Malaya Journal of Matematik, Vol. 8, No. 4, 2273-2276, 2020
https://doi.org/10.26637/MJM0804/0162

Semigroups on some new operations over intuitionistic fuzzy matrices

T. Muthuraji [1,2]

Abstract
In this article, different kinds of component wise max-max operations are introduced on intuitionistic fuzzy matrix and some algebraic properties are studied together with the component wise min-min($\wedge_m$) operation . Also some semigroup algebraic structures are constructed using these new operations on intuitionistic fuzzy matrices.

Keywords
Intuitionistic Fuzzy Set (IFS), Intuitionistic Fuzzy Matrix (IFM), Semigroup.

AMS Subject Classification
03E72, 15B15, 94D05.

[1] *Department of Mathematics, Annamalai University, Annamalainagar-608002, Tamil Nadu, India.*
[2] *(On Deputation) PG and Research Department of Mathematics, Government Arts College, Chidambaram, India.*
***Corresponding author**: [1] tmuthuraji@gmail.com
Article History: Received **11** October **2020**; Accepted **19** December **2020**

Contents

1. Introduction

The concept of fuzzy set has been found to be an effective tool to deal with fuzziness. However it often falls short of the expected standard in the description of neutral state. As a result a new concept called IFS was introduced by Atanassov in [1], when it is possible to model hesitation and uncertainty by using an additional degree. Later on, much fundamental works with new operations have done with concept by Atanassov in [2]. Im et.al. generalizes fuzzy matrix as IFM in [6, 7] and they studied the determinant and adjoint of square IFMs. Khan et al. established the same in [8] which has been useful in dealing with the areas such as decision making, relational equations, clustering analysis etc. Intuitionistic fuzzy algebra and its matrix theory are considered by several researchers in using component wise max-min and min-max operations in various years as follows.

In [1, 2] Atanassov defined component wise $\max-\min$ $(\vee)$ and $\min-\max(\wedge)$ operations on IFSs. Khan and Pal in [9] extended and investigated some operations on IFM and introduced intuitionistic fuzzy matrix product. From that a semi ring structure was constructed on IFM using the operations max-min intuitionistic fuzzy matrix product with component wise max-min operation in [14]. Ragab and Emam discussed some properties on $\min-\max$ fuzzy matrix product in [12] and then Emam and Fndh developed it to bi fuzzy matrices in [5]. Generalized interval valued IFMs was constructed by Adak et al. and have shown some a semiring structure in [3]. At the same time they initiated some properties of generalized intuitionistic fuzzy nilpotent matrices over distributive lattices in [4]. In this way the author introduced component wise $\min-\min(\wedge_m)$ operation on IFMS and an IFM decomposition was shown in [11]. Riyaz and Murugadas developed $\max-\max$ intuitionistic fuzzy matrix product in [13] and Lalitha in [10] discussed $\min-\min$ intuitionistic fuzzy matrix product. In this study some new kinds of $\max-\max$ (component wise) operations are introduced in section 3 and various algebraic properties are studied and semigroup structure is constructed.

Motivation of this work

All the research works on IFS theory as well as IFM theory based on the operations max-min($\vee$) and min-max($\wedge$) (component wise). From that the author introduced component wise min-min($\wedge_m$) operation in [13] and an IFM decomposition is obtained from modal operators. In this manner we why we can't consider component max-max operation, the reason for that is sometimes it affects the structure of intuitionistic fuzzy theory.

The aim of this work is how to handle this operation $\max-\max(\vee_m)$ without affecting structure within corresponding element of an IFM.

2. Preliminaries

Here some basic definitions and operations are recalled which are related to our study.

Intuitionistic Fuzzy Set and its Algebraic Operations

Definition 2.1. *[1, 2] An IFS A in E (universal set) is defined as an object of the following form* $A=\{(x,\mu_A(x)),\gamma_A(x)/x\in E\}$, *where the functions* $\mu_A(x):E\to[0,1]$ *and* $\gamma_A(x):E\to[0,1]$ *define the membership and non-membership function of the element* $x\in E$ *respectively for every* $x\in E, 0\leq\mu_A(x)+\gamma_A(x)\leq 1$.

For our convenience consider the elements of IFSs as in the form (x,x').
Let $(x,x'),(y,y')\in$ IFS, define

1. $(x,x')\vee(y,y')=[\max(x,y),\min(x',y')]$.
2. $(x,x')\wedge(y,y')=[\min(x,y),\max(x',y')]$.
3. $(x,x')^c=(x',x)$.
4. If $(x,x')\leq(y,y')$ then $x\leq y$ and $x'\geq y'$.

