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Interval neutrosophic sets applied to ideals in BCK/BCI-algebras

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Abstract: For $i, j, k, l, m, n \in \{1, 2, 3, 4\}$, the notion of $(T(i, j), I(k, l), F(m, n))$ -interval neutrosophic ideals in

BCK/BCI -algebras is introduced, and their properties and relations are investigated.

Keywords: interval neutrosophic set; interval neutrosophic ideal.

1 Introduction

BCK -algebras entered into mathematics in 1966 through the work of Imai and Iséki [3], and have been applied to many branches of mathematics, such as group theory, functional analysis, probability theory and topology. Such algebras generalize Boolean rings as well as Boolean D -posets (= MV -algebras). Also, Iséki introduced the notion of a BCI -algebra which is a generalization of a BCK -algebra (see [4]). The neutrosophic set developed by Smarandache [7, 8, 9] is a formal framework which generalizes the concept of the classic set, fuzzy set [14], interval valued fuzzy set, intuitionistic fuzzy set [1], interval valued intuitionistic fuzzy set and paraconsistent set etc. Neutrosophic set theory is applied to various part, including algebra, topology, control theory, decision making problems, medicines and in many real life problems. Wang et al. [11, 12, 13] presented the concept of interval neutrosophic sets, which is more precise and more flexible than the single-valued neutrosophic set. An interval-valued neutrosophic set is a generalization of the concept of single-valued neutrosophic set, in which three membership (t, i, f) functions are independent, and their values belong to the unit interval $[0, 1]$. The interval neutrosophic set can represent uncertain, imprecise, incomplete and inconsistent information which exists in real world. Jun et al. [5] discussed interval neutrosophic sets in BCK/BCI -algebras, and introduced the notion of $(T(i, j), I(k, l), F(m, n))$ -interval neutrosophic subalgebras in BCK/BCI -algebras for $i, j, k, l, m, n \in \{1, 2, 3, 4\}$. They also introduced the notion of interval neutrosophic length of an interval neutrosophic set, and investigated related properties.

In this article, we apply the notion of interval neutrosophic sets to ideal theory in BCK/BCI -algebras. We introduce the notion of $(T(i, j), I(k, l), F(m, n))$ -interval neutrosophic ideals in BCK/BCI -algebras for $i, j, k, l, m, n \in \{1, 2, 3, 4\}$, and investigate their properties and relations.

2 Preliminaries

By a BCI -algebra (see [2, 6]) we mean a system $X := (X, *, 0)$ in which the following axioms hold:

- (I) $((x * y) * (x * z)) * (z * y) = 0$,
- (II) $(x * (x * y)) * y = 0$,
- (III) $x * x = 0$,
- (IV) $x * y = y * x = 0 \Rightarrow x = y$

for all $x, y, z \in X$. If a BCI -algebra X satisfies $0 * x = 0$ for all $x \in X$, then we say that X is a BCK -algebra (see [2, 6]).

A non-empty subset S of a BCK/BCI -algebra X is called a *subalgebra* (see [2, 6]) of X if $x * y \in S$ for all $x, y \in S$.

The collection of all BCK -algebras and all BCI -algebras are denoted by $\mathcal{B}_K(X)$ and $\mathcal{B}_I(X)$, respectively. Also $\mathcal{B}(X) := \mathcal{B}_K(X) \cup \mathcal{B}_I(X)$.

We refer the reader to the books [2] and [6] for further information regarding BCK/BCI -algebras.

By a *fuzzy structure* over a nonempty set X we mean an ordered pair (X, ρ) of X and a fuzzy set ρ on X .

Definition 2.1 ([10]). A fuzzy structure (X, μ) over $(X, *, 0) \in \mathcal{B}(X)$ is called a

- *fuzzy ideal* of $(X, *, 0)$ with type 1 (briefly, *1-fuzzy ideal* of $(X, *, 0)$) if

$$(\forall x \in X) (\mu(0) \geq \mu(x)), \quad (2.1)$$

$$(\forall x, y \in X) (\mu(x) \geq \min\{\mu(x * y), \mu(y)\}), \quad (2.2)$$

- *fuzzy ideal* of $(X, *, 0)$ with type 2 (briefl , 2-*fuzzy ideal* of $(X, *, 0)$) if

$$(\forall x \in X) (\mu(0) \leq \mu(x)), \tag{2.3}$$

$$(\forall x, y \in X) (\mu(x) \leq \min\{\mu(x * y), \mu(y)\}), \tag{2.4}$$

- *fuzzy ideal* of $(X, *, 0)$ with type 3 (briefl , 3-*fuzzy ideal* of $(X, *, 0)$) if it satisfie (2.1) and

$$(\forall x, y \in X) (\mu(x) \geq \max\{\mu(x * y), \mu(y)\}), \tag{2.5}$$

- *fuzzy ideal* of $(X, *, 0)$ with type 4 (briefl , 4-*fuzzy ideal* of $(X, *, 0)$) if it satisfie (2.3) and

$$(\forall x, y \in X) (\mu(x) \leq \max\{\mu(x * y), \mu(y)\}). \tag{2.6}$$

Let X be a non-empty set. A neutrosophic set (NS) in X (see [8]) is a structure of the form:

$$A := \{ \langle x; A_T(x), A_I(x), A_F(x) \rangle \mid x \in X \}$$

where $A_T : X \rightarrow [0, 1]$ is a truth membership function, $A_I : X \rightarrow [0, 1]$ is an indeterminate membership function, and $A_F : X \rightarrow [0, 1]$ is a false membership function.

An interval neutrosophic set (INS) A in X is characterized by truth-membership function T_A , indeterminacy membership function I_A and falsity-membership function F_A . For each point x in X , $T_A(x), I_A(x), F_A(x) \in [0, 1]$ (see [12, 13]).

In what follows, let $(X, *, 0) \in \mathcal{B}(X)$ and $\mathcal{P}^*([0, 1])$ be the family of all subintervals of $[0, 1]$ unless otherwise specific .

Definition 2.2 ([12, 13]). An *interval neutrosophic set* in a nonempty set X is a structure of the form:

$$\mathcal{I} := \{ \langle x, \mathcal{I}[T](x), \mathcal{I}[I](x), \mathcal{I}[F](x) \rangle \mid x \in X \}$$

where

$$\mathcal{I}[T] : X \rightarrow \mathcal{P}^*([0, 1])$$

which is called *interval truth-membership function*,

$$\mathcal{I}[I] : X \rightarrow \mathcal{P}^*([0, 1])$$

which is called *interval indeterminacy-membership function*, and

$$\mathcal{I}[F] : X \rightarrow \mathcal{P}^*([0, 1])$$

which is called *interval falsity-membership function*.

