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Fuzzy algorithm to decompose combinational conditions and Conclusions in fuzzy systems

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Abstract— ***This paper describes an algorithm to decompose the combination arising from multidimensional conditions into individual crisp value and thereby improving the fuzzy modelling. Numerical value of each combination "c" is calculated first. Formulation of relation matrix between "c" and "z" is the next step. Next step is the calculation of crisp value of each component is the final step. The algorithm is demonstrated in this paper with the help of a case study for calculating the combination of resources like N and K2O to realize the targeted yield of cassava in the agro climatic zone 12 of India***

Keywords— Fuzzy logic, Cassava, Targeted yield, Algorithm, Defuzzification

1. INTRODUCTION

Fuzzy logic (FL) provides a simple way to arrive at precise conclusions from vague and imprecise input information[3]. FL is an effective tool for modelling complex mathematical problems with parameters that demonstrate uncertainty[2]. The systems existing in agriculture are generally vague especially when dealt from farmers point of view. Modelling these systems is a complex task and fuzzy logic is a suitable option to do it[1]. In such complex systems each parameter of the system is governed by many other parameters. Fuzzy rules connecting the parameters may involve multidimensional conditions/conclusions. In some cases many such conditions together or separately leads to a conclusion. By combining the fuzzy sets involved in these conditions through maximum/minimum operation we arrive at a single fuzzy set with single membership function. In the modelling process relations can be formulated by combining membership functions of the fuzzy sets representing the attributes through maximum or minimum functions. Membership function of the condition/conclusion obtained through generalised modus ponens (GMP)/generalised modus tollens (GMT) result in the membership function of the combination. By defuzzifying it we get the crisp value of the combination. This paper describes an algorithm to decompose the combination into individual crisp value and thereby improving the fuzzy modelling

II. ALGORITHM

Let X={ x1,x2 ..... xn}, Y={ y1,y2 ..... yn} and Z={ z1,z2 ..... zn}.

Let A1,A2, A3 and A4 be three fuzzy sets

A1={ (x1, μ A1(x1)), (x2, μ A1(x2)), (x3, μ A1 (x3))}
A2={ (x2, μ A2 (y1)), (x3, μ A2 (y2)), (x4, μ A2 (y3))}
A3={ (y1, μ A3 (y1)), (y2, μ A3 (y2)), (y3, μ A3 (y3))}
A4={ (y3, μ A4 (y3)), (y4, μ A4 (y4)), (y5, μ A4 (y5))}

P1={ (z1, μ P1 (z1)), (z2, μ P1 (z2)), (z3, μ P1 (z3))}
P2={ (z2, μ P2 (z2)), (z3, μ P2 (z3)), (z4, μ P2 (z4))}

To define the system, relations between these fuzzy sets are established. These relations are:
R1: if x ϵ A1 and y ϵ A3 then p ϵ P1
R2: if x ϵ A1 and y ϵ A4 then p ϵ P1
R3: if x ϵ A2 and y ϵ A3 then p ϵ P2
R4: if x ϵ A2 and y ϵ A4 then p ϵ P2

Implication relation R1 can be represented as:

$$R1(x,y,z) = \max\left(\min\left(A1, A3\right)\times P1, (1-\min\left(A1, A3\right))\times Z\right)$$

min(A1,A3) X P1=

	z1	z2	z3
c1	min(μ(c1), μ(z1))	min(μ(c1), μ(z2))	min(μ(c1), μ(z3))
c2	min(μ(c2), μ(z1))	min(μ(c2), μ(z2))	min(μ(c2), μ(z3))
c3	min(μ(c3), μ(z1))	min(μ(c3), μ(z2))	min(μ(c3), μ(z3))
c4	min(μ(c4), μ(z1))	min(μ(c4), μ(z2))	min(μ(c4), μ(z3))
c5	min(μ(c5), μ(z1))	min(μ(c5), μ(z2))	min(μ(c5), μ(z3))
c6	min(μ(c6), μ(z1))	min(μ(c6), μ(z2))	min(μ(c6), μ(z3))
c7	min(μ(c7), μ(z1))	min(μ(c7), μ(z2))	min(μ(c7), μ(z3))
c8	min(μ(c8), μ(z1))	min(μ(c8), μ(z2))	min(μ(c8), μ(z3))
c9	min(μ(c9), μ(z1))	min(μ(c9), μ(z2))	min(μ(c9), μ(z3))

