APPLICATION OF A FUZZY LOGIC ORDERING METHOD TO PRELIMINARY MECHANISM DESIGN

APPLICATION D'UNE MÉTHODE DE CLASSEMENT PAR LA LOGIQUE FLOUE À LA CONCEPTION PRELIMINAIRE DE MÉCANISMES

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1 - INTRODUCTION

About **fuzzy logic** :
- Considerable **growth** in various domains
- Still **underused** in mechanical engineering
- Of promising interest in the **early stages of design**, where qualitative reasoning is mostly performed

Our **work** :
- Integration of fuzzy logic in a **geared mechanism preliminary design system**
- Fuzzy logic fits perfectly to the **vagueness of the designer knowledge** at this early stage of design
- This method is an **interesting alternative** to conventional multi-criterion methods because it directly uses qualitative data

2 - NATURE OF THE PROBLEM

Purpose : improving our existing geared mechanism preliminary design system [FAU.97] with fuzzy logic. This program provides a list of mechanical solutions which comply with given specifications.

A 3 step method (*Fig. 1*)

1. Scanning of the mechanical solution domain

2. Elimination of candidates which do not meet the design rules

3. Sorting of the remaining candidates by preference order

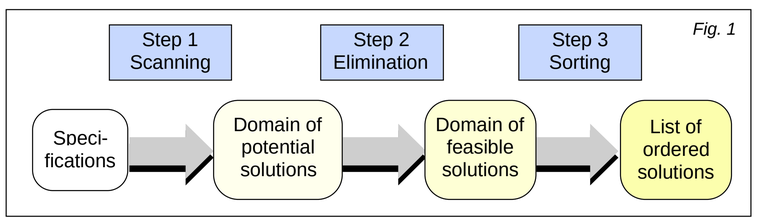

Fig. 1

Focus on step 3 (ordering)

The existing ordering method = classical multi-criterion ordering method (*Fig. 2*) :
- A **mark** for each solution ⇒ ordered list of solutions
- The mark of solution *Mi* is the **mean** of the *Ne* elementary stage marks
- **Weighting coefficients** *Kc* permit to adjust the respective influence of criteria.

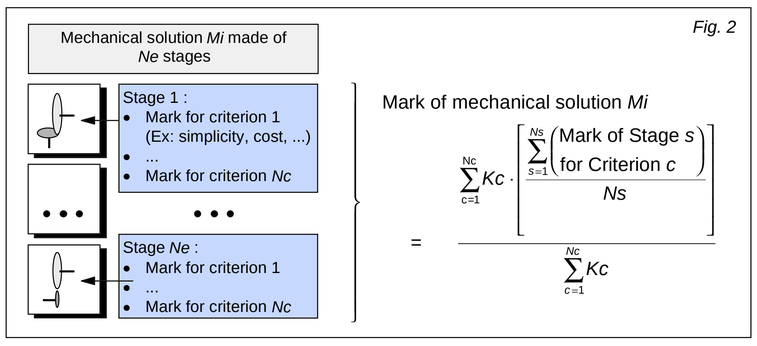

Fig. 2

Advantages of the multi-criterion method :
- **Simplicity** (for programmer as well as for user)
- Execution **speed**
- **Reliable** and practically confirmed **results**

Drawbacks :
- Necessity of giving **numerical marks** instead of "thinking qualitative"
- The global mark is a **mixing** of several quantities which are **not of the same nature**

3 - FUZZY ALGORITHM

Goal : defining the "**fuzzy comparison**" notion ⇒ easy to implement a "**fuzzy sorting**" method for step 3.

Example : Two mechanical solutions A and B must be compared (*Table 3*)
- Each one made of **two stages** (respectively A1, A2 et B1, B2)
- Evaluated according to **two criteria** (named C1 and C2)

Table 3	Solution A		Solution B	
Criteria	Stage A1	Stage A2	Stage B1	Stage B2
Criterion C1	G	VB	G	M
Criterion C2	VB	B	B	VG

Color code
VG : Very Good
G : Good
M : Medium
B : Bad
VB : Very Bad

- Five **quality classes** are used, each one being defined by a **triangular shape membership function** (*Fig. 6*).
- The number of quality classes might be increased for bigger problems.