For the sake of simplicity, we will use the notation $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ for the interval neutrosophic set

$$\mathcal{I} := \{ \langle x, \mathcal{I}[T](x), \mathcal{I}[I](x), \mathcal{I}[F](x) \rangle \mid x \in X \}.$$

Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in X , we consider the following functions (see [5]):

$$\mathcal{I}[T]_{\text{inf}} : X \rightarrow [0, 1], x \mapsto \inf\{\mathcal{I}[T](x)\}$$

$$\mathcal{I}[I]_{\text{inf}} : X \rightarrow [0, 1], x \mapsto \inf\{\mathcal{I}[I](x)\}$$

$$\mathcal{I}[F]_{\text{inf}} : X \rightarrow [0, 1], x \mapsto \inf\{\mathcal{I}[F](x)\}$$

and

$$\mathcal{I}[T]_{\text{sup}} : X \rightarrow [0, 1], x \mapsto \sup\{\mathcal{I}[T](x)\}$$

$$\mathcal{I}[I]_{\text{sup}} : X \rightarrow [0, 1], x \mapsto \sup\{\mathcal{I}[I](x)\}$$

$$\mathcal{I}[F]_{\text{sup}} : X \rightarrow [0, 1], x \mapsto \sup\{\mathcal{I}[F](x)\}.$$

3 Interval neutrosophic ideals

Definition 3.1. For any $i, j, k, l, m, n \in \{ 1, 2, 3, 4 \}$, an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in X is called a $(T(i, j), I(k, l), F(m, n))$ -*interval neutrosophic ideal* of X if the following assertions are valid.

(1) $(X, \mathcal{I}[T]_{\text{inf}})$ is an i -fuzzy ideal of $(X, *, 0)$ and $(X, \mathcal{I}[T]_{\text{sup}})$ is a j -fuzzy ideal of $(X, *, 0)$,

(2) $(X, \mathcal{I}[I]_{\text{inf}})$ is a k -fuzzy ideal of $(X, *, 0)$ and $(X, \mathcal{I}[I]_{\text{sup}})$ is an l -fuzzy ideal of $(X, *, 0)$,

(3) $(X, \mathcal{I}[F]_{\text{inf}})$ is an m -fuzzy ideal of $(X, *, 0)$ and $(X, \mathcal{I}[F]_{\text{sup}})$ is an n -fuzzy ideal of $(X, *, 0)$.

Example 3.2. Consider a *BCK*-algebra $X = \{0, 1, 2, 3\}$ with the binary operation $*$ which is given in Table 1 (see [6]).

Table 1: Cayley table for the binary operation “ $*$ ”

$*$	0	1	2	3
0	0	0	0	0
1	1	0	0	1
2	2	2	0	2
3	3	3	3	0

(1) Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be an interval neutrosophic set in $(X, *, 0)$ for which $\mathcal{I}[T], \mathcal{I}[I]$ and $\mathcal{I}[F]$ are given as follows:

$$\mathcal{I}[T] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.4, 0.6] & \text{if } x = 0, \\ [0.3, 0.6] & \text{if } x = 1, \\ [0.2, 0.7] & \text{if } x = 2, \\ [0.1, 0.8] & \text{if } x = 3, \end{cases}$$

$$\mathcal{I}[I] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.5, 0.6] & \text{if } x = 0, \\ [0.4, 0.6] & \text{if } x = 1, \\ [0.2, 0.9] & \text{if } x = 2, \\ [0.5, 0.7] & \text{if } x = 3, \end{cases}$$

and

$$\mathcal{I}[F] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.4, 0.5] & \text{if } x = 0, \\ [0.3, 0.5] & \text{if } x = 1, \\ [0.1, 0.7] & \text{if } x = 2, \\ [0.2, 0.8] & \text{if } x = 3. \end{cases}$$

$$\mathcal{I}[I] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.22, 0.65] & \text{if } x = 0, \\ [0.52, 0.55] & \text{if } x = a, \\ [0.62, 0.65] & \text{if } x = b, \\ [0.62, 0.55] & \text{if } x = c, \end{cases}$$

and

It is routine to verify that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$.

(2) Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be an interval neutrosophic set in $(X, *, 0)$ for which $\mathcal{I}[T], \mathcal{I}[I]$ and $\mathcal{I}[F]$ are given as follows:

$$\mathcal{I}[T] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.1, 0.4] & \text{if } x = 0, \\ [0.2, 0.7] & \text{if } x = 1, \\ [0.3, 0.8] & \text{if } x = 2, \\ [0.4, 0.6] & \text{if } x = 3, \end{cases}$$

$$\mathcal{I}[I] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.2, 0.5] & \text{if } x = 0, \\ [0.5, 0.6] & \text{if } x = 1, \\ [0.6, 0.7] & \text{if } x = 2, \\ [0.3, 0.8] & \text{if } x = 3, \end{cases}$$

and

$$\mathcal{I}[F] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.3, 0.4] & \text{if } x = 0, \\ [0.4, 0.7] & \text{if } x = 1, \\ [0.6, 0.8] & \text{if } x = 2, \\ [0.4, 0.6] & \text{if } x = 3. \end{cases}$$

By routine calculations, we know that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 4), I(4, 4), F(4, 4))$ -interval neutrosophic ideal of $(X, *, 0)$.

Example 3.3. Consider a BCI-algebra $X = \{0, a, b, c\}$ with the binary operation $*$ which is given in Table 2 (see [6]).

