

# L-R 퍼지수의 집합-이론적 연산과 제2형 퍼지집합의 기수

## The set-theoretic operations of L-R fuzzy numbers and cardinalities of type-two fuzzy sets.

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### 요약

본논문에서는 L-R퍼지수의 집합-이론적 연산의 개념을 정의하고, 이들 개념의 성질들을 조사한다. 이들 연산들의 결과들을 이용하여 제2형 퍼지집합의 기수개념에 관하여 연구한다.

### ABSTRACT

In this paper, we define concepts of some set-theoretical operations of L-R fuzzy numbers and discuss some properties of these concepts. Using these results, we discuss a concept of cardinality of type-two fuzzy sets.

**Key Words** : L-R fuzzy number, fuzzy cardinality, type-two fuzzy sets, type-two fuzzy cardinality.

### 1. Introduction

Let  $X = \{x_1, x_2, \dots, x_n\}$  be a finite set. A fuzzy set  $A$  in  $X$  is defined by

$$A = \{(x, \mu_A(x)) \mid x \in X\}$$

where  $\mu_A : X \rightarrow [0, 1]$  is the membership function of  $A$ . The complement  $\bar{A}$  of a fuzzy set  $A$  has the membership function  $\mu_{\bar{A}} = 1 - \mu_A$ . Zadeh[10], A. Ralescu[7], D. Ralescu[8], Dubois and Prade[1,2,3], and Yager[14] introduced concepts of cardinality of a fuzzy set and obtained some properties of these concepts. In this paper, we define the set-theoretic operations  $\max^*$ ,  $\min^*$ , and complement of L-R type fuzzy numbers on  $[0, 1]$  and investigate some properties of these operations. Using these properties, we define a new concept of cardinality of type-two fuzzy sets and verify that this definition is a generalized concept of the cardinality of a fuzzy set. Furthermore, we obtain some results of this concept. In Section 2, we introduce the set-theoretic operations of L-R fuzzy numbers and discuss some properties of these operations. In section 3, by using these properties in section 2, we define a concept of cardinality of a type-two fuzzy set and discuss some results of type-two fuzzy cardinalities.

### 2. Preliminaries and definitions.

In this section, we introduce fuzzy numbers, L-R fuzzy numbers, and some operations of L-R type fuzzy numbers.

Definition 2.1 [2] A fuzzy set  $M$  of  $[0, 1]$  is called a fuzzy number if

- (1)  $M$  is normal, i.e.  $\exists_1 x_0 \in [0, 1]$  such that  $\mu_M(x_0) = 1$  ;
- (2)  $M$  is convex, i.e.  $\mu_M(\lambda x + (1 - \lambda)y) \geq \min(\mu_M(x), \mu_M(y))$  for all  $x, y, \lambda \in [0, 1]$ ;
- (3)  $\mu_M$  is piecewise continuous.

Let  $L$  and  $R$  be strictly decreasing continuous functions from  $[0, 1]$  to  $[0, 1]$  such that  $L(0) = R(0) = 1$  and  $L(1) = R(1) = 0$ . Then,  $L$  and  $R$  is called the left and the right shape function, respectively(see [6]).

Definition 2.2 A fuzzy number  $M$  of  $[0, 1]$  is said to be an L-R fuzzy number,  $M = (m, \alpha, \beta)_{LR}$  if its membership function is defined by

(i) When  $\alpha > 0$  and  $\beta > 0$ ,

$$\mu_M(x) = \begin{cases} L\left(\frac{m-x}{\alpha}\right) & \text{for } m-\alpha \leq x \leq m \leq 1, x \geq 0, \\ R\left(\frac{x-m}{\beta}\right) & \text{for } m+\beta \geq x \geq m \geq 0, x \leq 1, \\ 0 & \text{else.} \end{cases}$$