4 - FUZZY COMPARISON PRINCIPLE

Comparison between two solutions A and B is a **3 phase process** (Fig.4) :
- First each solution is **evaluated** according to each criterion
- Then solutions are **compared criterion by criterion**
- Finally, all the **comparisons are mixed up** in a global comparison

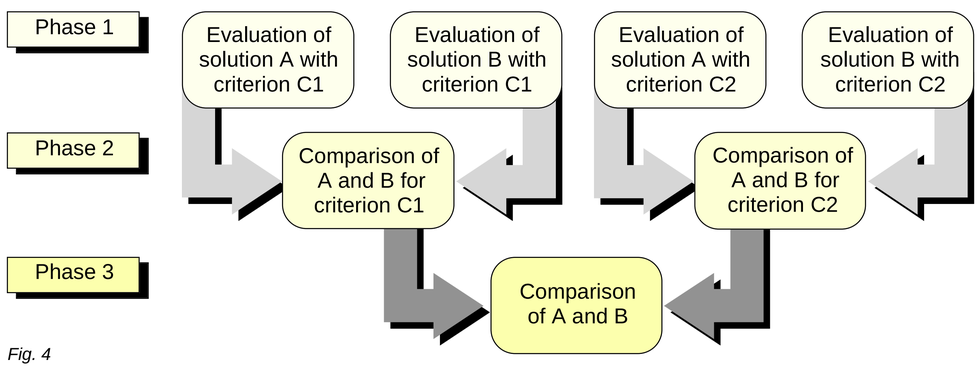

Fig. 4

5 - PHASE 1 : Evaluation of each solution according to a criterion

Quality evaluation of the constitutive stages of solution A according to criterion C1 (*Tab. 5*)

Table 5	Solution A	
Criteria	Stage A1	Stage A2
Criterion C1	G	VB

Mamdani method : the barycentre of the areas delimited by the corresponding membership functions is calculated (*Fig. 6*).

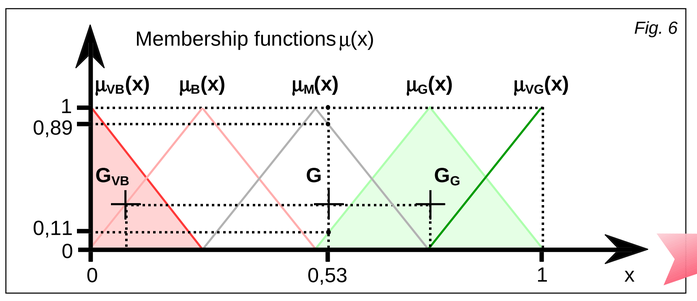

Fig. 6

Abscissa of the global barycentre (x = 0,53) gives the membership degrees of solution A to each of the five quality classes.

This calculation is repeated identically for solution B and criterion C2 (*Tab. 7*)

	Table 7	Value of x	VB	B	M	G	VG
Eval. of	A according to C1	0,53	0,00	0,00	0,89	0,11	0,00
	B according to C1	0,63	0,00	0,00	0,50	0,50	0,00
	A according to C2	0,19	0,22	0,78	0,00	0,00	0,00
	B according to C2	0,47	0,00	0,11	0,89	0,00	0,00

6 - PHASE 2 : Comparison of the solutions for each criterion

Five degrees of comparison between solutions are defined (*Tab. 8*)

Table 8	Solution B				
Solution A	VB	B	M	G	VG
VB	E	S	VS	VS	VS
B	I	E	S	VS	VS
M	VI	I	E	S	VS
G	VI	VI	I	E	S
VG	VI	VI	VI	I	E

Color code
VS : Very Superior
S : Superior
E : Equivalent
I : Inferior
VI : Very Inferior

Comparison of A and B according to C1. The left rule is equivalent to the right one :

If (B has the same quality degree as A) Then (B is Equivalent to A) ⇔ If ((B='VB' And A='VB') Or (B='B' And A='B') Or (B='M' And A='M') Or (B='G' And A='G') Or (B='VG' And A='VG')) Then (B is Equivalent to A)

We then use **Mamdani definition [FOU.94] for the AND connector** : $\mu_{P \text{ and } Q(x,y)} = \min(\mu_{P(x)}, \mu_{Q(y)})$

This definition is applied and illustrated in *Table 9* for criterion C1 only : the numerical value in each cell is obtained by taking the **minimum** of the corresponding row and column values.