Table 2: Cayley table for the binary operation “ $*$ ”

$*$	0	a	b	c
0	0	a	b	c
a	a	0	c	b
b	b	c	0	a
c	c	b	a	0

Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be an interval neutrosophic set in $(X, *, 0)$ where $\mathcal{I}[T], \mathcal{I}[I]$ and $\mathcal{I}[F]$ are given as follows:

$$\mathcal{I}[T] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} [0.33, 0.91] & \text{if } x = 0, \\ [0.72, 0.91] & \text{if } x = a, \\ [0.72, 0.82] & \text{if } x = b, \\ [0.55, 0.82] & \text{if } x = c, \end{cases}$$

$$\mathcal{I}[F] : X \rightarrow \mathcal{P}^*([0, 1]) \quad x \mapsto \begin{cases} (0.25, 0.63) & \text{if } x = 0, \\ [0.45, 0.63] & \text{if } x = a, \\ (0.35, 0.53] & \text{if } x = b, \\ [0.45, 0.53] & \text{if } x = c. \end{cases}$$

Routine calculations show that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 1), I(4, 1), F(4, 1))$ -interval neutrosophic ideal of $(X, *, 0)$. But it is not a $(T(2, 1), I(2, 1), F(2, 1))$ -interval neutrosophic ideal of $(X, *, 0)$ since

$$\mathcal{I}[T]_{\text{inf}}(a) = 0.72 > 0.55 = \min\{\mathcal{I}[T]_{\text{inf}}(a * b), \mathcal{I}[T]_{\text{inf}}(b)\},$$

$$\mathcal{I}[I]_{\text{inf}}(b) = 0.62 > 0.52 = \min\{\mathcal{I}[I]_{\text{inf}}(b * c), \mathcal{I}[I]_{\text{inf}}(c)\},$$

and/or

$$\mathcal{I}[F]_{\text{inf}}(c) = 0.45 > 0.35 = \min\{\mathcal{I}[F]_{\text{inf}}(c * a), \mathcal{I}[F]_{\text{inf}}(a)\}.$$

Also, it is not a $(T(4, 3), I(4, 3), F(4, 3))$ -interval neutrosophic ideal of $(X, *, 0)$ since

$$\mathcal{I}[T]_{\text{sup}}(c) = 0.82 < 0.91 = \max\{\mathcal{I}[T]_{\text{inf}}(c * b), \mathcal{I}[T]_{\text{inf}}(b)\}$$

and/or

$$\mathcal{I}[F]_{\text{sup}}(b) = 0.35 < 0.62 = \max\{\mathcal{I}[F]_{\text{inf}}(b * a), \mathcal{I}[F]_{\text{inf}}(a)\}.$$

We also know that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is not a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$.

Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be an interval neutrosophic set in X . We consider the following sets (see [5]):

$$U(\mathcal{I}[T]_{\psi}; \alpha_I) := \{x \in X \mid \mathcal{I}[T]_{\psi}(x) \geq \alpha_I\},$$

$$L(\mathcal{I}[T]_{\psi}; \alpha_S) := \{x \in X \mid \mathcal{I}[T]_{\psi}(x) \leq \alpha_S\},$$

$$U(\mathcal{I}[I]_{\psi}; \beta_I) := \{x \in X \mid \mathcal{I}[I]_{\psi}(x) \geq \beta_I\},$$

$$L(\mathcal{I}[I]_{\psi}; \beta_S) := \{x \in X \mid \mathcal{I}[I]_{\psi}(x) \leq \beta_S\},$$

and

$$U(\mathcal{I}[F]_{\psi}; \gamma_I) := \{x \in X \mid \mathcal{I}[F]_{\psi}(x) \geq \gamma_I\},$$

$$L(\mathcal{I}[F]_{\psi}; \gamma_S) := \{x \in X \mid \mathcal{I}[F]_{\psi}(x) \leq \gamma_S\},$$

where $\psi \in \{\text{inf}, \text{sup}\}$, and $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I$ and γ_S are numbers in $[0, 1]$.

Theorem 3.4. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

- (1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 1), I(4, 1), F(4, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 1), I(1, 1), F(1, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (4) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 4), I(4, 4), F(4, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

Proof. (1) Assume that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$. Then $(X, \mathcal{I}[T]_{\text{inf}})$, $(X, \mathcal{I}[I]_{\text{inf}})$ and $(X, \mathcal{I}[F]_{\text{inf}})$ are 1-fuzzy ideals of X ; and $(X, \mathcal{I}[T]_{\text{sup}})$, $(X, \mathcal{I}[I]_{\text{sup}})$ and $(X, \mathcal{I}[F]_{\text{sup}})$ are 4-fuzzy ideals of X . Let $\alpha_I, \alpha_S \in [0, 1]$ be such that $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$ and $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$ are nonempty. Obviously, $0 \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$ and $0 \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$. Let $x, y \in X$ be such that $x * y \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$ and $y \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$. Then $\mathcal{I}[T]_{\text{inf}}(x * y) \geq \alpha_I$ and $\mathcal{I}[T]_{\text{inf}}(y) \geq \alpha_I$, and so

$$\mathcal{I}[T]_{\text{inf}}(x) \geq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} \geq \alpha_I,$$

that is, $x \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$. If $x * y \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$ and $y \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, then $\mathcal{I}[T]_{\text{sup}}(x * y) \leq \alpha_S$ and $\mathcal{I}[T]_{\text{sup}}(y) \leq \alpha_S$, which imply that

$$\mathcal{I}[T]_{\text{sup}}(x) \leq \max\{\mathcal{I}[T]_{\text{sup}}(x * y), \mathcal{I}[T]_{\text{sup}}(y)\} \leq \alpha_S,$$

that is, $x \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$. Hence $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$ and $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$ are ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S \in [0, 1]$. Similarly, we can prove that $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or subalgebras of $(X, *, 0)$ for all $\beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$. By the similarly way to the proof of (1), we can prove that (2), (3) and (4) are true. \square

Corollary 3.5. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

- (1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 4), I(3, 4), F(3, 4))$ -interval neutrosophic ideal of $(X, *, 0)$ or a $(T(i, 2), I(i, 2), F(i, 2))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{1, 3\}$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 3), I(4, 3), F(4, 3))$ -interval neutrosophic ideal of $(X, *, 0)$ or a $(T(2, j), I(2, j), F(2, j))$ -interval neutrosophic ideal of $(X, *, 0)$ for $j \in \{1, 3\}$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 1), I(3, 1), F(3, 1))$ -interval neutrosophic ideal of $(X, *, 0)$ or a $(T(i, 3), I(i, 3), F(i, 3))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{1, 3\}$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (4) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 4), I(2, 4), F(2, 4))$ -interval neutrosophic ideal of $(X, *, 0)$ or a $(T(i, 2), I(i, 2), F(i, 2))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{2, 4\}$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

Proof. Straightforward since every 3-fuzzy (resp., 2-fuzzy) ideal is a 1-fuzzy (resp., 4-fuzzy) ideal. \square

Theorem 3.6. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, the following assertions are valid.

- (1) If $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are nonempty ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$, then $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$.
- (2) If $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are nonempty ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$, then $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 1), I(1, 1), F(1, 1))$ -interval neutrosophic ideal of $(X, *, 0)$.
- (3) If $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are nonempty ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$, then $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 1), I(4, 1), F(4, 1))$ -interval neutrosophic ideal of $(X, *, 0)$.
- (4) If $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are

nonempty ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$, then $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 4), I(4, 4), F(4, 4))$ -interval neutrosophic ideal of $(X, *, 0)$.