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(ii) When  $\alpha=0$  and  $\beta>0$ ,

$$\mu_M(x) = \begin{cases} R\left(\frac{x-m}{\beta}\right) & \text{for } m+\beta \geq x \geq m \geq 0, x \leq 1, \\ 0 & \text{else.} \end{cases}$$

(iii) When  $\alpha>0$  and  $\beta=0$ ,

$$\mu_M(x) = \begin{cases} L\left(\frac{m-x}{\alpha}\right) & \text{for } m-\alpha \leq x \leq m \leq 1, x \geq 0, \\ 0 & \text{else.} \end{cases}$$

(i) When  $\alpha=0$  and  $\beta=0$ ,

$$\mu_M(x) = \begin{cases} 1 & \text{for } x = m, \\ 0 & \text{else.} \end{cases}$$

Here,  $\alpha$  and  $\beta$  are called the left and the right spreads of an  $L-R$  fuzzy number  $M$ , respectively.

$A_{LR}$  will stand for the class of all  $L-R$  fuzzy numbers of  $[0,1]$ .

**Definition 2.3** Let  $M=(m, \alpha, \beta)_{LR}$  and  $N=(n, \gamma, \delta)_{LR}$  be elements of  $A_{LR}$ . Then  $\max^*(M, N)$ ,  $\min^*(M, N)$  are defined by

$$\max^*\{M, N\} = (m \vee n, \alpha \wedge \beta, \beta \vee \delta)_{LR},$$

$$\min^*\{M, N\} = (m \wedge n, \alpha \vee \beta, \beta \wedge \delta)_{LR},$$

where  $x \vee y$  and  $x \wedge y$  are  $\max\{x, y\}$  and  $\min\{x, y\}$ , respectively.

**Theorem 2.4** Let  $M=(m, \alpha, \beta)_{LR}$  and  $N=(n, \gamma, \delta)_{LR}$  be elements of  $A_{LR}$ . Then, we have  $\max^*(M, N)=M$ ,  $\min^*(M, N)=N$  if and only if  $m \leq n$ ,  $\alpha \geq \gamma$ , and  $\beta \leq \delta$ .

**Proof.**

$$\max^*\{M, N\} = M, \min^*\{M, N\} = N$$

$$\Leftrightarrow (m \wedge n, \alpha \vee \gamma, \beta \wedge \delta)_{LR}$$

$$= (m, \alpha, \beta)_{LR} \text{ and } (m \vee n, \alpha \wedge \gamma, \beta \vee \delta)_{LR} = (n, \gamma, \delta)_{LR}$$

$$\Leftrightarrow m \wedge n = m$$

$$\text{and } m \vee n = n, \alpha \vee \gamma = \alpha \text{ and } \alpha \wedge \gamma = \gamma, \beta \wedge \delta = \beta$$

$$\text{and } \beta \vee \delta = \delta$$

$$\Leftrightarrow m \leq n, \alpha \geq \gamma, \text{ and } \beta \leq \delta.$$

In order to define the complement of  $L-R$  fuzzy numbers, we introduce the following definition of subtraction of fuzzy numbers.

**Definition 2.5** [2,3] Let  $M$  and  $N$  be fuzzy numbers on  $[0,1]$ . Then, the subtraction of  $M$  and  $N$  is a function  $M \ominus N: [0,1] \rightarrow [0,1]$  with its membership function defined by

$$\mu_{M \ominus N}(z) = \sup_{z=x-y} \mu_M(x) \wedge \mu_N(y) \text{ for all } z \in [0,1]$$

By using Definition 2.5 and Eq.(4.2.1) of [3], we can

obtain the following theorem.

**Theorem 2.6** [3] (1) If  $M=(m, \alpha, \beta)_{LR}$  and  $N=(n, \gamma, \delta)_{RL}$  is a element of  $A_{LR}$  and  $A_{RL}$ , respectively, then  $M \ominus N=(m-n, \alpha+\gamma, \beta+\delta)_{LR}$ .