Table 9	Solution B (with membership values)				
Solution A (val.)	VB (0,00)	B (0,00)	M (0,50)	G (0,50)	VG (0,00)
VB (0,00)	E (0,00)	S (0,00)	VS (0,00)	VS (0,00)	VS (0,00)
B (0,00)	I (0,00)	E (0,00)	S (0,00)	VS (0,00)	VS (0,00)
M (0,89)	VI (0,00)	I (0,00)	E (0,50)	S (0,50)	VS (0,00)
G (0,11)	VI (0,00)	VI (0,00)	I (0,11)	E (0,11)	S (0,00)
VG (0,00)	VI (0,00)	VI (0,00)	VI (0,00)	I (0,00)	E (0,00)

Then, Mamdani definition for the **OR connector** is used : $\mu_{P \text{ or } Q(x,y)} = \max(\mu_{P(x)}, \mu_{Q(y)})$

Next, *Table 10* is constructed in this way : for each comparison degree in *Table 9* (coloured areas), the only value to be kept is the maximum one.

Table 10	VI	I	E	S	VS
Criterion C1	0,00	0.11	0,50	0,50	0,00
Criterion C2	0,00	0,00	0,11	0,78	0,22

Thus, for instance, we can see from *Table 10* that there is a 50 % probability that B is superior to A according to C1 and 78 % according to C2.

7 - PHASE 3 : Final comparison

Combining the various comparisons (one per criterion) in a unique one :

Reasoning : "If there is superiority according to C1 and inferiority according to C2 then there is equivalence". This can be translated into :

If ((C1='S') And (C2='I')) Then ('E')

Next, we apply the same process as in Step 2 (**min** operator for *Table 11*, **max** operator for *Table 12*).

Table 11	Criterion C2 (with membership values)				
Criterion C1 (val.)	VI (0,00)	I (0,00)	E (0,11)	S (0,78)	VS (0,22)
VI (0,00)	I (0,00)	I (0,00)	I (0,00)	I (0,00)	E (0,00)
I (0,11)	I (0,00)	I (0,00)	I (0,11)	E (0,11)	S (0,11)
E (0,50)	I (0,00)	I (0,00)	E (0,11)	S (0,50)	S (0,22)
S (0,50)	I (0,00)	E (0,00)	S (0,11)	S (0,50)	S (0,22)
VS (0,00)	E (0,00)	S (0,00)	S (0,00)	S (0,00)	S (0,00)

Proposition "S" (i.e. B > A) seems to be the most plausible because its membership function has the highest value of all.

Thus, this result confirms what *Table 3* already seemed to suggest.

Table 12	I	E	S
Combined criteria	0,11	0,11	0,50

8 - COMPARATIVE EXAMPLE

Comparison between the **traditional** ordering method with its **fuzzy version** :

As we did not want to loose the subtleties contained in the expert database, we chose to use a **seven quality degree representation** (instead of five for the example). Of course, this choice leads to a heavier computational load.

Set of 1016 mechanical solutions ordered with the **traditional multi-criterion method** :
- Marks on a scale of 100
- Duration : 10 seconds

Set of 1016 mechanical solutions ordered with the **new fuzzy logic method** :
- Marks : seven quality degree representation
- Duration : 180 seconds

As for the quality of the resulting set (that is to say the good ordering of solutions, see *Fig. 13*), it is similar in both cases.