Proof. (1) Suppose that $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I), L(\mathcal{I}[T]_{\text{sup}}; \alpha_S), U(\mathcal{I}[I]_{\text{inf}}; \beta_I), L(\mathcal{I}[I]_{\text{sup}}; \beta_S), U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are nonempty ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$. If $(X, \mathcal{I}[T]_{\text{inf}})$ is not a 1-fuzzy ideal of $(X, *, 0)$, then there exist $x, y \in X$ such that

$$\mathcal{I}[T]_{\text{inf}}(x) < \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\}.$$

If we take $\alpha_I = \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\}$, then $x * y, y \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$ but $x \notin U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$. This is a contradiction, and so $(X, \mathcal{I}[T]_{\text{inf}})$ is a 1-fuzzy ideal of $(X, *, 0)$. If $(X, \mathcal{I}[T]_{\text{sup}})$ is not a 4-fuzzy ideal of $(X, *, 0)$, then

$$\mathcal{I}[T]_{\text{sup}}(a) > \max\{\mathcal{I}[T]_{\text{sup}}(a * b), \mathcal{I}[T]_{\text{sup}}(b)\}$$

for some $a, b \in X$, and so $a * b, b \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$ and $a \notin L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$ by taking

$$\alpha_S := \max\{\mathcal{I}[T]_{\text{sup}}(a * b), \mathcal{I}[T]_{\text{sup}}(b)\}.$$

This is a contradiction, and therefore $(X, \mathcal{I}[T]_{\text{sup}})$ is a 4-fuzzy ideal of $(X, *, 0)$. Similarly, we can verify that $(X, \mathcal{I}[I]_{\text{inf}})$ is a 1-fuzzy ideal of $(X, *, 0)$ and $(X, \mathcal{I}[I]_{\text{sup}})$ is a 4-fuzzy ideal of $(X, *, 0)$, and $(X, \mathcal{I}[F]_{\text{inf}})$ is a 1-fuzzy ideal of $(X, *, 0)$ and $(X, \mathcal{I}[F]_{\text{sup}})$ is a 4-fuzzy ideal of $(X, *, 0)$. Consequently, $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$. The assertions (2), (3) and (4) can be proved by the similar way to the proof of (1). \square

Theorem 3.7. *If an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$ is a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c, L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c, U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c, L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c, U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.*

Proof. Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$. Then

- (1) $(X, \mathcal{I}[T]_{\text{inf}}), (X, \mathcal{I}[I]_{\text{inf}})$ and $(X, \mathcal{I}[F]_{\text{inf}})$ are 2-fuzzy ideals of $(X, *, 0)$,
- (2) $(X, \mathcal{I}[T]_{\text{sup}}), (X, \mathcal{I}[I]_{\text{sup}})$ and $(X, \mathcal{I}[F]_{\text{sup}})$ are 3-fuzzy ideals of $(X, *, 0)$.

Let $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$ be such that $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c, L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c, U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c, L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c, U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are nonempty. Then there exist $x, y, z, a, b, d \in X$ such that $x \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c, a \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c, y \in U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c, b \in L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c, z \in U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $d \in L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$. Hence

$$\mathcal{I}[T]_{\text{inf}}(0) \leq \mathcal{I}[T]_{\text{inf}}(x) < \alpha_I \text{ and } \mathcal{I}[T]_{\text{sup}}(0) \geq \mathcal{I}[T]_{\text{sup}}(a) > \alpha_S,$$

$$\mathcal{I}[I]_{\text{inf}}(0) \leq \mathcal{I}[I]_{\text{inf}}(y) < \beta_I \text{ and } \mathcal{I}[I]_{\text{sup}}(0) \geq \mathcal{I}[I]_{\text{sup}}(b) > \beta_S,$$

$$\mathcal{I}[F]_{\text{inf}}(0) \leq \mathcal{I}[F]_{\text{inf}}(z) < \gamma_I \text{ and } \mathcal{I}[F]_{\text{sup}}(0) \geq \mathcal{I}[F]_{\text{sup}}(d) > \gamma_S,$$

and so $0 \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c \cap L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c, 0 \in U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c \cap L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, and $0 \in U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c \cap L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$. Let $x, y \in X$ be such that $x * y \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$ and $y \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$. Then $\mathcal{I}[T]_{\text{inf}}(x * y) < \alpha_I$ and $\mathcal{I}[T]_{\text{inf}}(y) < \alpha_I$. Hence

$$\mathcal{I}[T]_{\text{inf}}(x) \leq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} < \alpha_I,$$

and so $x \in U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$. Thus $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$ is an ideal of $(X, *, 0)$. Similarly, we can verify that

- If $x * y \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$ and $y \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, then $x \in L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$,
- If $x * y \in U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$ and $y \in U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, then $x \in U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$,
- If $x * y \in L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$ and $y \in L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, then $x \in L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$,
- If $x * y \in U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $y \in U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$, then $x \in U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$,
- If $x * y \in L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ and $y \in L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$, then $x \in L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$.

Therefore $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c, U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c, L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c, U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are ideals of $(X, *, 0)$. \square

The converse of Theorem 3.7 is not true in general as seen in the following example.

Example 3.8. Consider a BCI-algebra $X = \{0, 1, a, b, c\}$ with the binary operation $*$ which is given in Table 3 (see [6]).

Table 3: Cayley table for the binary operation “ $*$ ”

$*$	0	1	a	b	c
0	0	0	a	b	c
1	1	0	a	b	c
a	a	a	0	c	b
b	b	b	c	0	a
c	c	c	b	a	0

Let $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ be an interval neutrosophic set in $(X, *, 0)$ where $\mathcal{I}[T], \mathcal{I}[I]$ and $\mathcal{I}[F]$ are given as follows:

$$\mathcal{I}[T] : X \rightarrow \tilde{\mathcal{P}}([0, 1]), \quad x \mapsto \begin{cases} [0.25, 0.85] & \text{if } x = 0, \\ [0.45, 0.83] & \text{if } x = 1, \\ [0.55, 0.73] & \text{if } x = a, \\ [0.65, 0.73] & \text{if } x = b, \\ [0.65, 0.75] & \text{if } x = c, \end{cases}$$

$$\mathcal{I}[I] : X \rightarrow \tilde{\mathcal{P}}([0, 1]), \quad x \mapsto \begin{cases} [0.3, 0.75] & \text{if } x = 0, \\ [0.3, 0.70] & \text{if } x = 1, \\ [0.6, 0.63] & \text{if } x = a, \\ [0.5, 0.63] & \text{if } x = b, \\ [0.6, 0.68] & \text{if } x = c, \end{cases}$$

and

$$\mathcal{I}[F] : X \rightarrow \tilde{\mathcal{P}}([0, 1]), \quad x \mapsto \begin{cases} [0.44, 0.9] & \text{if } x = 0, \\ [0.55, 0.9] & \text{if } x = 1, \\ [0.55, 0.7] & \text{if } x = a, \\ [0.66, 0.8] & \text{if } x = b, \\ [0.66, 0.7] & \text{if } x = c. \end{cases}$$