(2) If  $M=(m, \alpha, \beta)_{LR}$  and  $\check{1}=(1, 0, 0)_{RL}$  is a element of  $A_{LR}$  and  $A_{RL}$ , respectively, then  $\check{1} \ominus M=(1-m, \beta, \alpha)_{RL}$ .

From Theorem 2.6(2), we can the following complement of  $L-R$  type fuzzy numbers.

**Definition 2.7** Let  $M=(m, \alpha, \beta)_{LR}$  and  $\check{1}=(1, 0, 0)_{RL}$  be a element of  $A_{LR}$  and  $A_{RL}$ , respectively. The complement  $\overline{M^*}$  of  $M$  is defined by  $\overline{M^*} = \check{1} \ominus M=(1-m, \beta, \alpha)_{RL}$ .

### 3. Type-two fuzzy cardinalities.

Let  $X=\{x_1, x_2, \dots, x_n\}$  be a finite set. Using the set-theoretic operations of  $L-L$  type fuzzy numbers on  $[0,1]$ , we define the following new concept of type-two fuzzy cardinality.

**Definition 3.1** Let  $F: X \rightarrow A_{LL}$  be a type-two fuzzy set and  $F(x_k)=M_k=(m_k, \alpha_k, \beta_k)_{LL}$  for  $k=1, 2, \dots, n$ . Then, a type-two fuzzy cardinality of  $F$  is a function  $f_2\text{-card } F: \{0, 1, \dots, n\} \rightarrow A_{LL}$  defined by

$$f_2\text{-card } F(k) = \min^*\{M_{(k)}, \overline{M^*}_{(k+1)}\} \text{ for } k=1, 2, \dots, n$$

where  $M_{(1)}, M_{(2)}, \dots, M_{(n)}$  are  $L-L$  type fuzzy numbers of  $M_1, M_2, \dots, M_n$  arranged in decreasing order of magnitude of the normal points  $m_k$ , for  $k=1, 2, \dots, n$ , and  $M_{(0)}=(1, 0, 0)_{LL}$ ,  $M_{(n+1)}=(0, 1, 0)_{LL}$ .

From Definition 3.1, we can obtain the following proposition.

**Proposition 3.2** Let  $F: X \rightarrow A_{LL}$  be as in Definition 3.1. Then we have that  $f_2\text{-card } F(k)=(m_k) \wedge (1-m_{(k+1)}, \alpha_{(k)} \vee \beta_{(k+1)}, \beta_{(k)} \wedge \alpha_{(k+1)})_{LL}$  for  $k=0, 1, \dots, n$ , where  $m_{(0)}=1$ ,  $m_{(n+1)}=0$ .

**Proof.** Since  $M_{(k+1)} \in A_{LL}$ , by using Theorem 2.6(2), we have

$$\overline{M^*}_{(k+1)} = (1-m_{(k+1)}, \beta_{(k+1)}, \alpha_{(k+1)})_{LL}.$$

Then, we have

$$\begin{aligned} f_2\text{-card } F(k) &= \min^*\{M_{(k)}, \overline{M^*}_{(k+1)}\} \\ &= (m_{(k)} \wedge (1-m_{(k+1)}), \alpha_{(k)} \vee \beta_{(k+1)}, \\ &\quad \beta_{(k)} \wedge \alpha_{(k+1)})_{LL}. \end{aligned}$$

**Remark 3.3** If

$$F(k) = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=1, 2, \dots, r \\ (0, 0, 0)_{LL} & \text{if } k=r+1, \dots, n \end{cases},$$

then  $F$  is a nonfuzzy set with  $r$  elements by convention.

**Theorem 3.4** Let  $F : X \rightarrow A_{LL}$  be a type-two fuzzy set. Then,

$$f_2 - \text{card}F(k) = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=r \\ (0, 0, 0)_{LL} & \text{if } k \neq r \end{cases}$$

if and only if  $F$  is a nonfuzzy set with  $r$  elements.

