i4}}\right\}$ may be removed here and we get

$$\mu_{i4} = \frac{\min_i\{\mu'_{i4}\}}{\mu'_{i4}}$$

and thus

$$F(e_4) = \{(u_i, \mu_{i4}) : i = 1, 2, \dots, m\}.$$

For $j = 5$: Since the number of test in all regions are not same so directly total active cases has no significant role. So we consider the ratio of active cases to the total test in each region.

Let r = active cases/test.

We find this ratio r for each day for fixed i and then average $\bar{r}_i$ for the region u_i and we do same for each $i = 1, 2 \dots, m$. Membership of u_i in $F(e_5)$ is given by

$$\mu_{i5} = \frac{\bar{r}_i}{\max_i\{\bar{r}_i\}}$$

and thus

$$F(e_5) = \{(u_i, \mu_{i5}) : i = 1, 2, \dots, m\}.$$

For $j = 6$: First we find membership function for recovery i.e. $\neg e_6$.

Let

$$r = \frac{\text{number of recovered in } u_i}{\text{total case in } u_i}$$

for fixed u_i we find r of each day and then average $\bar{r}_i$ then membership grade of u_i in $F(\neg e_6)$ (say μ'_{i6}),

$$\mu'_{i6} = \frac{\bar{r}_i}{\max_i\{\bar{r}_i\}}.$$

Now, the membership μ_{i6} of each u_i is

$$\frac{\min_i\{\mu'_{i6}\}}{\mu'_{i6}}$$

thus, we have

$$F(e_6) = \{(u_i, \mu_{i6}) : i = 1, 2, \dots, m\}.$$

For $j = 7$: Let

$$r = \frac{\text{number of death}}{\text{total case in } u_i}$$

for fixed u_i we find r for each day and then average $\bar{r}_i$ for the region u_i and we do same for each $i = 1, 2, \dots, m$.

Membership of u_i in $F(e_7)$ is given by,

$$\mu_{i7} = \frac{\bar{r}_i}{\max_i\{\bar{r}_i\}}$$

and thus

$$F(e_7) = \{(u_i, \mu_{i7}) : i = 1, 2, \dots, m\}.$$

Decision making: We construct fuzzy soft matrix $[c_{ij}]_{m\times 7}$ where $c_{ij} = \mu_{ij}$ and calculate $d_i = c_{i1} + c_{i2} + \ldots + c_{i7}$ for each i. Now, $(\{d_i\}, \leq)$ is an ordered set, greater d_i shows the higher risk in u_i.

3.1 Weighted Fuzzy Soft Matrix

Further, we are interested in the analysis that every parameter is of same significance or not. Indeed each have different role in present case. To measure the importance of parameters and find more accurate decision we determine the weightage for parameters.

We consider rate of increment "I_r" of Covid cases and the parameter which affects it more, more weightage will be given.

By affection we mean how I_r varies with respect to a parameter.

Now, first we find I_{r_i} (rate of increment in total cases of region u_i.

Consider the region u_i (i fixed) and daily increment in cases:

$$\triangle C_{k+1} = \frac{\text{total cases on } (k+1)\text{th day} - \text{total cases on } k\text{th day}}{\text{case on } k\text{th day}}$$

(Suppose we find for n days) $I_{r_i} = \frac{\sum_{k=2}^{n} \triangle C_k}{(n-1)}$, we find I_{r_i} for each $i = 1, 2, \ldots, m$.

Weightage of parameters: consider the weight function $w : E \to [0,1]$. Obviously, I_r is monotonically increasing with respect to the considered parameters, if parameter e_j makes more variation in I_r, we give more weightage to it.

Concept of weightage: Let the parameter e_j, j fixed. If we are able to find the slope of curve plotted by taking μ_{ij} on X-axis and I_r on Y-axis, we plot the point (μ_{ij}, I_{r_i}) and find the slope $\frac{\partial I_r}{\partial \mu_{ij}}$.

Similarly, we find this slope for each $j = 1, 2, \ldots, 7$.

Now, $w(e_j) = \dfrac{\frac{\partial I_r}{\partial \mu_{ij}}}{\max_j \left\{\frac{\partial I_r}{\partial \mu_{ij}}\right\}}$.

Required slope by given data: Finding slope by plotting the curve is very tough task and also number of points (μ_{ij}, I_{r_i}) may not be sufficient.