Then

$$U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c = \begin{cases} \emptyset & \text{if } \alpha_I \in [0, 0.25], \\ \{0\} & \text{if } \alpha_I \in (0.25, 0.45], \\ \{0, 1\} & \text{if } \alpha_I \in (0.45, 0.55], \\ \{0, 1, a\} & \text{if } \alpha_I \in (0.55, 0.65], \\ X & \text{if } \alpha_I \in (0.65, 1.0], \end{cases}$$

$$L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c = \begin{cases} \emptyset & \text{if } \alpha_S \in [0.85, 1.0], \\ \{0\} & \text{if } \alpha_S \in [0.83, 0.85), \\ \{0, 1\} & \text{if } \alpha_S \in [0.75, 0.83), \\ \{0, 1, c\} & \text{if } \alpha_S \in [0.73, 0.75), \\ X & \text{if } \alpha_S \in [0, 0.73), \end{cases}$$

$$U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c = \begin{cases} \emptyset & \text{if } \beta_I \in [0, 0.3], \\ \{0, 1\} & \text{if } \beta_I \in (0.3, 0.5], \\ \{0, 1, b\} & \text{if } \beta_I \in (0.5, 0.6], \\ X & \text{if } \beta_I \in (0.6, 1.0], \end{cases}$$

$$L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c = \begin{cases} \emptyset & \text{if } \beta_S \in [0.75, 1.0], \\ \{0\} & \text{if } \beta_S \in [0.70, 0.75), \\ \{0, 1\} & \text{if } \beta_S \in [0.68, 0.70), \\ \{0, 1, c\} & \text{if } \beta_S \in [0.63, 0.68), \\ X & \text{if } \beta_S \in [0, 0.63), \end{cases}$$

$$U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c = \begin{cases} \emptyset & \text{if } \gamma_I \in [0, 0.44], \\ \{0\} & \text{if } \gamma_I \in (0.44, 0.55], \\ \{0, 1, a\} & \text{if } \gamma_I \in (0.55, 0.66], \\ X & \text{if } \gamma_I \in (0.66, 1.0], \end{cases}$$

$$L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c = \begin{cases} \emptyset & \text{if } \gamma_S \in [0.9, 1.0], \\ \{0, 1\} & \text{if } \gamma_S \in [0.8, 0.9), \\ \{0, 1, b\} & \text{if } \gamma_S \in [0.7, 0.8), \\ X & \text{if } \gamma_S \in [0, 0.7). \end{cases}$$

Hence the nonempty sets $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

$\gamma_I, \gamma_S \in [0, 1]$. But $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is not a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$ since

$$\mathcal{I}[T]_{\text{inf}}(c) = 0.65 > 0.55 = \min\{\mathcal{I}[T]_{\text{inf}}(c * a), \mathcal{I}[T]_{\text{inf}}(a)\},$$

$$\mathcal{I}[T]_{\text{sup}}(a) = 0.73 < 0.75 = \max\{\mathcal{I}[T]_{\text{sup}}(a * c), \mathcal{I}[T]_{\text{sup}}(c)\},$$

$$\mathcal{I}[I]_{\text{inf}}(c) = 0.6 > 0.5 = \min\{\mathcal{I}[I]_{\text{inf}}(c * a), \mathcal{I}[I]_{\text{inf}}(a)\},$$

$$\mathcal{I}[I]_{\text{sup}}(a) = 0.63 < 0.68 = \max\{\mathcal{I}[I]_{\text{sup}}(a * c), \mathcal{I}[I]_{\text{sup}}(c)\},$$

$$\mathcal{I}[F]_{\text{inf}}(c) = 0.66 > 0.55 = \min\{\mathcal{I}[F]_{\text{inf}}(c * a), \mathcal{I}[F]_{\text{inf}}(a)\},$$

and/or

$$\mathcal{I}[F]_{\text{sup}}(a) = 0.7 < 0.8 = \max\{\mathcal{I}[F]_{\text{sup}}(a * c), \mathcal{I}[F]_{\text{sup}}(c)\}.$$

Using the similar way to the proof of Theorem 3.7, we have the following theorems.

Theorem 3.9. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

- (1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 2), I(2, 2), F(2, 2))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 2), I(3, 2), F(3, 2))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.
- (3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 3), I(3, 3), F(3, 3))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

Using the similar way to the proofs of Theorems 3.4 and 3.7, we have the following theorem.

Theorem 3.10. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

- (1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 2), I(1, 2), F(1, 2))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 3), I(1, 3), F(1, 3))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 1), I(2, 1), F(2, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(4) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 1), I(3, 1), F(3, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(5) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 4), I(2, 4), F(2, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then $U(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $U(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $U(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(6) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(3, 4), I(3, 4), F(3, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)^c$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)^c$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)^c$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(7) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 2), I(4, 2), F(4, 2))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $U(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $U(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $U(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

(8) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 3), I(4, 3), F(4, 3))$ -interval neutrosophic ideal of $(X, *, 0)$, then $L(\mathcal{I}[T]_{\text{inf}}; \alpha_I)$, $L(\mathcal{I}[T]_{\text{sup}}; \alpha_S)^c$, $L(\mathcal{I}[I]_{\text{inf}}; \beta_I)$, $L(\mathcal{I}[I]_{\text{sup}}; \beta_S)^c$, $L(\mathcal{I}[F]_{\text{inf}}; \gamma_I)$ and $L(\mathcal{I}[F]_{\text{sup}}; \gamma_S)^c$ are either empty or ideals of $(X, *, 0)$ for all $\alpha_I, \alpha_S, \beta_I, \beta_S, \gamma_I, \gamma_S \in [0, 1]$.

neutrosophic ideal $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ of $(X, *, 0)$ satisfies

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) \geq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \mathcal{I}[F]_{\text{sup}}(y) \end{cases} \quad (3.1)$$

for all $x, y \in X$ with $x \leq y$.