(1-min(A1,A3)) X Z =

	z1	z2	z3
c1	min(μ(c1), 1)	min(μ(c1), 1)	min(μ(c1), 1)
c2	min(μ(c2), 1)	min(μ(c2), 1)	min(μ(c2), 1)
c3	min(μ(c3), 1)	min(μ(c3), 1)	min(μ(c3), 1)
c4	min(μ(c4), 1)	min(μ(c4), 1)	min(μ(c4), 1)
c5	min(μ(c5), 1)	min(μ(c5), 1)	min(μ(c5), 1)
c6	min(μ(c6), 1)	min(μ(c6), 1)	min(μ(c6), 1)
c7	min(μ(c7), 1)	min(μ(c7), 1)	min(μ(c7), 1)
c8	min(μ(c8), 1)	min(μ(c8), 1)	min(μ(c8), 1)
c9	min(μ(c9), 1)	min(μ(c9), 1)	min(μ(c9), 1)

where,
c1=min(μ A1(x1), μ A3 (y1)),
c2=min(μ A1(x1), μ A3 (y2)),
c3=min(μ A1(x1), μ A3 (y3)),
c4=min(μ A1(x2), μ A3 (y1)),
c5=min(μ A1(x2), μ A3 (y2)),
c6=min(μ A1(x2), μ A3 (y3)),
c7=min(μ A1(x3), μ A3 (y1)),
c8=min(μ A1(x3), μ A3 (y2)) and
c9=min(μ A1(x3), μ A3 (y3))

similarly other relations are represented as:

$$R2(x,y,z) = \max\left(\min\left(A1, A4\right)\times P1, (1-\min\left(A1, A4\right))\times Z\right)$$
$$R3(x,y,z) = \max\left(\min\left(A2, A3\right)\times P2, (1-\min\left(A2, A3\right))\times Z\right)$$
$$R4(x,y,z) = \max\left(\min\left(A2, A4\right)\times P2, (1-\min\left(A2, A4\right))\times Z\right)$$

The relation R representing the system can be denoted as:
R= R1(x,y,z) U R2(x,y,z) U R3(x,y,z) U R4(x,y,z)

For doing fuzzy inference through GMT, following steps should be followed

Step 1: Compute a numerical value (NVc i,) for each of the combinations c i, where i=1(1)n
Let ci represent the combination on n fuzzy values (log(vi,1),μ(v i,1)), (log(vi,2),μ(v i,2)), (log(vi,3),μ(v i,3)), ... (log(vi,n),μ(v i,n)),

$$NVc_i = \sum_{l=1}^{n} v_{i,l} \times 10^{(l-1)3+2}$$

Vi,l should be represented as floating point value round off to one position.

Step 2: Find out the relation matrix R(c,z) representing relation between c and z as:

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$$R(c, z) = \begin{array}{c} \\ c1 \\ c2 \\ - \\ - \\ - \\ - \\ - \\ cn \end{array} \begin{pmatrix} z1 & z2 & z3 \\ \max(\min(\mu(c1), \mu(z1)), \min(\mu(c1), 1)) & - & - \\ - & - & - \\ - & - & - \\ - & - & - \\ - & - & - \\ - & - & - \\ - & - & - \\ - & - & \max(\min(\mu(cn),\mu(z3)),\min(\mu(cn),1)) \end{pmatrix}$$

