Chapter 2
On Generalised Interval-Valued Intuitionistic Fuzzy Soft Sets

Abstract Molodtsov initiated the concept of fuzzy soft set theory in 1999. Maji et al. introduced the notion of fuzzy soft sets. By introducing the concept of intuitionistic fuzzy sets into the theory of soft sets, Maji et al. proposed the concept of intuitionistic fuzzy soft set theory. The notion of the interval-valued intuitionistic fuzzy sets was first introduced by Atanassov and Gargov. It is characterised by an interval-valued membership degree and an interval-valued non-membership degree. In 2010, Y. Jiang et al. introduced the concept of interval-valued intuitionistic fuzzy soft sets. In this chapter, the concept of generalised interval-valued intuitionistic fuzzy soft sets is introduced. The basic properties of these sets are presented. Also, an application of generalised interval-valued intuitionistic fuzzy soft sets in decision-making with respect to interval of degree of preference is investigated.

Keywords Soft sets · Fuzzy soft sets · Interval-valued fuzzy sets · Intuitionistic fuzzy sets · Intuitionistic fuzzy soft sets · Generalised intuitionistic fuzzy soft sets · Interval-valued intuitionistic fuzzy sets · Interval-valued intuitionistic fuzzy soft sets · Generalised interval-valued intuitionistic fuzzy soft sets

In 1999, Molodtsov [9] initiated the concept of fuzzy soft set theory, which is completely a new approach for modelling vagueness and uncertainties. Soft set theory has a rich potential for application in solving various decision-making problems. Maji et al. [6] introduced the concept of fuzzy soft set theory. As a generalisation of fuzzy soft set theory, intuitionistic fuzzy soft set theory [7] makes description of the objective more realistic, more practical, and accurate in some cases, making it more promising. After the introduction of fuzzy set [10], Atanassov [1], introduced intuitionistic fuzzy set as a generalisation fuzzy set. Gorzalczany [4], introduced the interval-valued fuzzy set in 1987. In 2010, Majumder and Samanta [8], introduced generalised fuzzy soft set. Also in 2010, Dinda, Bera and Samanta [3], introduced generalised fuzzy soft set. Atanassov and Gargov [2] introduced the concept of interval-valued intuitionistic fuzzy set theory. In 2010, Jiang et al. [5] introduced the concept of interval-valued intuitionistic fuzzy soft sets which is a combination of an interval-valued intuitionistic fuzzy set theory and a soft set theory. In this chapter, the concept of generalised interval-valued intuitionistic fuzzy soft sets

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together with their basic properties is introduced. Also, an application of generalised interval-valued intuitionistic fuzzy soft sets in decision-making is presented.

Throughout the text, unless otherwise stated explicitly, U be the set of universe and E be the set of parameters, and we take $A, B, C \subseteq E$ and α, β, δ are fuzzy subsets of A, B, C, respectively.

Definition 2.1 Let U be an initial universe and E be a set of parameters. Let IVIFS^U be the set of all interval-valued intuitionistic fuzzy soft sets on U and $A \subseteq E$. Let F be a mapping given by $F: A \to \mathrm{IVIFS}^U$ and α be a mapping given by $\alpha: A \to \mathrm{Int}([0, 1])$. Let F_α be a mapping given by $F: A \to \mathrm{IVIFS}^U \times \mathrm{Int}([0, 1])$ and defined by

$$\begin{aligned} F_\alpha(e) &= (F(e), \alpha(e)) \\ &= \Big(\langle x, \mu_{F(e)}(x), \gamma_{F(e)}(x)\rangle, \alpha(e)\Big) \end{aligned}$$

where $e \in A$ and $x \in U$ where $\alpha(e) = [[\alpha(e)\downarrow, \alpha(e)\uparrow]]$.

Here, $\mu_{F(e)}(x)$ is the interval-valued fuzzy membership degree that object x holds on parameter ε and $\gamma_{F(\varepsilon)}(x)$ is the interval-valued fuzzy membership degree that object x does not hold on parameter ε. For each parameter e, $\alpha(e)$ will be termed as the interval of degree of preference. The pair (F_α, A) is called a generalised interval-valued intuitionistic fuzzy soft set over (U, E).