Proof. If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then $(X, \mathcal{I}[T]_{\text{inf}})$, $(X, \mathcal{I}[I]_{\text{inf}})$ and $(X, \mathcal{I}[F]_{\text{inf}})$ are 1-fuzzy ideals of $(X, *, 0)$, and $(X, \mathcal{I}[T]_{\text{sup}})$, $(X, \mathcal{I}[I]_{\text{sup}})$ and $(X, \mathcal{I}[F]_{\text{sup}})$ are 4-fuzzy ideals of $(X, *, 0)$. Let $x, y \in X$ be such that $x \leq y$. Then $x * y = 0$, and so

$$\begin{aligned} \mathcal{I}[T]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[T]_{\text{inf}}(0), \mathcal{I}[T]_{\text{inf}}(y)\} = \mathcal{I}[T]_{\text{inf}}(y), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[T]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[T]_{\text{sup}}(x * y), \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[T]_{\text{sup}}(0), \mathcal{I}[T]_{\text{sup}}(y)\} = \mathcal{I}[T]_{\text{sup}}(y), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[I]_{\text{inf}}(x * y), \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[I]_{\text{inf}}(0), \mathcal{I}[I]_{\text{inf}}(y)\} = \mathcal{I}[I]_{\text{inf}}(y), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[I]_{\text{sup}}(x * y), \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[I]_{\text{sup}}(0), \mathcal{I}[I]_{\text{sup}}(y)\} = \mathcal{I}[I]_{\text{sup}}(y), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[F]_{\text{inf}}(x * y), \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[F]_{\text{inf}}(0), \mathcal{I}[F]_{\text{inf}}(y)\} = \mathcal{I}[F]_{\text{inf}}(y), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[F]_{\text{sup}}(x * y), \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[F]_{\text{sup}}(0), \mathcal{I}[F]_{\text{sup}}(y)\} = \mathcal{I}[F]_{\text{sup}}(y). \end{aligned}$$

This completes the proof. □

Using the similar way to the proof of Proposition 3.11, we have the following proposition.

Proposition 3.12. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

Proposition 3.11. Every $(T(1, 4), I(1, 4), F(1, 4))$ -interval (1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 1), I(1, 1), F(1, 1))$ -

interval neutrosophic ideal of $(X, *, 0)$, then

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) \geq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \mathcal{I}[F]_{\text{sup}}(y) \end{cases} \quad (3.2)$$

for all $x, y \in X$ with $x \leq y$.

(2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 1), I(4, 1), F(4, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) \leq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \mathcal{I}[F]_{\text{sup}}(y) \end{cases} \quad (3.3)$$

for all $x, y \in X$ with $x \leq y$.

(2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 4), I(4, 4), F(4, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) \leq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \mathcal{I}[F]_{\text{sup}}(y) \end{cases} \quad (3.4)$$

for all $x, y \in X$ with $x \leq y$.

Proposition 3.13. For every $(i, j) \in \{(2, 2), (2, 3), (3, 2), (3, 3)\}$, Every $(T(i, j), I(i, j), F(i, j))$ -interval neutrosophic ideal $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ of $(X, *, 0)$ satisfies

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{cases} \quad (3.5)$$

for all $x, y \in X$ with $x \leq y$.

Proof. Assume that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$. Then $(X, \mathcal{I}[T]_{\text{inf}})$, $(X, \mathcal{I}[I]_{\text{inf}})$ and $(X, \mathcal{I}[F]_{\text{inf}})$ are 2-fuzzy ideals of $(X, *, 0)$, and $(X, \mathcal{I}[T]_{\text{sup}})$, $(X, \mathcal{I}[I]_{\text{sup}})$ and $(X, \mathcal{I}[F]_{\text{sup}})$ are

3-fuzzy ideals of $(X, *, 0)$. Let $x, y \in X$ be such that $x \leq y$. Then $x * y = 0$, and thus

$$\begin{aligned} \mathcal{I}[T]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[T]_{\text{inf}}(0), \mathcal{I}[T]_{\text{inf}}(y)\} = \mathcal{I}[T]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[T]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[T]_{\text{sup}}(x * y), \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[T]_{\text{sup}}(0), \mathcal{I}[T]_{\text{sup}}(y)\} = \mathcal{I}[T]_{\text{sup}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[I]_{\text{inf}}(x * y), \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[I]_{\text{inf}}(0), \mathcal{I}[I]_{\text{inf}}(y)\} = \mathcal{I}[I]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[I]_{\text{sup}}(x * y), \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[I]_{\text{sup}}(0), \mathcal{I}[I]_{\text{sup}}(y)\} = \mathcal{I}[I]_{\text{sup}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[F]_{\text{inf}}(x * y), \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[F]_{\text{inf}}(0), \mathcal{I}[F]_{\text{inf}}(y)\} = \mathcal{I}[F]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[F]_{\text{sup}}(x * y), \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[F]_{\text{sup}}(0), \mathcal{I}[F]_{\text{sup}}(y)\} = \mathcal{I}[F]_{\text{sup}}(0). \end{aligned}$$

It follows that $\mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0)$, $\mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0)$, $\mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0)$, $\mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0)$, $\mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0)$ and $\mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0)$ for all $x, y \in X$ with $x \leq y$. Similarly, we can verify that (3.5) is true for $(i, j) \in \{(2, 2), (3, 2), (3, 3)\}$. \square

Using the similar way to the proof of Propositions 3.11 and 3.13, we have the following proposition.

Proposition 3.14. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

(1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, j), I(1, j), F(1, j))$ -interval neutrosophic ideal of $(X, *, 0)$ for $j \in \{2, 3\}$, then

$$\begin{cases} \mathcal{I}[T]_{\text{inf}}(x) \geq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{cases} \quad (3.6)$$

for all $x, y \in X$ with $x \leq y$.

(2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(i, 1), I(i, 1), F(i, 1))$ -

interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{2, 3\}$, then and so

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \mathcal{I}[F]_{\text{sup}}(y) \end{array} \right. \quad (3.7)$$

for all $x, y \in X$ with $x \leq y$.

(3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(i, 4), I(i, 4), F(i, 4))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{2, 3\}$, then

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \mathcal{I}[T]_{\text{sup}}(y) \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \mathcal{I}[I]_{\text{sup}}(y) \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \mathcal{I}[F]_{\text{sup}}(y) \end{array} \right. \quad (3.8)$$

for all $x, y \in X$ with $x \leq y$.