Intuitionistic Fuzzy Matrix and its Operations

Definition 2.2. *[8, 9] An intuitionistic fuzzy matrix* $A=[(a_{ij},a'_{ij})]_{m\times n}$ *be a matrix where* a_{ij} *and* a'_{ij} *are the membership value and non membership value of the* ij^{th} *element of A satisfying the condition that* $0\leq a_{ij}+a'_{ij}\leq 1$ *for all i, j as well as its operations are defined as follows*

For any two elements $A=[(a_{ij},a'_{ij})], B=[(b_{ij},b'_{ij})]\in\mathscr{F}_{mn}$, $\mathscr{F}_{mn}$ denotes the set of all IFMs of order $m\times n$.
Where $i=1,2,\cdots,m$, $j=1,2,\cdots,n$ define

1. $A\vee B=[(a_{ij},a'_{ij})\vee(b_{ij},b'_{ij})]$.
2. $A\wedge B=[(a_{ij},a'_{ij})\wedge(b_{ij},b'_{ij})]$.
3. $A^c=[(a'_{ij},a_{ij})]$.
4. $A^T=[(a_{ji},a'_{ji})]$.
5. If $A\leq B$ then $a_{ij}\leq b_{ij}$ and $a'_{ij}\geq b'_{ij}$ for all i,j

Different types of IFMs

For all $i=1,2,\cdots,m$, $j=1,2,\cdots,n$, $A=[(a_{ij},a'_{ij})]$ we have

1. If $(a_{ij},a'_{ij})=(1,0)$ when $i=j$ otherwise $(a_{ij},a'_{ij})=(0,1)$ then the matrix A is said to be identity matrix denoted to I_n.
2. If $(a_{ij},a'_{ij})=(1,0)$ for all i,j then A is said to an universal matrix denoted by J.
3. If $(a_{ij},a'_{ij})=(0,1)$ for all i,j then A is said to be zero matrix denoted by 0.

Definition 2.3. *[11] Let* $A,B\in\mathscr{F}_{mn}$, *define* $[A\wedge_m B]=[(a_{ij},a'_{ij})\wedge_m(b_{ij},b'_{ij})]=[\min(a_{ij},b_{ij}),\min(a'_{ij},b'_{ij})]\forall i,j$.

Lemma 2.4. *[11] '$\wedge_m$'is commutative and associative.*

3. Different kinds of component wise max-max operations on IFMs

Now let us define various kinds of max-max operations on IFMs as follows:

Definition 3.1. *Let* $A,B\in\mathscr{F}_{mn}$, *define '$\vee_m$'in three kinds for all i, j.*

(i) $A\vee_{m1}B=[(a_{ij},a'_{ij})\vee_{m1}(b_{ij},b'_{ij})]$

$$=\begin{cases}[\max(a_{ij},b_{ij}),\max(a'_{ij},b'_{ij})] & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})\leq 1\\(0.5,0.5) & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})>1\end{cases}$$

(ii) $A\vee_{m2}B=[(a_{ij},a'_{ij})\vee_{m2}(b_{ij},b'_{ij})]$

$$=\begin{cases}[\max(a_{ij},b_{ij}),\max(a'_{ij},b'_{ij})] & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})\leq 1\\(1,0) & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})>1\end{cases}$$

(iii) $A\vee_{m3}B=[(a_{ij},a'_{ij})\vee_{m3}(b_{ij},b'_{ij})]$

$$=\begin{cases}[\max(a_{ij},b_{ij}),\max(a'_{ij},b'_{ij})] & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})\leq 1\\(0,1) & \text{if } \max(a_{ij},b_{ij})+\max(a'_{ij},b'_{ij})>1\end{cases}$$

The intuitionistic fuzzy matrix representation can be illustrated by the following example.

Consider a group of articles received by a journal as $a_1,a_2,a_3,\cdots,a_m$ which are under reviewed by two reviewers by 'n'qualities like originality, soundness and validity of contents, clarity of presentation, adequacy of references to literature, general interest in this subject etc. In this case, the articles are crisp, they are fixed, but the qualities measured by the reviewers are fuzzy qualities. Let the matrix A and B denote the gradation of each article in each quality from two reviewers.