Example 2.2 Let $U = \{h_1, h_2, h_3, h_4, h_5\}$ be the set of five houses under the consideration of a decision-maker to purchase. Let $A \subseteq E$ and $A = \{e_1$(beautiful), e_2(expensive), e_3(wooden), e_4(in good repair), e_5(in green surroundings)$\}$. Let α: $A \to \mathrm{Int}([0, 1])$ be defined by

$$\begin{aligned} &\alpha(e_1) = [0.6, 0.8], \quad \alpha(e_2) = [0.5, 0.7], \quad \alpha(e_3) = [0.4, 0.5], \\ &\alpha(e_4) = [0.3, 0.45], \quad \alpha(e_5) = [0.2, 0.5]. \end{aligned}$$

Now, we define F_α as follows:

$$\begin{aligned} F_\alpha(e_1) = (\{&\langle h_1, [0.5, 0.7], [0.1, 0.2]\rangle, \langle h_2, [0.7, 0.8], [0.05, 0.1]\rangle, \langle h_3, [0.6, 0.7], [0.2, 0.24]\rangle, \\ &\langle h_4, [0.3, 0.4], [0.4, 0.5]\rangle, \langle h_5, [0.01, 0.05], [0.07, 0.09]\rangle\}, [0.6, 0.8]) \\ F_\alpha(e_2) = (\{&\langle h_1, [0.7, 0.8], [0.1, 0.2]\rangle, h_2, [0.5, 0.6], [0.2, 0.3]\rangle, \langle h_3, [0.4, 0.6], [0.3, 0.37]\rangle, \\ &\langle h_4, [0.1, 0.3], [0.4, 0.5]\rangle, \langle h_5, [0.55, 0.7], [0.25, 0.29]\rangle, [0.5, 0.7]) \\ F_\alpha(e_3) = (\{&\langle h_1, [0.3, 0.4], [0.4, 0.5]\rangle, \langle h_2, [0.65, 0.75], [0.01, 0.23]\rangle, \langle h_3, [0.55, 0.7], [0.2, 0.25]\rangle, \\ &\langle h_4, [0.6, 0.8], [0.1, 0.2]\rangle, \langle h_5, [0.3, 0.6], [0.1, 0.2]\rangle\}, [0.4, 0.5]) \\ F_\alpha(e_4) = (\{&\langle h_1, [0.1, 0.3], [0.5, 0.6]\rangle, \langle h_2, [0.25, 0.75], [0.05, 0.2]\rangle, \langle h_3, [0.6, 0.7], [0.1, 0.2]\rangle, \\ &\langle h_4, [0.1, 0.4], [0.2, 0.5]\rangle, \langle h_5, [0.4, 0.5], [0.2, 0.35]\rangle\}, [0.3, 0.45]) \\ F_\alpha(e_5) = (\{&\langle h_1, [0.2, 0.4], [0.3, 0.5]\rangle, \langle h_2, [0.3, 0.4], [0.35, 0.55]\rangle, \langle h_3, [0.5, 0.6], [0.05, 0.15]\rangle, \\ &\langle h_4, [0.6, 0.7], [0.1, 0.2]\rangle, \langle h_5, [0.1, 0.5], [0.2, 0.3]\rangle\}, [0.2, 0.5]) \end{aligned}$$

Here, (F_α, A) is a generalised interval-valued intuitionistic fuzzy soft set over (U, E).

Definition 2.3 Let (F_α, A) and (G_β, B) be two generalised interval-valued intuitionistic fuzzy soft sets over (U, E). Then, (F_α, A) is called a generalised interval-valued intuitionistic fuzzy soft subset of (G_β, B), denoted by $(F_\alpha, A) \subseteq (G_\beta, B)$ if

(a) $A \subseteq B$
(b) $\forall e \in A$, $\alpha(e) \subseteq \beta(e)$
(c) $\forall e \in A$, $F(e)$ is an interval-valued intuitionistic fuzzy subset of $G(e)$.