Let the implication relation between c and z is given by the relation
IF x=C THEN z=D
To find out x from the R(x,y) Generalised Modus Tollens procedure can be used as

IF x=C THEN z=D
z=D'
____
x=C'

From this step the numerical value NVc' corresponding to C' is obtained.
Step 3: Calculation of the components of C'

$$V_i = \frac{V_{i-1} - \text{int}\left(\frac{V_{i-1}}{10^{(i-1)3}}\right)10^{(i-1)3}}{10^{(l-1)3-1}} \quad ,i=1,2....n$$

V0=NVc
V1 is the value at the most significant position

III. RESULTS AND DISCUSSIONS

While developing a fuzzy model from the data sets of a system, compound conditions may exist in the fuzzy relations between various attributes of the system. Same conditions giving same fuzzy outputs can be grouped together and simplified using OR operation
If a1 ϵ X1 AND b1 ϵ X2 THEN c1=Y OR
If a2 ϵ X1 AND b2 ϵ X2 THEN c1=Y OR
If a3 ϵ X1 AND b3 ϵ X2 THEN c1=Y

All these conditions can be summarised into one condition as
if (a1 ϵ X1 AND b1 ϵ X2) OR (a2 ϵ X1 AND b2 ϵ X2) OR (a3 ϵ X1 AND b3 ϵ X2) THEN c1=Y
Let the whole condition be denoted as P and the result as Q so that P => Q is true
Membership function of P, μ(P) is given by

$\mu(P) = \max(\min(\mu(a1), \mu(b1)), \min(\mu(a2), \mu(b2)), \min(\mu(a3), \mu(b3)))$
A single relation matrix showing the relation between the combination of all the conditions and the conclusion can be formed. From this relation through the procedure of GMT the membership values of the combination can be computed. By defuzzification the crisp value of the combination can be worked out. By following this algorithm each component of the combination can be calculated.

A case study where this algorithm is used for calculating the combination of resources like N and K2O to realize a targeted yield of cassava in the agro climatic zone 12 of India is given below:
Potential yield of cassava in the agro climatic zone 12 of India varies between 22.4 Mg ha-1 and 112.5 Mg ha-1. The average temperature of the zone varies between 160C and 330C and the average daily sunshine hours varies between 3 and 11. Average daily precipitation of the region is around 8 mm.

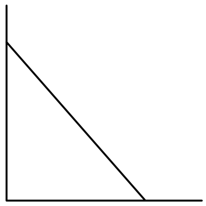
The potential yield of cassava(DMT) is divided into three fuzzy sets low(LDMT), medium(MDMT) and high(HDMT). These sets are defined as:

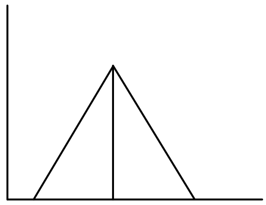
LDMT= $\{x/0 \le x \le 40\}$,

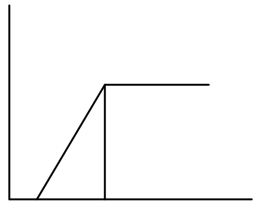
MDMT= $\{x/30 \le x \le 70\}$ and

HDMT= $\{x/x \ge 55\}$

Membership function for these classes are:







LDMT: $\frac{1}{1+x}$

MDMT : $\begin{Bmatrix} \frac{x-30}{50-30}, 30 \le x \le 50 \\ \frac{70-x}{70-50}, 50 < x \le 70 \end{Bmatrix}$

HDMT: $\frac{x-55}{130-55}$

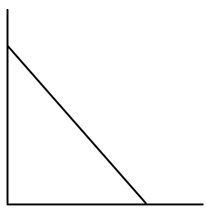
The yield of cassava obtained in the field (DMTWNK) in this zone ranges between about 12-45 Mg ha-1 This is divided into three fuzzy sets low DMTWNK (LDMTWNK), medium DMTWNK (MDMTWNK) and high DMTWNK (HDMTWNK). These sets are defined as:

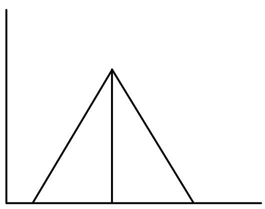
LDMTWNK = $\{x/0 \le x \le 15\}$,

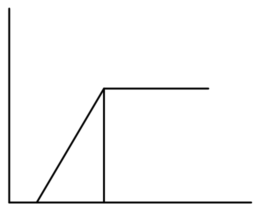
MDMTWNK = $\{x/10 \le x \le 30\}$ and

HDMTWNK = $\{x/x \ge 50\}$

Membership function for these classes are:







LDMTwnk: $\frac{1}{1+x}$

MDMTwnk : $\begin{Bmatrix} \frac{x-10}{20-10}, 10 \le x \le 20 \\ \frac{30-x}{30-20}, 20 < x \le 30 \end{Bmatrix}$

HDMTwnk: $\frac{x-50}{70-50}$

Average daily mean temperature (TEMP) is divided into three fuzzy sets low (LT), medium (MT) and high (HT). These sets are defined as:

LT = $\{x/0 \le x \le 24\}$,

MT = $\{x/21 \le x \le 27\}$ and

HT = $\{x/x \ge 25\}$

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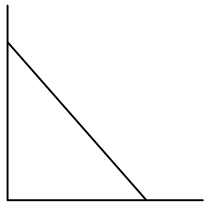
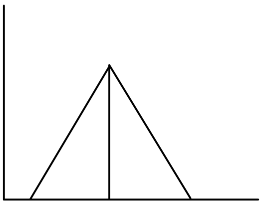
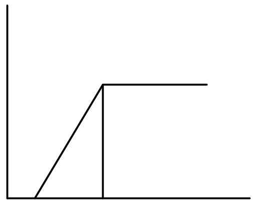
Membership function for these classes are:







LT: $\frac{1}{1+x}$

MT : $\begin{Bmatrix} \frac{x-21}{24-21}, 21 \le x \le 24 \\ \frac{27-x}{27-24}, 24 < x \le 27 \end{Bmatrix}$

HT: $\frac{x-25}{30-25}$

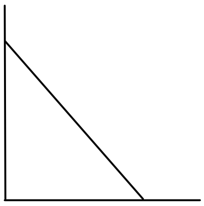
Sunshine hours (SHR) is divided into three fuzzy sets low sunshine(LS), medium sunshine(MS) and high sunshine(HS). These sets are defined as:

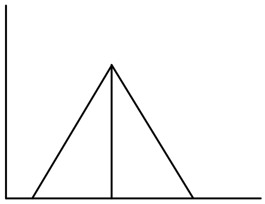
LS = $\{x / 0 \le x \le 5\}$,

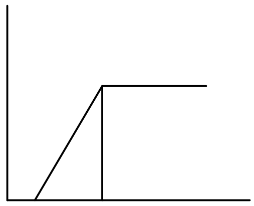
MS = $\{x / 4 \le x \le 8\}$ and

HS = $\{x / x \ge 7\}$

Membership function for these classes are:







LS: $\frac{1}{1+x}$

MS : $\begin{Bmatrix} \frac{x-4}{6-4}, 4 \le x \le 6 \\ \frac{8-x}{8-6}, 6 < x \le 8 \end{Bmatrix}$

HS: $\frac{x-7}{10-7}$

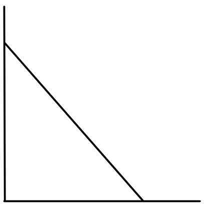
Precipitation (PPTN) is divided into three fuzzy sets low precipitation(LP), medium precipitation (MP) and high precipitation (HP). These sets are defined as:

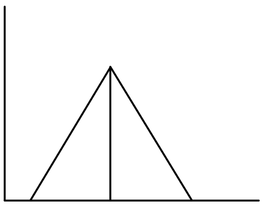
LP = $\{x / 0 \le x \le 10\}$,

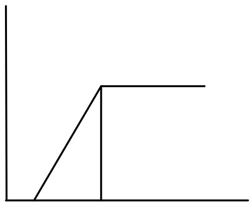
MP = $\{x / 8 \le x \le 18\}$ and

HP = $\{x / x \ge 16\}$

Membership function for these classes are:







LP: $\frac{1}{1+x}$

MP : $\begin{Bmatrix} \frac{x-8}{13-8}, 8 \le x \le 13 \\ \frac{18-x}{18-13}, 13 < x \le 18 \end{Bmatrix}$

HP: $\frac{x-16}{20-16}$

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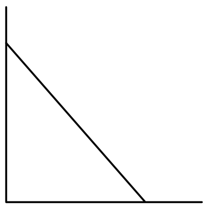
Nitrogen(N) can be applied to cassava up to around 100 kg ha-1 to obtain yield increase. The quantity of N applied is divided into three fuzzy sets low N (LN), medium N (MN) and high N (HN). These sets are defined as:

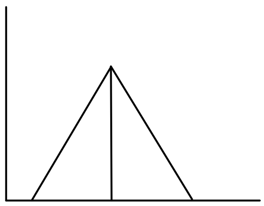
LN = $\{x / 0 \le x \le 60\}$,

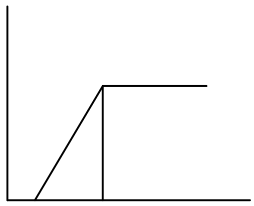
MN = $\{x / 40 \le x \le 105\}$ and

HN = $\{x / x \ge 80\}$

Membership function for these classes are:







LN: $\frac{1}{1+x}$

$$MN: \begin{cases} \frac{x-40}{72.5-40}, 40 \le x \le 72.5 \\ \frac{105-x}{105-72.5}, 72.5 < x \le 105 \end{cases}$$

HN: $\frac{x-80}{115-80}$

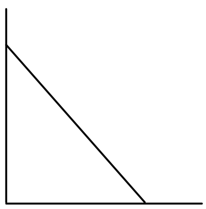
Potassium (K) also can be applied to cassava up to around 100 kg ha-1 to obtain yield increase. The quantity of K applied is divided into three fuzzy sets low K (LK), medium K (MK) and high K (HK). These sets are defined as:

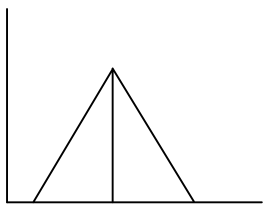
LK = $\{x / 0 \le x \le 60\}$,

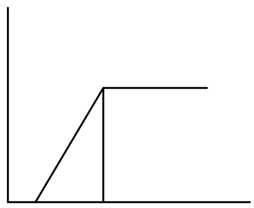
MK = $\{x / 40 \le x \le 105\}$ and

HK = $\{x / x \ge 80\}$

Membership function for these classes are:







LK: $\frac{1}{1+x}$

$$MK: \begin{cases} \frac{x-40}{72.5-40}, 40 \le x \le 72.5 \\ \frac{105-x}{105-72.5}, 72.5 < x \le 105 \end{cases}$$

HK: $\frac{x-80}{115-80}$

After examining the data carefully following fuzzy rules were formulated to define the implication relation to determine DMTWNK.