Here the entry (a_{ij}) represents the percentage of marks to accept the i_{th} article under j_{th} quality given by the reviewer and the entry (a'_{ij}) represents the percentage of marks to reject the i_{th} article under j_{th} quality given by the reviewer. Let us assume that we have three articles to be reviewed under three qualities by two reviewers with some arbitrary membership and non membership then the matrix A, B are given as follows

$$A=\begin{bmatrix}(0.6,0.3) & (0.0,1.0) & (0.8,0.0)\\(0.2,0.3) & (0.8,0.1) & (0.7,0.1)\\(0.5,0.2) & (1.0,0.0) & (0.1,0.2)\end{bmatrix}$$

$$B=\begin{bmatrix}(0.5,0.3) & (1.0,0.0) & (0.6,0.1)\\(0.3,0.5) & (0.2,0.7) & (0.4,0.5)\\(0.3,0.5) & (0.0,1.0) & (0.4,0.3)\end{bmatrix}$$

Now consider the corresponding entries of $(1,2),(2,2)$, $(2,3)$ and $(3,2)$indicate that the opinion about that particular i^{th} article under j_{th} quality is differ totally. In this case if we choose max-min($\vee$) then the editor's gradation using max-min operation go with first reviewer only. Similarly for min-max go with second reviewer. But in max-max operations we distribute the maximum element as $(0.5,0.5)$ or the maximum element $(1,0)$ or minimum element $(0,1)$ as it is for editors gradation since the averaging operator does not satisfy many algebraic properties including associativity. Suppose the corresponding entries are not comparable under inequality which is defined in definition 2.1 then the previous operation takes the value either (a_{ij},a'_{ij}) or (b_{ij},b'_{ij}).

Lemma 3.2. *The operations '$\vee_{m1}$', '$\vee_{m2}$'and '$\vee_{m3}$'are commutative.*

Proof. Let $A,B \in \mathscr{F}_{mn}$,
$$\begin{aligned} A \vee_{m1} B &= [\max(a_{ij},b_{ij}),\max(a'_{ij},b'_{ij})] \\ &= [\max(b_{ij},a_{ij}),\max(b'_{ij},a'_{ij})] \\ &= B \vee_{m1} A. \end{aligned}$$ □

Lemma 3.3. *The operations '$\vee_{m1}$, '$\vee_{m2}$ and '$\vee_{m3}$'are associative.*