Definition 2.4 Let (F_α, A) and (G_β, B) be two generalised interval-valued intuitionistic fuzzy soft sets over (U, E). Then, the intersection of (F_α, A) and (G_β, B) is a generalised interval-valued intuitionistic fuzzy soft sets over (U, E), denoted by $(F_\alpha, A) \cap (G_\beta, B)$, and is defined by $(F_\alpha, A) \cap (G_\beta, B) = (H_\delta, A \cap B)$, where $H_\delta\colon A \cap B \to \mathrm{IVIFS}^U \times \mathrm{Int}([0,1])$ is a mapping such that $\forall e \in A \cap B$ and $x \in U$,

$$H_\delta(e) = \left(\left\langle x, \mu_{H(e)}(x), \gamma_{H(e)}(x)\right\rangle, \delta(e)\right),$$

where

$$\begin{aligned}\mu_{H(e)}(x) &= \left[\inf\left(\underline{\mu}_{F(e)}(x), \underline{\mu}_{G(e)}(x)\right), \inf\left(\overline{\mu}_{F(e)}(x), \overline{\mu}_{G(e)}(x)\right)\right],\\ \gamma_{H(e)}(x) &= \left[\sup\left(\underline{\gamma}_{F(e)}(x), \underline{\gamma}_{G(e)}(x)\right),\ \sup\left(\overline{\gamma}_{F(e)}(x), \overline{\gamma}_{G(e)}(x)\right)\right] \text{ and}\\ \delta(e) &= \alpha(e) * \beta(e)[\alpha(e)\downarrow \cdot \beta(e)\downarrow, \alpha(e)\uparrow \cdot \beta(e)\uparrow].\end{aligned}$$

Definition 2.5 Let (F_α, A) and (G_β, B) be two generalised interval-valued intuitionistic fuzzy soft sets over (U, E). Then, the union of (F_α, A) and (G_β, B) is a generalised interval-valued intuitionistic fuzzy soft sets over (U, E), denoted by $(F_\alpha, A) \cup (G_\beta, B)$, and is defined by

$$(F_\alpha, A) \cup (G_\beta, B) = (H_\delta, A \cup B)$$

where H_δ: $A \cup B \to \mathrm{IVIFS}^U \times \mathrm{Int}([0, 1])$ is a mapping such that $\forall e \in A \cup B$ and $x \in U$,

$$\begin{aligned}H_\delta(e) &= \left(\left\langle x, \mu_{F(e)}(x), \gamma_{F(e)}(x)\right\rangle, \alpha(e)\right) \quad \text{if } e \in A - B\\ &= \left(\left\langle x, \mu_{G(e)}(x), \gamma_{G(e)}(x)\right\rangle, \beta(e)\right) \quad \text{if } e \in B - A\\ &= \left(\left\langle x, \mu_{H(e)}(x), \gamma_{H(e)}(x)\right\rangle, \delta(e)\right) \quad \text{if } e \in A \cap B,\end{aligned}$$

where

$$\mu_{H(e)}(x) = \left[\inf\left(\underline{\mu}_{F(e)}(x), \underline{\mu}_{G(e)}(x)\right), \inf\left(\overline{\mu}_{F(e)}(x), \overline{\mu}_{G(e)}(x)\right)\right],$$
$$\gamma_{H(e)}(x) = \left[\sup\left(\underline{\gamma}_{F(e)}(x), \underline{\gamma}_{G(e)}(x)\right), \sup\left(\overline{\gamma}_{F(e)}(x), \overline{\gamma}_{G(e)}(x)\right)\right] \text{ and}$$
$$\delta(e) = \alpha(e)\Delta\beta(e) = [\alpha(e)\downarrow + \beta(e)\downarrow - \alpha(e)\downarrow \cdot \beta(e)\downarrow, \alpha(e)\uparrow + \beta(e)\uparrow - \alpha(e)\uparrow \cdot \beta(e)\uparrow]$$