**Proof.** Suppose that

$$f_2 - \text{card}F(k) = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=r \\ (0, 0, 0)_{LL} & \text{if } k \neq r \end{cases}$$

When  $k=r$ , we have

$$\begin{aligned} & (m_{(r)} \wedge (1 - m_{(r+1)}), \alpha_{(r)} \vee \beta_{(r+1)}, \beta_{(r)} \wedge \alpha_{(r+1)})_{LL} \\ &= (1, 0, 0)_{LL}. \end{aligned}$$

Thus, we have

$$\begin{aligned} & m_{(r)} \wedge (1 - m_{(r+1)}) = 1, \quad \alpha_{(r)} \vee \beta_{(r+1)} = 0, \\ & \text{and } \beta_{(r)} \wedge \alpha_{(r+1)} = 0. \end{aligned}$$

Since  $m_{(0)} \geq m_{(1)} \geq \dots \geq m_{(n+1)}$  and  $\alpha_{(k)} \vee \beta_{(k+1)} = 0$ ,  $m_{(0)} = m_{(1)} = \dots = m_{(r)} = 1$  and  $m_{(r+1)} = \dots = m_{(n+1)} = 0$ , and

$$\alpha_{(r)} = \beta_{(r+1)} = 0 \quad (3-1)$$

When  $k \neq r$ , we have

$$\begin{aligned} & (m_{(k)} \wedge (1 - m_{(k+1)}), \alpha_{(k)} \vee \beta_{(k+1)}, \beta_{(k)} \wedge \alpha_{(k+1)})_{LL} \\ &= (0, 0, 0)_{LL}. \end{aligned}$$

Then,  $\alpha_{(k)} \vee \beta_{(k+1)} = 0$  and hence

$$\alpha_{(k)} = \beta_{(k+1)} = 0 \quad \text{for all } k \neq 0 \quad (3-2)$$

From (3-1) and (3-2),  $\alpha_{(1)} = \alpha_{(2)} = \dots = \alpha_{(n)} = 0$  and  $\beta_{(1)} = \beta_{(2)} = \dots = \beta_{(n)} = 0$ . If we put  $F(k) = M_k$ , then we have

$$M_{(k)} = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=1, 2, \dots, r \\ (0, 0, 0)_{LL} & \text{if } k=r+1, \dots, n \end{cases},$$

By Remark 3.3,  $F$  is a nonfuzzy set with  $r$  elements.

Conversely, if we put  $F(x_k) = M_k = (m_k, 0, 0)_{LL}$  for  $k=1, 2, \dots, n$ , by Remark 3.3 and the hypothesis,

$$M_{(k)} = (m_{(k)}, \alpha_{(k)}, \beta_{(k)})_{LL} = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=1, 2, \dots, r \\ (0, 0, 0)_{LL} & \text{if } k=r+1, \dots, n \end{cases},$$

Thus,  $m_{(0)} = m_{(1)} = \dots = m_{(r)} = 1$ ,  $m_{(r+1)} = \dots = m_{(n+1)} = 0$ , and  $\alpha_{(k)} = \beta_{(k)} = 0$  for  $k=1, 2, \dots, n$ . If we set  $m_{(0)} = 1$ ,  $m_{(n+1)} = 0$ ,  $\alpha_{(0)} = \alpha_{(n+1)} = \beta_{(0)} = \beta_{(n+1)} = 0$ , by using the definition of  $f_2 - \text{card} F(k)$ , we have

$$f_2 - \text{card}F(k) = \begin{cases} (1, 0, 0)_{LL} & \text{if } k=r \\ (0, 0, 0)_{LL} & \text{if } k \neq r \end{cases}$$

**Lemma 3.5** Let  $\{a_{(k)}\}_{k=1}^n$  be a sequence in  $[0, 1]$  and  $a_{(1)} \geq a_{(2)} \geq \dots \geq a_{(n)} \geq 0$ . If  $k \geq l$ , then we have  $a_{(k)} \geq a_{(k+1)} \geq a_{(l)}$ .