IF LS and LP and LDMT and LN and LK THEN LDMTWNK or MDMTWNK or HDMTWNK
IF MS and L P and LDMT and L N and L K THEN LDMTWNK or MDMTWNK or HDMTWNK
IF HS and L P and LDMT and L N and L K THEN LDMTWNK or MDMTWNK or HDMTWNK
IF LS and M P and LDMT and L N and L K THEN LDMTWNK or MDMTWNK or HDMTWNK
IF MS and M P and LDMT and L N and L K THEN LDMTWNK or MDMTWNK or HDMTWNK
IF H S and M P and L DMT and L N and L K THEN LDMTWNK or MDMTWNK or HDMTWNK
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Generalized Modus Ponens procedure which was followed to predict DMTWNK was:

$$\frac{\begin{array}{c}\text{If } x \text{ is } A \text{ THEN } y \text{ is } B \\ x \text{ is } \neg A\end{array}}{y \text{ is } \neg B}$$

Where,
A is the conjunction of fuzzy sets of sunshine hours, precipitation, DMT, N and K
B is the fuzzy set of DMTWNK.

In this case the clients input the yield and what the output they want is the quantity of N,K and water to be applied to realize that yield. Hence we follow Generalized Modus Tollens procedure as:

If x is A THEN y is B
y is ¬B
x is ¬A

Thus we get the output x ϵ A.

The implication relation R(x,y) between A and B (Table) is derived using the fuzzy rules given in Appendix. Numerical value of each of the combinations is computed (Table 1) as per the algorithm described. Combination is taken in the order given below:

SHR,PPTN,DMT,N,K

position=5
Most significant variable

position=1
Least significant variable

R(x,y) =

						DMT_{WNK}	
SHR	PPTN	DMT	N	K	L	M	H
L	L	L	L	L	0	0	0
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
L	L	M	L	L	0	0	0.038462
M	L	M	L	L	0.090909	0.038462	0.038462
-	-	-	-	-	-	-	-
L	L	H	L	L	0	0.090909	0.038462
M	L	H	L	L	0.090909	0.090909	0.038462
H	L	H	L	L	0.090909	0.090909	0.038462
L	M	H	L	L	0	0.090909	0.038462
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-
M	M	H	M	M	0	0	0.288391
H	M	H	M	M	0	0	0
L	H	H	M	M	0	0	0.139511
M	H	H	M	M	0	0	0.139511
L	L	H	H	H	0	0	0.103404
M	L	H	H	H	0.16611	0.343168	0.33333
H	L	H	H	H	0.106383	0.679744	0.092088
L	M	H	H	H	0	0	0.238385
-	-	-	-	-	-	-	-
L	H	H	H	H	0	0	0.139511
M	H	H	H	H	0	0	0.139511
H	H	H	H	H	0	0	0

If the yield targeted by the client is 60 Mg ha-1, then to find out the water, K and N required for realizing the yield composition rule can be used as:

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NVC= [0,0,0.5] × R(x,y)T

In this equation [0,0,0.5] shows the membership function values of targeted yield in the fuzzy sets LDMTWNK, MDMTWNK and LDMTWNK respectively.

NVC was computed as 78070211185185.0

By following the algorithm, this value can be decomposed into the values of SHR, PPTN, DMT, N and K.

SHR=6.03 hrs; PPTN=5.01 mm; DMT=128.82; N=70.79; K=70.79;

TABLE 1
NUMERICAL VALUE OF FUZZY SET COMBINATIONS OF SHR,PPTN,DMT,N AND K

SHR	PPTN	DMT	N	K	$NVc_i = \sum_{l=1}^{n} v_{i,l} \times 10^{(l-1)4+1}$
L	L	L	L	L	3000500200003000000.00
M	L	L	L	L	6000500200003000000.00
H	L	L	L	L	10000500200003000000.00
L	M	L	L	L	3001300200003000000.00
M	M	L	L	L	6001300200003000000.00
H	M	L	L	L	10001300200003000000.00
L	H	L	L	L	3002000200003000000.00
M	H	L	L	L	6002000200003000000.00
H	H	L	L	L	10002000200003000000.00
L	L	M	L	L	3000500500003000000.00
M	L	M	L	L	6000500500003000000.00
H	L	M	L	L	10000500500003000000.00
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