Proposition 2.6 *Let* (F_α, A), (G_β, B), *and* (H_δ, C) *be three generalised interval-valued intuitionistic fuzzy soft sets over* (U, E). *Then*

(a) $(F_\alpha, A) \cup (G_\beta, B) = (G_\beta, B) \cup (F_\alpha, A)$
(b) $(F_\alpha, A) \cap (G_\beta, B) = (G_\beta, B) \cap (F_\alpha, A)$
(c) $(F_\alpha, A) \cup ((G_\beta, B) \cup (H_\delta, C)) = ((F_\alpha, A) \cup (G_\beta, B)) \cup (H_\delta, C)$
(d) $(F_\alpha, A) \cap ((G_\beta, B) \cap (H_\delta, C)) = ((F_\alpha, A) \cap (G_\beta, B)) \cap (H_\delta, C)$
(e) $(F_\alpha, A) \cup ((G_\beta, B) \cap (H_\delta, C)) = ((F_\alpha, A) \cup (G_\beta, B)) \cap ((F_\alpha, A) \cup ((H_\delta, C))$
(f) $(F_\alpha, A) \cap ((G_\beta, B) \cup (H_\delta, C)) = ((F_\alpha, A) \cap (G_\beta, B)) \cup ((F_\alpha, A) \cap ((H_\delta, C))$.

Definition 2.7 Let (F_α, A) be a generalised interval-valued intuitionistic fuzzy soft set over (U, E). Then, the complement of (F_α, A) is a generalised interval-valued intuitionistic fuzzy soft sets over (U, E), denoted by $(F_\alpha, A)^c$, and is defined by

$$(F_\alpha, A)^c = (F_\alpha^c, A^c)$$

where F_α^c: $A^c \to \text{IVIFS}^U \times \text{Int}([0, 1])$ is a function defined by

$$F_\alpha^c(\sim e) = \left(\left\langle x, \gamma_{F(e)}(x), \mu_{F(e)}(x)\right\rangle, \alpha^c(e)\right)$$

where $\sim e \in A^c$ and $x \in U$ and α^c: $A^c \to \text{Int}([0, 1])$ is defined as

$$\alpha^c(\sim e) = [1\alpha(e)\uparrow -, 1 - \alpha(e)\downarrow] \quad \text{if } \alpha(e) = [\alpha(e)\downarrow, \alpha(e)\uparrow] \in \text{Int}[0, 1],\ e \in A.$$

Proposition 2.8: *Let* (F_α, A) *be a generalised interval-valued intuitionistic fuzzy soft set over* (U, E). *Then*, $[(F_\alpha, A)^c]^c = (F_\alpha, A)$.

2.1 An Application of Generalised Interval-Valued Intuitionistic Fuzzy Soft Sets in Decision-Making

Let us consider the Example 2.2. Let $E = \{e_1$(beautiful), e_2(expensive), e_3(wooden), e_4(in good repair), e_5(in green surroundings), e_6(cheap), e_7(modern)$\}$.

The problem is that out of the available houses in U, we have to select that house which qualifies with all or maximum number of parameters of the parameter set A.

Now, we introduce the following two operations:

- *For interval-valued fuzzy membership degree*:

$$\text{For } e \in A, x \in U \text{ and } \alpha(e) = [\alpha(e)\downarrow, \alpha(e)\uparrow]$$

$$\mu'_{F(e)}(x) = \left[\underline{\mu}_{F(e)}(x) + \alpha(e)\downarrow - \underline{\mu}_{F(e)}(x) \cdot \alpha(e)\downarrow, \bar{\mu}_{F(e)}(x) + \alpha(e)\downarrow - \bar{\mu}_{F(e)}(x) \cdot \alpha(e)\downarrow\right]$$