(4) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, j), I(4, j), F(4, j))$ -interval neutrosophic ideal of $(X, *, 0)$ for $j \in \{2, 3\}$, then

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \leq \mathcal{I}[T]_{\text{inf}}(y) \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \mathcal{I}[I]_{\text{inf}}(y) \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \mathcal{I}[F]_{\text{inf}}(y) \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{array} \right. \quad (3.9)$$

for all $x, y \in X$ with $x \leq y$.

Proposition 3.15. Every $(T(1, 4), I(1, 4), F(1, 4))$ -interval neutrosophic ideal $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ of $(X, *, 0)$ satisfies

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \geq \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right. \quad (3.10)$$

for all $x, y, z \in X$ with $x * y \leq z$.

Proof. Let $x, y, z \in X$ be such that $x * y \leq z$. Then $(x * y) * z = 0$,

$$\begin{aligned} \mathcal{I}[T]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} \\ &\geq \min\{\min\{\mathcal{I}[T]_{\text{inf}}((x * y) * z), \mathcal{I}[T]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[T]_{\text{inf}}(0), \mathcal{I}[T]_{\text{inf}}(z)\}, \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\}, \end{aligned}$$

$$\begin{aligned} \mathcal{I}[T]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[T]_{\text{sup}}(x * y), \mathcal{I}[T]_{\text{sup}}(y)\} \\ &\leq \max\{\max\{\mathcal{I}[T]_{\text{sup}}((x * y) * z), \mathcal{I}[T]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[T]_{\text{sup}}(0), \mathcal{I}[T]_{\text{sup}}(z)\}, \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\}, \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[I]_{\text{inf}}(x * y), \mathcal{I}[I]_{\text{inf}}(y)\} \\ &\geq \min\{\min\{\mathcal{I}[I]_{\text{inf}}((x * y) * z), \mathcal{I}[I]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[I]_{\text{inf}}(0), \mathcal{I}[I]_{\text{inf}}(z)\}, \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\}, \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[I]_{\text{sup}}(x * y), \mathcal{I}[I]_{\text{sup}}(y)\} \\ &\leq \max\{\max\{\mathcal{I}[I]_{\text{sup}}((x * y) * z), \mathcal{I}[I]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[I]_{\text{sup}}(0), \mathcal{I}[I]_{\text{sup}}(z)\}, \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\}, \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{inf}}(x) &\geq \min\{\mathcal{I}[F]_{\text{inf}}(x * y), \mathcal{I}[F]_{\text{inf}}(y)\} \\ &\geq \min\{\min\{\mathcal{I}[F]_{\text{inf}}((x * y) * z), \mathcal{I}[F]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[F]_{\text{inf}}(0), \mathcal{I}[F]_{\text{inf}}(z)\}, \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\}, \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{sup}}(x) &\leq \max\{\mathcal{I}[F]_{\text{sup}}(x * y), \mathcal{I}[F]_{\text{sup}}(y)\} \\ &\leq \max\{\max\{\mathcal{I}[F]_{\text{sup}}((x * y) * z), \mathcal{I}[F]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[F]_{\text{sup}}(0), \mathcal{I}[F]_{\text{sup}}(z)\}, \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\}. \end{aligned}$$

This completes the proof. □

Using the similar way to the proof of Proposition 3.15, we have the following proposition.

Proposition 3.16. Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:

(1) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, 1), I(1, 1), F(1, 1))$ -

interval neutrosophic ideal of $(X, *, 0)$, then

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \geq \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

(2) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 1), I(4, 1), F(4, 1))$ -interval neutrosophic ideal of $(X, *, 0)$, then

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \leq \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

(3) If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, 4), I(4, 4), F(4, 4))$ -interval neutrosophic ideal of $(X, *, 0)$, then

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \leq \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

Proposition 3.17. For every $(i, j) \in \{(2, 2), (2, 3), (3, 2), (3, 3)\}$, Every $(T(i, j), I(i, j), F(i, j))$ -interval neutrosophic ideal $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ of $(X, *, 0)$ satisfies

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{array} \right. \quad (3.11)$$

for all $x, y, z \in X$ with $x * y \leq z$.

Proof. Assume that $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(2, 3), I(2, 3), F(2, 3))$ -interval neutrosophic ideal of $(X, *, 0)$. Then $(X, \mathcal{I}[T]_{\text{inf}})$, $(X, \mathcal{I}[I]_{\text{inf}})$ and $(X, \mathcal{I}[F]_{\text{inf}})$ are 2-fuzzy ideals of

$(X, *, 0)$, and $(X, \mathcal{I}[T]_{\text{sup}})$, $(X, \mathcal{I}[I]_{\text{sup}})$ and $(X, \mathcal{I}[F]_{\text{sup}})$ are 3-fuzzy ideals of $(X, *, 0)$. Let $x, y, z \in X$ be such that $x * y \leq z$. Then $(x * y) * z = 0$, and thus

$$\begin{aligned} \mathcal{I}[T]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[T]_{\text{inf}}(x * y), \mathcal{I}[T]_{\text{inf}}(y)\} \\ &\leq \min\{\min\{\mathcal{I}[T]_{\text{inf}}((x * y) * z), \mathcal{I}[T]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[T]_{\text{inf}}(0), \mathcal{I}[T]_{\text{inf}}(z)\}, \mathcal{I}[T]_{\text{inf}}(y)\} \\ &= \mathcal{I}[T]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[T]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[T]_{\text{sup}}(x * y), \mathcal{I}[T]_{\text{sup}}(y)\} \\ &\geq \max\{\max\{\mathcal{I}[T]_{\text{sup}}((x * y) * z), \mathcal{I}[T]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[T]_{\text{sup}}(0), \mathcal{I}[T]_{\text{sup}}(z)\}, \mathcal{I}[T]_{\text{sup}}(y)\} \\ &= \mathcal{I}[T]_{\text{sup}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[I]_{\text{inf}}(x * y), \mathcal{I}[I]_{\text{inf}}(y)\} \\ &\leq \min\{\min\{\mathcal{I}[I]_{\text{inf}}((x * y) * z), \mathcal{I}[I]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[I]_{\text{inf}}(0), \mathcal{I}[I]_{\text{inf}}(z)\}, \mathcal{I}[I]_{\text{inf}}(y)\} \\ &= \mathcal{I}[I]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[I]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[I]_{\text{sup}}(x * y), \mathcal{I}[I]_{\text{sup}}(y)\} \\ &\geq \max\{\max\{\mathcal{I}[I]_{\text{sup}}((x * y) * z), \mathcal{I}[I]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[I]_{\text{sup}}(0), \mathcal{I}[I]_{\text{sup}}(z)\}, \mathcal{I}[I]_{\text{sup}}(y)\} \\ &= \mathcal{I}[I]_{\text{sup}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{inf}}(x) &\leq \min\{\mathcal{I}[F]_{\text{inf}}(x * y), \mathcal{I}[F]_{\text{inf}}(y)\} \\ &\leq \min\{\min\{\mathcal{I}[F]_{\text{inf}}((x * y) * z), \mathcal{I}[F]_{\text{inf}}(z)\}, \\ &\quad \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \min\{\min\{\mathcal{I}[F]_{\text{inf}}(0), \mathcal{I}[F]_{\text{inf}}(z)\}, \mathcal{I}[F]_{\text{inf}}(y)\} \\ &= \mathcal{I}[F]_{\text{inf}}(0), \end{aligned}$$