Proof. Let $A,B,C \in \mathscr{F}_{mn}$.
Consider any ij^{th} entry of $(B \vee_{m1} C)$ as follows
$$(b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}) = \begin{cases} [\max(b_{ij},c_{ij}),\max(b'_{ij},c'_{ij})] & \text{if } \max(b_{ij},c_{ij})+\max(b'_{ij},c'_{ij}) \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Case 1. If $(b_{ij},b'_{ij}) \ge (c_{ij},c'_{ij})$ then
$$(b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}) = \begin{cases} (b_{ij},c'_{ij}) & \text{if } b_{ij}+c'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Subcase 1.1
If $(a_{ij},a'_{ij}) \ge (b_{ij},b'_{ij}) \ge (c_{ij},c'_{ij})$ and $b_{ij}+c'_{ij} \le 1$ then the corresponding $(i,j)^{th}$ element of
$$[A \vee_{m1} (B \vee_{m1} C)] = \begin{cases} (a_{ij},c'_{ij}) & \text{if } a_{ij}+c'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Suppose $b_{ij}+c'_{ij} > 1$ then the ij^{th} entry of $[A \vee_{m1} (B \vee_{m1} C)]$
$$\begin{aligned} &= [\max(a_{ij},0.5),\max(a'_{ij},0.5)] \\ &= \begin{cases} (0.5,0.5) & \text{when } a_{ij} < 0.5 \text{ and } a'_{ij} < 0.5 \\ (0.5,0.5) & \text{when } a_{ij} < 0.5 \text{ and } a'_{ij} > 0.5 \\ (0.5,0.5) & \text{when } a_{ij} > 0.5 \text{ and } a'_{ij} < 0.5 \end{cases} \end{aligned}$$
since $a_{ij}+a'_{ij} \le 1$. Therefore $A \vee_{m1} (B \vee_{m1} C)$
$$= \begin{cases} (a_{ij},c'_{ij}) & \text{if } b_{ij}+c'_{ij} \le 1 \text{ and } a_{ij}+c'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Now consider the same in
$$[A \vee_{m1} B] = \begin{cases} (a_{ij},b'_{ij}) & \text{if } a_{ij}+b'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
$[(A \vee_{m1} B) \vee_{m1} C]$
$$= \begin{cases} (a_{ij},c'_{ij}) & \text{if } b_{ij}+c'_{ij} \le 1 \text{ and } a_{ij}+c'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Thus $[(A \vee_{m1} B) \vee_{m1} C] = [A \vee_{m1} (B \vee_{m1} C)]$.
Subcase 1.2
If $(b_{ij},b'_{ij}) \ge (a_{ij},a'_{ij}) \ge (c_{ij},c'_{ij})$ then similar to subcase 1.1 the ij^{th} entry of
$$\begin{aligned} [A \vee_{m1} (B \vee_{m1} C)] &= \begin{cases} (b_{ij},c'_{ij}) & \text{if } b_{ij}+c'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases} \\ &= [(A \vee_{m1} B) \vee_{m1} C]. \end{aligned}$$
Subcase 1.3
If $(b_{ij},b'_{ij}) \ge (c_{ij},c'_{ij}) \ge (a_{ij},a'_{ij})$ then similar to subcase 1.1 the ij^{th} entry of $[A \vee_{m1} (B \vee_{m1} C)$
$$\begin{aligned} &= \begin{cases} (b_{ij},a'_{ij}) & \text{if } b_{ij}+c'_{ij} \le 1 \text{ and } b_{ij}+a'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases} \\ &= [(A \vee_{m1} B) \vee_{m1} C]. \end{aligned}$$
Case 2. Suppose $(b_{ij},b'_{ij}) \le (c_{ij},c'_{ij})$ then
$$(b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}) = \begin{cases} (c_{ij},b'_{ij}) & \text{if } c_{ij}+b'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Subcase 2.1
If $(b_{ij},b'_{ij}) \le (c_{ij},c'_{ij}) \le (a_{ij},a'_{ij})$ then the ij^{th} entry of
$$[A \vee_{m1} (B \vee_{m1} C)] = \begin{cases} (a_{ij},b'_{ij}) & \text{if } a_{ij}+b'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Also $[A \vee_{m1} B] = \begin{cases} (a_{ij},b'_{ij}) & \text{if } a_{ij}+b'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$
$$[(A \vee_{m1} B) \vee_{m1} C] = \begin{cases} (a_{ij},b'_{ij}) & \text{if } a_{ij}+b'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
Thus in this case also $[A \vee_{m1} (B \vee_{m1} C)] = [(A \vee_{m1} B) \vee_{m1} C]$.
Similarly we can prove sub case 2.2 and 2.3 when
$(b_{ij},b'_{ij}) \le (a_{ij},a'_{ij}) \le (c_{ij},c'_{ij})$ and
$(a_{ij},a'_{ij}) \le (b_{ij},b'_{ij}) \le (c_{ij},c'_{ij})$.
Case 3: Suppose for some i and j the elements of IFMs are not comparable then
$$(a_{ij},a'_{ij}) \vee_{m1} (b_{ij},b'_{ij})] = \begin{cases} (a_{ij},a'_{ij}) & \text{if } a_{ij} \ge b_{ij} \text{ and } a'_{ij} \ge b'_{ij} \\ (b_{ij},b'_{ij}) & \text{if } b_{ij} \ge a_{ij} \text{ and } b'_{ij} \ge a'_{ij} \end{cases}$$
$((a_{ij},a'_{ij}) \vee_{m1} (b_{ij},b'_{ij})) \vee_{m1} (c_{ij},c'_{ij})$
$$= \begin{cases} (a_{ij},a'_{ij}) & \text{if } a_{ij} \ge b_{ij} \text{ and } a_{ij} \ge c_{ij} \text{ and } a'_{ij} \ge b'_{ij} \text{ and } a'_{ij} \ge c'_{ij} \\ (c_{ij},c'_{ij}) & \text{if } a_{ij} \ge b_{ij} \text{ and } c_{ij} \ge a_{ij} \text{ and } a'_{ij} \ge b'_{ij} \text{ and } c'_{ij} \ge a'_{ij} \\ (b_{ij},b'_{ij}) & \text{if } b_{ij} \ge a_{ij} \text{ and } b_{ij} \ge c_{ij} \text{ and } b'_{ij} \ge a'_{ij} \text{ and } b'_{ij} \ge c'_{ij} \end{cases}$$
Similarly we have
$$(b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}) = \begin{cases} (b_{ij},b'_{ij}) & \text{if } b_{ij} \ge c_{ij} \text{ and } b'_{ij} \ge c'_{ij} \\ (c_{ij},c'_{ij}) & \text{if } c_{ij} \ge b_{ij} \text{ and } c'_{ij} \ge b'_{ij} \end{cases}$$
$[(a_{ij},a'_{ij}) \vee_{m1} ((b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}))]$
$$= \begin{cases} (b_{ij},b'_{ij}) & \text{if } b_{ij} \ge c_{ij} \text{ and } b_{ij} \ge a_{ij} \text{ and } b'_{ij} \ge c'_{ij} \text{ and } b'_{ij} \ge a'_{ij} \\ (c_{ij},c'_{ij}) & \text{if } c_{ij} \ge b_{ij} \text{ and } c_{ij} \ge a_{ij} \text{ and } c'_{ij} \ge b'_{ij} \text{ and } c'_{ij} \ge a'_{ij} \\ (a_{ij},a'_{ij}) & \text{if } c_{ij} \ge b_{ij} \text{ and } a_{ij} \ge c_{ij} \text{ and } c'_{ij} \ge b'_{ij} \text{ and } a'_{ij} \ge c'_{ij} \end{cases}$$
Thus in this case also $[A \vee_{m1} (B \vee_{m1} C)] = [(A \vee_{m1} B) \vee_{m1} C]$.
Case 4: In this case, among the three IFMs suppose for some i,j two of them comparable and third is not comparable for example $(a_{ij},a'_{ij}) \le (b_{ij},b'_{ij})$ but (c_{ij},c'_{ij}) is comparable then
$$(a_{ij},a'_{ij}) \vee_{m1} (b_{ij},b'_{ij}) = \begin{cases} (b_{ij},a'_{ij}) & \text{if } b_{ij}+a'_{ij} \le 1 \\ (0.5,0.5) & \text{otherwise} \end{cases}$$
$$(b_{ij},b'_{ij}) \vee_{m1} (c_{ij},c'_{ij}) = \begin{cases} (b_{ij},b'_{ij}) & \text{if } b_{ij} \ge c_{ij} \text{ and } b'_{ij} \ge c'_{ij} \\ (c_{ij},c'_{ij}) & \text{if } c_{ij} \ge b_{ij} \text{ and } c'_{ij} \ge b'_{ij} \end{cases}$$
$((a_{ij},a'_{ij}) \vee_{m1} (b_{ij}.b'_{ij})) \vee_{m1} (c_{ij},c'_{ij})$
$$= \begin{cases} (b_{ij},a'_{ij}) & \text{if } b_{ij}+a'_{ij} \le 1 \text{ and } b_{ij} \ge c_{ij} \text{ and } a'_{ij} \ge c'_{ij} \\ (c_{ij},c'_{ij}) & \text{if } b_{ij}+a_{ij} \le 1 \text{ and } c_{ij} \ge b_{ij} \text{ and } c'_{ij} \ge a'_{ij} \\ (0.5,0.5) & \text{otherwise} \end{cases}$$