**Proof.** If  $k \geq l$ , we have either  $k+1 = l$  or  $k+1 < l$ . When  $k+1 = l$ ,  $a_{(k+1)} = a_{(l)}$ ; when  $k+1 < l$ ,  $a_{(k+1)} \geq a_{(l)}$ . Thus,  $a_{(k+1)} \geq a_{(l)}$  and hence  $a_{(k)} \geq a_{(k+1)} \geq a_{(l)}$ .

**Definition 3.6** Let  $M = (m, \alpha, \beta)_{LL}$  and  $N = (n, \gamma, \delta)_{LL}$  be elements of  $A_{LL}$ . Then, we define the order  $\leq$  of  $M$  and  $N$ ;

$$M \leq N \text{ if and only if } m \leq n, \alpha \geq \gamma, \text{ and } \beta \leq \delta.$$

We remark that the condition  $M_{(1)} \geq M_{(2)} \geq \dots \geq M_{(n)}$  is equivalent to the following condition

$$\begin{aligned} & m_{(1)} \geq m_{(2)} \geq \dots \geq m_{(n)}, \quad \alpha_{(1)} \leq \alpha_{(2)} \leq \dots \leq \alpha_{(n)}, \\ & \text{and } \beta_{(1)} \geq \beta_{(2)} \geq \dots \geq \beta_{(n)}. \end{aligned}$$

**Definition 3.7** Let  $G : \{0, 1, \dots, n\} \rightarrow A_{LL}$  be a type -two fuzzy set. Then,  $G$  is said to be convex if

$$G(l) \geq \min^* \{G(k), G(r)\} \text{ whenever } k \leq l \leq r.$$

**Theorem 3.8** Let  $F : X \rightarrow A_{LL}$  be a  $L-L$  type fuzzy number and  $F(x_k) = M_k = (m_k, \alpha_k, \beta_k)_{LL}$  for  $k=1, 2, \dots, n$ . Assume that  $M_{(1)} \geq M_{(2)} \geq \dots \geq M_{(n)}$ . Then,  $f_2 - \text{card} F$  is convex.

**Proof.** When  $k \leq l \leq r$ , we should prove that

$$f_2 - \text{card}F(l) \geq \min^* \{f_2 - \text{card}F(k), f_2 - \text{card}F(r)\}.$$

By Definition 3.7, it is sufficient to show that

- (i)  $\{m_{(k)} \wedge (1 - m_{(k+1)})\} \wedge \{m_{(r)} \wedge (1 - m_{(r+1)})\} \leq m_{(l)} \wedge (1 - m_{(l+1)})$ ,
- (ii)  $\{\alpha_{(k)} \vee \beta_{(k+1)}\} \vee \{\alpha_{(r)} \vee \beta_{(r+1)}\} \geq \alpha_{(l)} \vee \beta_{(l+1)}$ , and
- (iii)  $\{\beta_{(k)} \wedge \alpha_{(k+1)}\} \wedge \{\beta_{(r)} \wedge \alpha_{(r+1)}\} \leq \beta_{(l)} \wedge \alpha_{(l+1)}$ .

Since  $m_{(k)} \geq m_{(l)} \geq m_{(r)}$  when  $k \leq l \leq r$ , by using Lemma 3.5,

$$m_{(k)} \geq m_{(k+1)} \geq m_{(l)} \geq m_{(l+1)} \geq m_{(r)} \geq m_{(r+1)}.$$

Thus, we have

$$\begin{aligned} & \{m_{(k)} \wedge (1 - m_{(k+1)})\} \wedge \{m_{(r)} \wedge (1 - m_{(r+1)})\} \\ & \leq (1 - m_{(k+1)}) \wedge m_{(r)} \\ & \leq (1 - m_{(l+1)}) \wedge m_{(l)} \\ & = m_{(l)} \wedge (1 - m_{(l+1)}) \end{aligned}$$