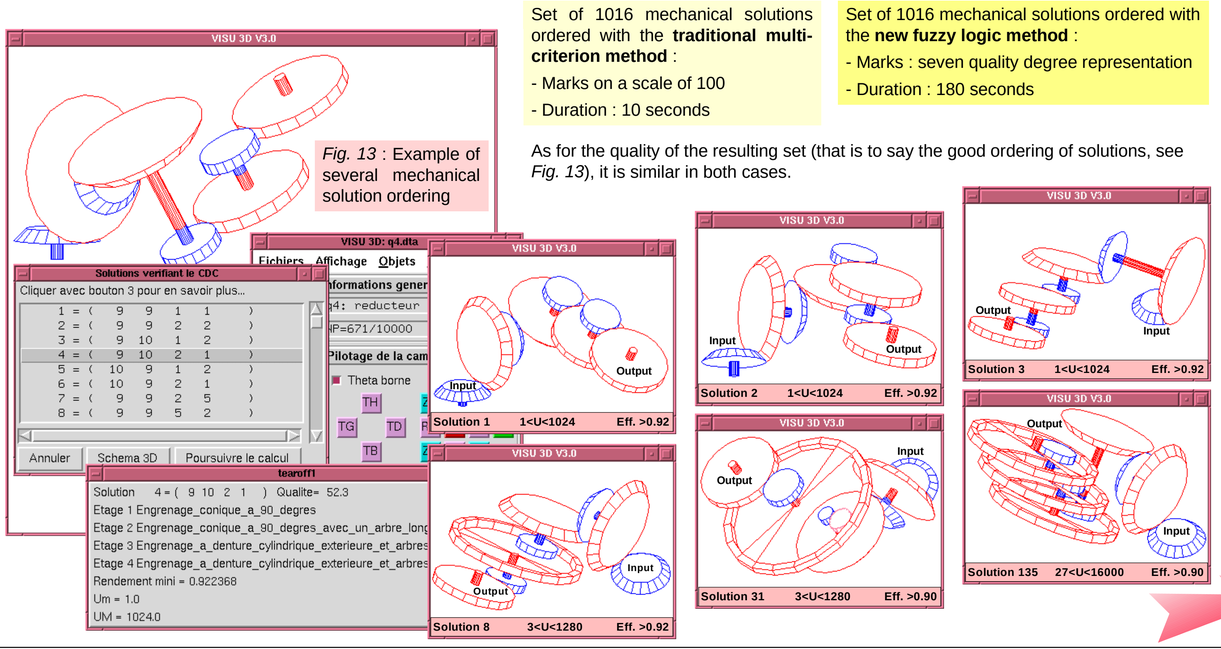

Fig. 13 : Example of several mechanical solution ordering

9 - CONCLUSION

*Undeniably, fuzzy logic suits perfectly the **representation of qualitative information**, such as those used at the beginning of a design process. The fuzzy algorithm previously described gives **correct results**, similar to those obtained with the traditional method. It is **more satisfactory for representing expert knowledge** and fits well to ordinary human expression.*

*However, these qualities are obtained at the cost of **heavier computations**.*

References

[DUB.94] DUBOIS Didier, PRADE Henri. « Ensembles flous et théorie des possibilités : notions de base », ARAGO 14 - Logique Floue, Masson (France), 1994, N° ISBN 2-22-584474-7, pp. 29-62.

[FAU.97] FAUROUX Jean-Christophe, SARTOR Marc. « Conception qualitative de mécanismes. Application aux réducteurs à engrenages », AUM'97, Poitiers (France), 1er-5 septembre 1997, Vol. 3, pp. 319-322.

[FOU.94] FOULLOY Laurent, TITLI André. « Aspects généraux de la commande floue », ARAGO 14 - Logique Floue, Masson (France), 1994, N° ISBN 2-22-584474-7, pp. 64-79.

[THU.92] THURSTON D.L., CARNAHAN J.V. « Fuzzy ratings and utility analysis in preliminary design evaluation of multiple attributes », Journal of Mechanical Design, Vol. 114, Dec. 1992, pp. 648-658.