- *For interval-valued fuzzy non-membership degree*:

$$\text{For } e \in A, x \in U \text{ and } \alpha(e) = [\alpha(e)\downarrow, \alpha(e)\uparrow],$$

$$\begin{aligned}\gamma'_{F(e)} &= \left[\underline{\gamma}_{F(e)}(x) \cdot \alpha(e)\uparrow, \underline{\gamma}_{F(e)}(x) \cdot \alpha(e)\uparrow\right] \quad \text{if} \quad \overline{\mu}_{F(e)}(x) + \alpha(e)\downarrow \\ &\quad - \overline{\mu}_{F(e)}(x) \cdot \alpha(e)\downarrow + \overline{\gamma}_{F(e)}(x) \cdot \alpha(e)\uparrow \le 1 \\ &= [0, 0], \text{otherwise}\end{aligned}$$

Actually, we have taken these two operations to ascend the interval-valued fuzzy membership degree and to descend the interval-valued fuzzy non-membership degree on the basis of the interval of degree of preference. Then, the generalised interval-valued intuitionistic fuzzy soft set (F_α, A) is reduced to an interval-valued intuitionistic fuzzy soft set (F', A) which is given as follows:

$$\begin{aligned}F'(e_1) = \{&\langle h_1, [0.8, 0.88], [0, 0]\rangle, \langle h_2, [0.88, 0.92], [0.04, 0.08]\rangle, \\ &\langle h_3, [0.84, 0.88], [0, 0]\rangle, \langle h_4, [0.72, 0.76], [0, 0]\rangle, \\ &\langle h_5, [0.604, 0.62], [0.056, 0.072]\rangle\} \\ F'(e_2) = \{&\langle h_1, [0.85, 0.90], [0, 0]\rangle, \langle h_2, [0.75, 0.80], [0, 0]\rangle, \langle h_3, [0.70, 0.80], [0, 0]\rangle, \\ &\langle h_4, [0.55, 0.65], [0.28, 0.35]\rangle, \langle h_5, [0.775, 0.85], [0.0]\rangle\} \\ F'(e_3) = \{&\langle h_1, [0.58, 0.64], [0.20, 0.25]\rangle, \langle h_2, [0.79, 0.85], [0.005, 0.115]\rangle, \\ &\langle h_3, [0.73, 0.82], [0.10, 0.125]\rangle, \langle h_4, [0.76, 0.88], [0.05, 0.10]\rangle, \\ &\langle h_5, [0.58, 0.76], [0.05, 0.10]\rangle\} \\ F'(e_4) = \{&\langle h_1, [0.37, 0.51], [0.225, 0.270]\rangle, \langle h_2, [0.475, 0.825], [0.0225, 0.09]\rangle, \\ &\langle h_3, [0.72, 0.79], [0.045, 0.09]\rangle, \langle h_4, [0.37, 0.58], [0.09, 0.225]\rangle, \\ &\langle h_5, [0.58, 0.65], [0.09, 0.1575]\rangle\} \\ F'(e_5) = \{&\langle h_1, [0.36, 0.52], [0.15, 0.25]\rangle, \langle h_2, [0.44, 0.52], [0.175, 0.275]\rangle, \\ &\langle h_3, [0.60, 0.68], [0.025, 0.075]\rangle, \langle h_4, [0.68, 0.76], [0.05, 0.10]\rangle, \\ &\langle h_5, [0.28, 0.60], [0.10, 0.15]\rangle\}\end{aligned}$$

Now to reduce the above interval-valued intuitionistic fuzzy soft set (F', A) into an intuitionistic fuzzy soft set (F'', A), we apply the following two operations:

- *For membership function*:

$$\mu''_{F(e)}(x) = \left(\inf \mu'_{F(e)}(x), \sup\mu'_{F(e)}(x)\right)/2, \quad \text{for } e \in A \ \& \ x \in U$$

- *For non-membership function*:

$$\gamma''_{F(e)}(x) = \left(\inf \gamma'_{F(e)}(x), \sup \gamma'_{F(e)}(x)\right)/2, \quad \text{for } e \in A \ \& \ x \in U$$