Similarly on the other hand
$(a_{ij},a'_{ij})\vee_{m1}((b_{ij}.b'_{ij})\vee_{m1}(c_{ij},c'_{ij}))$
$=\begin{cases}(b_{ij},a'_{ij}) & \text{if } b_{ij}\geq c_{ij} \text{ and } b_{ij}\geq a_{ij} \text{ and } a'_{ij}\geq c'_{ij} \text{ and } b'_{ij}\geq c'_{ij}\\ (c_{ij},c'_{ij}) & \text{if } c_{ij}\geq a_{ij} \text{ and } c_{ij}\geq b_{ij} \text{ and } c'_{ij}\geq a'_{ij} \text{ and } c'_{ij}\geq b'_{ij}\\ (0.5,0.5) & \text{otherwise}\end{cases}$
Thus the component wise $\max-\max(\vee_{m1})$ is associative whether the elements of any IFM are comparable or not. In this way we shall prove '$\vee_{m2}$'and '$\vee_{m3}$'are also associative. □

Lemma 3.4. *'$\vee_m$'and '$\wedge_m$ are idempotent.*

Proof. $A\vee_m A=[\max(a_{ij},a_{ij}),\max(a'_{ij},a'_{ij})]$
$=(a_{ij},a'_{ij})=A.$
Clearly $A\vee_m A=A$ and $A\wedge_m A=A$.
From lemma 3.2 and 2.1, the following theorem is trivial. □

Theorem 3.5. *The structures* $[\mathscr{F}_{mn},\vee_{m1}],[\mathscr{F}_{mn},\vee_{m2}],[\mathscr{F}_{mn},\vee_{m3}]$ *and* $[\mathscr{F}_{mn},\wedge_m]$ *form a semi group.*

4. Conclusion

All the results which were proved earlier in intuitionistic fuzzy theory based on the usual composition operator $\wedge$ (meet) and $\vee$ (join). In this work different kinds component wise max-max operations are introduced directly on IFMs. Some algebraic properties are investigated. In future all the previous works done using usual component wise max-min and min-max operations may be redirected to these max-max and min-min operations.

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ISSN(P):2319 − 3786
Malaya Journal of Matematik
ISSN(O):2321 − 5666
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