Hence (i) holds. Since  $\alpha_{(k)} \leq \alpha_{(l)} \leq \alpha_{(r)}$  and  $\beta_{(k)} \geq \beta_{(l)} \geq \beta_{(r)}$  when  $k \leq l \leq r$ , by using Lemma 3.5, we have

$$\alpha_{(k+1)} \leq \alpha_{(k)} \leq \alpha_{(l+1)} \leq \alpha_{(l)} \leq \alpha_{(r+1)} \leq \alpha_{(r)}$$

and

$$\beta_{(k+1)} \geq \beta_{(k)} \geq \beta_{(l+1)} \geq \beta_{(l)} \geq \beta_{(r+1)} \geq \beta_{(r)}.$$

Then, we have

$$\begin{aligned} \{\alpha_{(k)} \vee \beta_{(k+1)}\} \vee \{\alpha_{(r)} \vee \beta_{(r+1)}\} &\geq \alpha_{(k)} \vee \beta_{(r+1)} \\ &\geq \alpha_{(l)} \vee \beta_{(l+1)}, \end{aligned}$$

and

$$\begin{aligned} \beta_{(k)} \wedge \alpha_{(k+1)} \wedge \{\beta_{(r)} \wedge \alpha_{(r+1)}\} &\leq \beta_{(k)} \wedge \alpha_{(r+1)} \\ &\leq \beta_{(l)} \wedge \alpha_{(l+1)}. \end{aligned}$$

Hence (ii) and (iii) hold.

**Theorem 3.9** Let  $F : X \rightarrow A_{LL}$  be a type-two fuzzy set and

$$F(x_k) = M_k = (m_k, \alpha_k, \beta_k)_{LL} \text{ for } k=1, 2, \dots, n.$$

If  $M_{(1)} \geq M_{(2)} \geq \dots \geq M_{(n)}$ , then we have

$$f_2\text{-card } \overline{F}(k) = f_2\text{-card } F(n-k) \text{ for } k=0, 1, \dots, n.$$

where

$$\overline{F}^*(k) = \overline{M}_k^* = (1 - m_k, \beta_k, \alpha_k)_{LL} \text{ for } k=1, 2, \dots, n.$$

**Proof.** If we put  $\overline{F}^*(k) = M'_k$  and  $M'_k = (m'_k, \alpha'_k, \beta'_k)_{LL}$  for  $k=1, 2, \dots, n$ , by using the hypothesis  $M_{(1)} \geq M_{(2)} \geq \dots \geq M_{(n)}$ , then we have

$$M'_{(1)} \leq M'_{(2)} \leq \dots \leq M'_{(n)}.$$

That is,

$$(i) \quad m'_{(k)} = 1 - m_{(n-k+1)},$$

$$(ii) \quad \alpha'_{(k)} = \beta_{(n-k+1)},$$

$$(iii) \quad \beta'_{(k)} = \alpha_{(n-k+1)}.$$

From (i),(ii),and (iii), we have

$$\begin{aligned} f_2\text{-card } \overline{F}^*(k) &= \min^* \{M'_{(k)}, \overline{M}'_{(k+1)}\} \\ &= (m'_{(k)} \wedge (1 - m'_{(k+1)}), \alpha'_{(k)} \vee \beta'_{(k+1)}, \beta'_{(k)} \wedge \alpha'_{(k+1)})_{LL} \\ &= ((1 - m_{(n-k+1)}) \wedge m_{(n-k)}, \beta_{(n-k+1)} \vee \alpha_{(n-k)}, \alpha_{(n-k+1)} \wedge \beta_{(n-k)})_{LL} \\ &= (m_{(n-k)} \wedge (1 - m_{(n-k+1)}), \alpha_{(n-k)} \vee \beta_{(n-k+1)}, \beta_{(n-k)} \wedge \alpha_{(n-k+1)})_{LL} \\ &= f_2\text{-card } F(n-k) \end{aligned}$$

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