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PREDICTING THE DIFFICULTY OF WEAVING A NEW FABRIC USING ARTIFICIAL INTELLIGENCE (FUZZY LOGIC)

M. EL BAKKALI[#1], R. MESSNAOUI[#2], O. CHERKAOUI[#3] and AZIZ SOULHI[*4]

[#]Ecole Supérieure des Industries du Textile et de l'Habillement
Route El Jadida Km 8, BP : 7731, Casablanca Morocco
[*] Ecole Nationale Supérieure des Mines de Rabat, Rabat, Morocco
ORCID: 10000-0003-3285-2040.
20000-0003-1904-513X; Scopus Author ID: 42162322200
E-mail:[1]elbakkali@esith.ac.ma , [2]messnaoui@esith.ac.ma , [3]cherkaoui@esith.ac.ma, [4]Soulhi@enim.ac.ma

ABSTRACT

This research work presented in this paper is the modelling of the prediction of the weavability of a new fabric at the time of its creation. Using artificial intelligence (fuzzy logic), we show the feasibility of a decision support model for designers and production experts. This model is based on fuzzy set theory and uses knowledge and expertise to help designers predict the degree of difficulty in making new fabric and to avoid material waste, time loss, and material damage. With this model, designers have more opportunity to choose the right decisions. Below we find an application of this model based on fuzzy logic. The simulations produced convincing results, and demonstrated the extent to which the knowledge and expertise of weaving experts can be exploited to anticipate production problems.
Keywords: *Weaving, Weavability Limits, Fuzzy Logic, Modelling, Saturation Index.*

1. INTRODUCTION

After 23 years of experience in different weaving companies, the problem for the designers of new fabrics is that we don't know how the weaveability [1] of the new fabric will be on the loom. Therefore, each time a new fabric is created, a sample piece must be made to judge the feasibility and weaving problems before marketing. This sometimes results in loss of time, materials, and damage to the material. In general, the problem that arises is that it is necessary to consider the saturation of fabrics at the weaving level[2][3]. This can be defined as the maximum number of threads and wefts inserted in each fabric.

The fuzzy logic model can be used to solve weaveability problems when creating a new fabric [4]. It considers the weaving saturation criteria, the warp saturation index, the weft saturation index, and the fabric saturation index.

The integration of artificial intelligence (AI) in the textile domain to predict fabric properties is an active and promising research topic. In fact, Lalita Sunil Admuthe and Shaila Apte[5] have used an approach combining adaptive neuro-fuzzy inference system (ANFIS) and subtractive clustering to predict yarn properties. ANFIS is a neuro-fuzzy network-based inference system that combines the advantages of neural networks and fuzzy systems to model and predict complex relationships.
Subtractive clustering, on the other hand, is a data clustering technique that aims to identify underlying structures in a data set. It is used here to prepare input data for ANFIS by identifying groups of similar threads.

In their study, Tanveer Hussain, Abdul Jabbar and Shakeel Ahmed[6] demonstrated that adaptive neuro-fuzzy models slightly outperform the regression model in predicting compressed air consumption in air-jet weaving. These models have potential for estimating compressed air consumption, detecting air leaks, etc.

Murat Kodaloglu and Feyza Akarslan Kodaloglu[7] examined the use of fuzzy logic to assess temperature physiology and occupational health in weaving companies. The detection of risks in the working environment is the most crucial factor in the prevention of occupational diseases, work-related health problems and accidents.

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Predicting the weavability of a new fabric is a complex problem that requires an in-depth understanding of the characteristics of the material, the manufacturing techniques, and the specific requirements of the weaving process. Fuzzy logic is an approach that allows this complexity to be considered by using linguistic variables and rules based on the expertise of professionals in the field.

The scientific papers below have used artificial intelligence in the weaving sector, except that none of the work has dealt with the weavability of a new item. Therefore, our contribution is to use fuzzy logic to predict the weavability of a new product.

The basic methodology used to predict the degree of weavability of a fabric included the following sections: The second section begins with a presentation of the different criteria (saturation indices) [2]. We then present the concept of fuzzy logic in Section 3: the transformation of real values that have an impact on the output parameter into fuzzy values (membership function) by fuzzification. The fourth section presents the simulation of the model and the main results obtained. Finally, conclusions and future research directions are provided in Section 5.