Then, the reduced intuitionistic fuzzy soft set (F'', A) is given as follows:

$$\begin{aligned}
F''(e_1) &= \{\langle h_1, 0.84, 0\rangle, \langle h_2, 0.90, 0.06\rangle, \langle h_3, 0.86, 0\rangle, \\
&\quad \langle h_4, 0.74, 0\rangle, \langle h_5, 0.612, 0.064\rangle\} \\
F''(e_2) &= \{\langle h_1, 0.875, 0\rangle, \langle h_2, 0.775, 0\rangle, \langle h_3, 0.75, 0\rangle, \\
&\quad \langle h_4, 0.60, 0.315\rangle, \langle h_5, 0.8125, 0\rangle\} \\
F''(e_3) &= \{\langle h_1, 0.61, 0.225\rangle, \langle h_2, 0.82, 0.06\rangle, \langle h_3, 0.775, 0.1125\rangle, \\
&\quad \langle h_4, 0.82, 0.075\rangle, \langle h_5, 0.67, 0.075\rangle\} \\
F''(e_4) &= \{\langle h_1, 0.44, 0.2475\rangle, \langle h_2, 0.65, 0.05625\rangle, \langle h_3, 0.755, 0.0675\rangle, \\
&\quad \langle h_4, 0.475, 0.1575\rangle, \langle h_5, 0.615, 0.12375\rangle\} \\
F''(e_5) &= \{\langle h_1, 0.44, 0.20\rangle, \langle h_2, 0.48, 0225\rangle, \langle h_3, 0.64, 0.05\rangle, \\
&\quad \langle h_4, 0.72, 0.075\rangle, \langle h_5, 0.44, 0.125\rangle\}.
\end{aligned}$$

Algorithm

1. Input the set A of choice of parameters.
2. Consider the reduced intuitionistic fuzzy soft set in tabular form.
3. Compute the comparison table for both membership and non-membership function.
4. Compute the membership and non-membership score of each object.
5. Compute the final score.
6. If the maximum score occurs in the ith row, then the house h_i will be purchased.

Let us use the algorithm to solve the problem (Tables 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6).

Table 2.1 Tabular representation of intuitionistic fuzzy soft set (F'', A)

	e_1	e_2	e_3	e_4	e_5
h_1	(0.84, 0)	(0.875, 0)	(0.61, 0.225)	(0.44, 0.2475)	(0.44, 0.20)
h_2	(0.90, 0.06)	(0.775, 0)	(0.82, 0.06)	(0.65, 0.05625)	(0.48, 0.225)
h_3	(0.86, 0)	(0.75, 0)	(0.775, 0.1125)	(0.755, 0.0675)	(0.64, 0.05)
h_4	(0.74, 0)	(0.60, 0.315)	(0.82, 0.075)	(0.475, 0.1575)	(0.72, 0.075)
h_5	(0.612, 0.064)	(0.8125, 0)	(0.67, 0.075)	(0.615, 0.12375)	(0.44, 0.125)

Table 2.2 Comparison table for membership function

	h_1	h_2	h_3	h_4	h_5
h_1	5	1	1	2	3
h_2	4	5	3	4	4
h_3	4	2	5	3	4
h_4	3	2	2	5	3
h_5	3	1	1	2	5

Table 2.3 Comparison table for non-membership function

	$h\ h_1$	$h\ h_2\ h_2$	$h\ h_3$	$h\ h_4\ h_4$	$h\ h_5\ h_5$
h_1	5	3	5	4	4
h_2	3	5	3	2	2
h_3	2	3	5	2	2
h_4	2	3	4	5	3
h_5	2	4	4	3	5

Table 2.4 Membership score table

	Row sum	Column sum	Membership score
h_1	12	19	−7
h_2	20	11	9
h_3	18	12	6
h_4	15	16	−1
h_5	12	19	−7

Table 2.5 Non-membership score table

	Row sum	Column sum	Non-membership score
h_1	21	14	7
h_2	15	18	−3
h_3	14	21	−7
h_4	17	16	1
h_5	18	16	2

Table 2.6 Final score table

	Membership score	Non-membership score	Final score
h_1	−7	7	−14
h_2	9	−3	12
h_3	6	−7	13
h_4	−1	1	−2
h_5	−7	2	−9

2.2 Conclusion

As the maximum score is 13, so the decision-maker will purchase 'house h_3'.

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