We find the slope as follows:

$$\frac{\partial I_r}{\partial \mu_{ij}} = \text{average}\left\{\frac{I_{r_i} - I_{r_k}}{\mu_{ij} - \mu_{kj}}\right\}$$

for each fixed j and $i, k \in \{1, 2, \ldots, m\}$ s.t. there does not exist $\mu_{lj} \in [\mu_{ij}, \mu_{ik}]$ in given data.

Note. Sometimes it is possible that the slope $\frac{\partial I_r}{\partial \mu_{ij}} < 0$, for some j. In this case we define $\left(\frac{\partial I_r}{\partial \mu_{ij}}\right)^+ = \min_j \left\{\frac{\partial I_r}{\partial \mu_{ij}}\right\} + \frac{\partial I_r}{\partial \mu_{ij}}$ and replace $\frac{\partial I_r}{\partial \mu_{ij}}$ by $\left(\frac{\partial I_r}{\partial \mu_{ij}}\right)^+$ in determination of w_{e_j}.

Decision making. We represent the weighted fuzzy soft matrix by $[a_{ij} = \mu_{ij} \times w(e_j)]_{m\times 7}$, and find $d_i = \sum_{j=1}^{7} a_{ij}$. In this way we get an ordered set $(\{d_i\}, \leq)$, which is directly related to our universal set U i.e. greater the value of d_i shows the higher risk of virus in u_i and d_i gives the relative level of risk.

3.2 Example

Let $U = \{u_1, u_2, u_3, u_4, u_5\}$ be set of five regions and $E = \{e_1, e_2, e_3, e_4, e_5, e_6, e_7\}$ the set of parameters as stated above and fuzzy soft sets $F(e_j)$ as following:

$$F(e_1) = \{(u_1, 0.2), (u_2, 0.6), (u_3, 0.8), (u_4, 1), (u_5, 0.7)\},$$
$$F(e_2) = \{(u_1, 0.2), (u_2, 0.3), (u_3, 0.4), (u_4, 1), (u_5, 0.7)\},$$
$$F(e_3) = \{(u_1, 0.1), (u_2, 0.9), (u_3, 1), (u_4, 0.2), (u_5, 0.3)\},$$
$$F(e_4) = \{(u_1, 0.8), (u_2, 0.2), (u_3, 0.9), (u_4, 0.3), (u_5, 1)\},$$
$$F(e_5) = \{(u_1, 0.3), (u_2, 0.5), (u_3, 0.6), (u_4, 0.7), (u_5, 1)\},$$
$$F(e_6) = \{(u_1, 1), (u_2, 0.5), (u_3, 0.3), (u_4, 0.7), (u_5, 0.6)\},$$
$$F(e_7) = \{(u_1, 0.4), (u_2, 0.2), (u_3, 0.5), (u_4, 0.6), (u_5, 1)\}.$$

Matrix Representation of Fuzzy Soft Set (F, E) over U: We construct a 5×7 matrix whose entries c_{ij} = membership of u_i in $F(e_j)$ i.e. μ_{ij}.

$$\begin{bmatrix} 0.2 & 0.2 & 0.1 & 0.8 & 0.3 & 1 & 0.4 \\ 0.6 & 0.3 & 0.9 & 0.2 & 0.5 & 0.5 & 0.2 \\ 0.8 & 0.4 & 1 & 0.9 & 0.6 & 0.3 & 0.5 \\ 1 & 1 & 0.2 & 0.3 & 0.7 & 0.7 & 0.6 \\ 0.7 & 0.7 & 0.3 & 1 & 1 & 0.6 & 1 \end{bmatrix}$$

Decision Making: we find the choice value

$$d_i = c_{i1} + c_{i2} + \ldots + c_{i7}$$

corresponding to each u_i, $i = 1, 2, \ldots, 5$,

$$d_1 = 3,\ d_2 = 3.2,\ d_3 = 4.5,\ d_4 = 4.5,\ d_5 = 5.3$$

It follows that the region u_5 is on the heighest risk. Ordering "$\leq$" of regions with increasing risk is given as follows:

$$u_1 < u_2 < u_3 = u_4 < u_5.$$

Also, the membership grade (say ν_i) of region u_i, in fuzzy set of risky regions, is given by, $\nu_i = \frac{d_i}{\max_i\{d_i\}}$

$$\text{i.e. } \nu_1 = 0.57,\ \nu_2 = 0.6,\ \nu_3 = 0.85,\ \nu_4 = 0.85,\ \nu_5 = 1$$

Weightage of parameters: Let the rate of increment "I_r" for u_1, u_2, u_3, u_4, u_5 be $I_{r_1} = 0.65$, $I_{r_2} = 0.7$, $I_{r_3} = 0.8$, $I_{r_4} = 0.95$, $I_{r_5} = 1$, respectively.