2. PRESENTATION OF THE DIFFERENT SATURATION INDICES

In this paragraph we show the following formula of different saturation index:

Warp saturation index: (Iswarp or Iswp)

$$Iswarp\% = 100 \times \frac{Cwp}{Cwp_{\max}}$$

Weft saturation index: (Isweft or Iswf)

$$Isweft\% = 100 \times \frac{Cwf}{Cwf_{\max}}$$

Woven fabric saturation index:

$$Isw = \frac{Iswp \times Iswf}{100}$$

Cwarp: the warp thread count
Cweft: the weft thread count

Several research has been made to determine the formulas of these saturation indices. Love's equations[2], Peirce's theory [8], Ashenhurst's theory [9], Law's rules [10] , Brierley's theory [11] , Russell's index [3], Seyam and El Shiekh's saturation formulas [12][13], Booten's index [14] and M.DALAL’s relations [4]

With the following assumptions:

Assumption 1: The wire cross-section is assumed to be cylindrical. [15][16][17]

Assumption 2: if the wire count is contracted, the wires are separated only by a wire thickness (value of a diameter).

Assumption 3: the linear density and the density of the material (g/cm3) are known and homogeneous.

The formulas for these indices are as follows:

a. For woven fabric 2D (1 warp and 1 weft):

$$Iswp = K \times Cwp \times \left(\sqrt{\frac{Twp}{\phi \rho_{fwp}}} + (1-\alpha)\frac{Nwf}{Rwp}\sqrt{\frac{Twf}{\phi \rho_{fwf}}} \right)$$

$$Iswf = K \times Cwf \times \left(\sqrt{\frac{Twf}{\phi \rho_{fwf}}} + \alpha \frac{Nwp}{Rwf}\sqrt{\frac{Twp}{\phi \rho_{fwp}}} \right)$$

b. For woven fabric with 1 warp and n wefts:

$$Iswp = K \times Cwp \times \left(\sqrt{\frac{Twp}{\phi \rho_{fwp}}} + \alpha \sum_{i=1}^{n} \frac{Nwf_n}{Rwp} \times \sqrt{\frac{Twf_n}{\phi \rho_{fwf_n}}} \right)$$

$$Iswf = Sup_n \left\{ K \times Pwf_n \times Cwf \times \left(\sqrt{\frac{Twf_n}{\phi \rho_{fwf_n}}} + (1-\alpha)\frac{Nwp}{Rwf_n}\sqrt{\frac{Twp}{\phi \rho_{fwp}}} \right) \right\}$$

c. For woven fabric with n warps and 1 weft:

$$Iswp = Sup_n \left\{ K \times Pwp_n \times Cwp \times \left(\sqrt{\frac{Twp_n}{\phi \rho_{fwp_n}}} + \alpha \frac{Nwf}{Rwp_n}\sqrt{\frac{Twf}{\phi \rho_{fwf}}} \right) \right\}$$

$$Iswf = K \times Cwf \times \left(\sqrt{\frac{Twf}{\phi \rho_{fwf}}} + (1-\alpha)\sum_{i=1}^{n} \frac{Nwp_n}{Rwf} \times \sqrt{\frac{Twp_n}{\phi \rho_{fwp_n}}} \right)$$

With: $0 \leq \alpha \leq 1$

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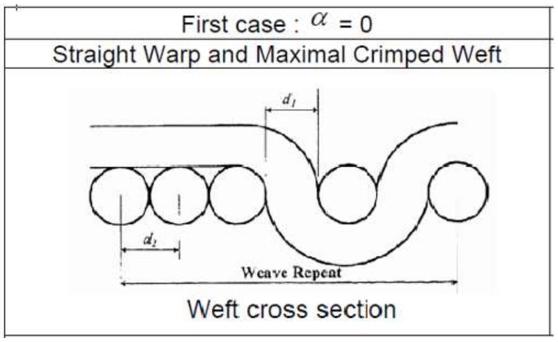
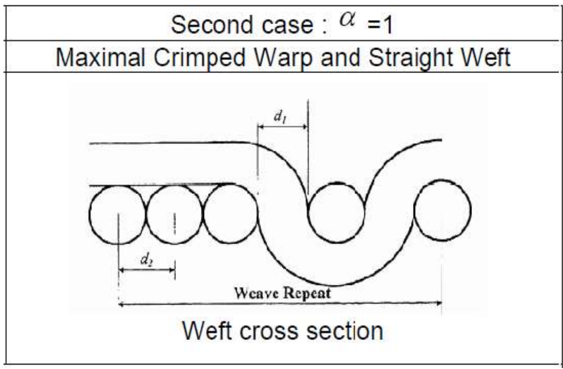