$$\begin{aligned} \mathcal{I}[F]_{\text{sup}}(x) &\geq \max\{\mathcal{I}[F]_{\text{sup}}(x * y), \mathcal{I}[F]_{\text{sup}}(y)\} \\ &\geq \max\{\max\{\mathcal{I}[F]_{\text{sup}}((x * y) * z), \mathcal{I}[F]_{\text{sup}}(z)\}, \\ &\quad \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \max\{\max\{\mathcal{I}[F]_{\text{sup}}(0), \mathcal{I}[F]_{\text{sup}}(z)\}, \mathcal{I}[F]_{\text{sup}}(y)\} \\ &= \mathcal{I}[F]_{\text{sup}}(0). \end{aligned}$$

Since $\mathcal{I}[T]_{\text{inf}}(0) \leq \mathcal{I}[T]_{\text{inf}}(x)$, $\mathcal{I}[T]_{\text{sup}}(0) \geq \mathcal{I}[T]_{\text{sup}}(x)$, $\mathcal{I}[I]_{\text{inf}}(0) \leq \mathcal{I}[I]_{\text{inf}}(x)$, $\mathcal{I}[I]_{\text{sup}}(0) \geq \mathcal{I}[I]_{\text{sup}}(x)$, $\mathcal{I}[F]_{\text{inf}}(0) \leq \mathcal{I}[F]_{\text{inf}}(x)$ and $\mathcal{I}[F]_{\text{sup}}(0) \geq \mathcal{I}[F]_{\text{sup}}(x)$, it follows that $\mathcal{I}[T]_{\text{inf}}(0) = \mathcal{I}[T]_{\text{inf}}(x)$, $\mathcal{I}[T]_{\text{sup}}(0) = \mathcal{I}[T]_{\text{sup}}(x)$, $\mathcal{I}[I]_{\text{inf}}(0) = \mathcal{I}[I]_{\text{inf}}(x)$, $\mathcal{I}[I]_{\text{sup}}(0) = \mathcal{I}[I]_{\text{sup}}(x)$, $\mathcal{I}[F]_{\text{inf}}(0) = \mathcal{I}[F]_{\text{inf}}(x)$, $\mathcal{I}[F]_{\text{sup}}(0) = \mathcal{I}[F]_{\text{sup}}(x)$.

$\mathcal{I}[F]_{\text{inf}}(x)$ and $\mathcal{I}[F]_{\text{sup}}(0) = \mathcal{I}[F]_{\text{sup}}(x)$. Similarly, we can verify that (3.11) is true for $(i, j) \in \{(2, 2), (3, 2), (3, 3)\}$. \square

Using the similar way to the proof of Propositions 3.15 and 3.17, we have the following proposition.

Proposition 3.18. *Given an interval neutrosophic set $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ in $(X, *, 0)$, we have the following assertions:*

(1) *If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(1, j), I(1, j), F(1, j))$ -interval neutrosophic ideal of $(X, *, 0)$ for $j \in \{2, 3\}$, then*

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \geq \min\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) \geq \min\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) \geq \min\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

(2) *If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(i, 1), I(i, 1), F(i, 1))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{2, 3\}$, then*

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) \geq \min\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) \geq \min\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) \geq \min\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

(3) *If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(i, 4), I(i, 4), F(i, 4))$ -interval neutrosophic ideal of $(X, *, 0)$ for $i \in \{2, 3\}$, then*

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) = \mathcal{I}[T]_{\text{inf}}(0) \\ \mathcal{I}[T]_{\text{sup}}(x) \leq \max\{\mathcal{I}[T]_{\text{sup}}(y), \mathcal{I}[T]_{\text{sup}}(z)\} \\ \mathcal{I}[I]_{\text{inf}}(x) = \mathcal{I}[I]_{\text{inf}}(0) \\ \mathcal{I}[I]_{\text{sup}}(x) \leq \max\{\mathcal{I}[I]_{\text{sup}}(y), \mathcal{I}[I]_{\text{sup}}(z)\} \\ \mathcal{I}[F]_{\text{inf}}(x) = \mathcal{I}[F]_{\text{inf}}(0) \\ \mathcal{I}[F]_{\text{sup}}(x) \leq \max\{\mathcal{I}[F]_{\text{sup}}(y), \mathcal{I}[F]_{\text{sup}}(z)\} \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

(4) *If $\mathcal{I} := (\mathcal{I}[T], \mathcal{I}[I], \mathcal{I}[F])$ is a $(T(4, j), I(4, j), F(4, j))$ -interval neutrosophic ideal of $(X, *, 0)$ for $j \in \{2, 3\}$, then*

$$\left\{ \begin{array}{l} \mathcal{I}[T]_{\text{inf}}(x) \leq \max\{\mathcal{I}[T]_{\text{inf}}(y), \mathcal{I}[T]_{\text{inf}}(z)\} \\ \mathcal{I}[T]_{\text{sup}}(x) = \mathcal{I}[T]_{\text{sup}}(0) \\ \mathcal{I}[I]_{\text{inf}}(x) \leq \max\{\mathcal{I}[I]_{\text{inf}}(y), \mathcal{I}[I]_{\text{inf}}(z)\} \\ \mathcal{I}[I]_{\text{sup}}(x) = \mathcal{I}[I]_{\text{sup}}(0) \\ \mathcal{I}[F]_{\text{inf}}(x) \leq \max\{\mathcal{I}[F]_{\text{inf}}(y), \mathcal{I}[F]_{\text{inf}}(z)\} \\ \mathcal{I}[F]_{\text{sup}}(x) = \mathcal{I}[F]_{\text{sup}}(0) \end{array} \right.$$

for all $x, y, z \in X$ with $x * y \leq z$.

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