Now, for each $j = 1, 2, \ldots, 7$, we find average value of $\frac{I_{r_i} - I_{r_k}}{\mu_{ij} - \mu_{kj}}$, $i, k \in \{1, 2, 3, 4, 5\}$ such that $\nexists$ $\mu_{lj} \in [\mu_{ij}, \mu_{ik}]$ in given data.

e.g. $j = 1$, we have $c_{i1}(= \mu_{i1})$, write these c_{i1}'s in increasing order with corresponding I_{r_i}'s i.e. $(0.2, 0.65)$, $(0.6, 0.7)$, $(0.7, 1)$, $(0.8, 0.8)$, $(1, 0.95)$. Plot these points on x-y plane and find the slope of line joining each pair of cosecutive points given above.

In this way the slope of line joining $(0.2, 0.65)$ and $(0.6, 0.7) = 0.125$.

Similarly, for $(0.6, 0.7)$ and $(0.7, 1)$ slope is 3 and so on. Then, average of these four values $\frac{\partial I_r}{\partial \mu_{i1}} = 0.47$.

Calculating for other values of j we have,

$$\frac{\partial I_r}{\partial \mu_{i1}} = 0.47,\ \frac{\partial I_r}{\partial \mu_{i2}} = 0.5,\ \frac{\partial I_r}{\partial \mu_{i3}} = 1,\ \frac{\partial I_r}{\partial \mu_{i4}} = 1.35,\ \frac{\partial I_r}{\partial \mu_{i5}} = 0.73,\ \frac{\partial I_r}{\partial \mu_{i6}} = 0.77,\ \frac{\partial I_r}{\partial \mu_{i7}} = 0.69$$

Since the maximum value is 1.35 therefore weightage "w_j" of parameter e_j is given by $(\frac{\partial I_r}{\partial \mu_{ij}})/1.35$, i.e.

$$w_1 = 0.35,\ w_2 = 0.37,\ w_3 = 0.74,\ w_4 = 1,\ w_5 = 0.54,\ w_6 = 0.57,\ w_7 = 0.51$$

Weighted Fuzzy Soft Matrix: We construct the matrix $[a_{ij} = w_j \times c_{ij}]$ where $c_{ij} \in$ fuzzy soft matrix $[c_{ij}]_{5\times 7}$,

$$\begin{bmatrix} 0.07 & 0.074 & 0.074 & 0.8 & 0.162 & 0.57 & 0.204 \\ 0.21 & 0.111 & 0.666 & 0.2 & 0.27 & 0.285 & 0.102 \\ 0.28 & 0.148 & 0.74 & 0.9 & 0.324 & 0.171 & 0.255 \\ 0.35 & 0.37 & 0.148 & 0.3 & 0.378 & 0.399 & 0.306 \\ 0.245 & 0.259 & 0.222 & 1 & 0.54 & 0.342 & 0.51 \end{bmatrix}$$

Decision making: We find the choice value $d_i = a_{i1} + a_{i2} + \ldots + a_{i7}$ for each u_i, $i = 1, 2, \ldots, 5$,

$$d_1 = 1.954,\ d_2 = 1.844,\ d_3 = 2.818,\ d_4 = 2.251,\ d_5 = 3.118$$

The membership grade "v_i" of u_i is given by $\frac{d_i}{3.118}$.
Thus we have the set

$$\{(u_i, v_i) : i = 1, 2, \ldots, 5\} = \{(u_1, 0.62), (u_2, 0.59), (u_3, 0.9), (u_4, 0.72), (u_5, 1)\}$$

which gives the rank of risk of Covid-19 pandemic in selected regions.

It follows that the region u_5 is at heighest risk.

We have the following ranking of regions in descending order of Covid-19 risk

$$u_5,\ u_3,\ u_4,\ u_1,\ u_2.$$

With membership grade of risk 1, 0.9, 0.72, 0.62 and 0.59 of u_5, u_3, u_4, u_1 and u_2, respectively.

4. Conclusion

In this paper, we give an application of fuzzy soft set by giving the weighted fuzzy soft matrix, which is the combination of fuzzy soft matrix and weighted table of soft set for ranking the risk of Covid-19 and determining the relative level of risk in different regions. Also, we discussed the process of weightage of parameters in this application. It is hoped that our work would help in facing the pandemic and enrich this study in modeling real life problems involving uncertainties.

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Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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