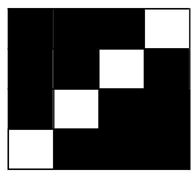


K : Constante (k=0.36) [12]
d1 : warp-thread diameter,
d2 : filling-thread diameter.
Cwp : Warp count per cm
Cwf : Weft count per cm
Pwf : Proportion of weft
Twp : Warp linear density Tex
Twf : Weft linear density Tex
Nwf : Weft number of face change by report
Nwp : Warp number of face change by report
Rwp : Warp pattern report
Rwf : Weft pattern report
n : Number of wefts (or warps)
ρ *f* = fiber density (g/cm3),
n : Number of wefts (or warps)
φ: yarn paking fraction (fiber density / yarn density).

Example of how these indices are calculated:

Data for 100% cotton Jean fabric (1 warp and 1 weft: n=1)

Figure 1. 100% cotton Jean fabric
Weave: 4-ply twill, straight cord effect



K = 0.36
d1 : 0,29 mm
d2 : 0,24 mm.
Cwp : 29,01
Cwf : 21,69
Twp : 99 Tex
Twf : 69 Tex
Nwf : 2
Nwp : 2
Rwp : 4
Rwf : 4
ρ f = 1,51 (g/cm3),
Iswp = 120 %
Iswf = 52%
Isw = 62,4 %

Weaving without problems.

3. THE FUZZY MODEL

Classical logic (Boolean) allows only two states: TRUE or FALSE (0 or 1)[18]. In 1965, Mr. Lotfi Zadeh proposed fuzzy logic which is defined as a set of mathematical principles for the representation of knowledge based on degrees of membership rather than on the raw membership of classical binary logic. For example: the engine is very hot, the engine is hot; what is the difference between hot and very hot?

Fuzzy logic uses a language that allows for

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ambiguous definitions, such as ¨ weak, medium much, little, small, high, dangerous...

In fuzzy logic, a fuzzy set contains several values. The fuzzy set is concerned by a degree of membership (or degree of truth). We use a set of logical values between 0 (false) and 1 (completely true). A membership function is used to map an element X in the real number domain to an interval from 0 to 1, which allows a degree of truth. The membership of a set represents a value between 0 and 1. A fuzzy set can be defined as a set with fuzzy boundaries[19]. A fuzzy set is defined as follows: let's be a set and x a member of this set. A fuzzy subset F of S is defined by a membership function µF(x) which measures the degree to which x belongs to F.

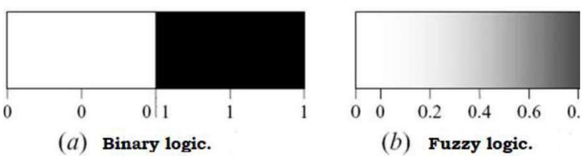


Figure 2. Differentiation between fuzzy logic and Binary Logic [20].

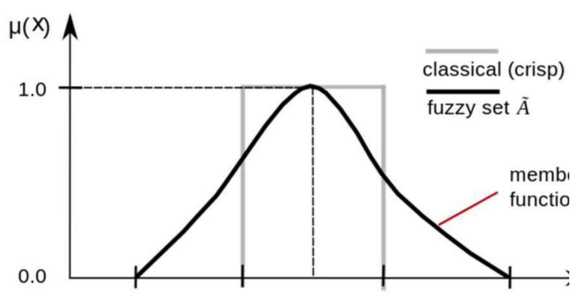


Figure 3. Classic and fuzzy sets.

This figures 1 and 2 illustrate the difference between the functions of membership of the classic logic and the fuzzy logic. In the 1st, the appearance is binary 0 or 1, in mathematical terms, a variable " X " is it contained to a set " E " " or not, on the other hand, in the 2nd degree of appearance is numerical value which varies in the interval [0 1]. Moreover, this variable can belong to several sets at the same time contrary to the classical logic.

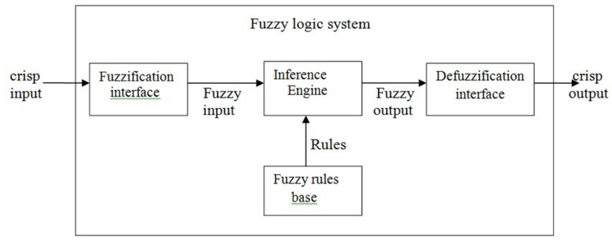


Figure 4. Architecture of fuzzy logic

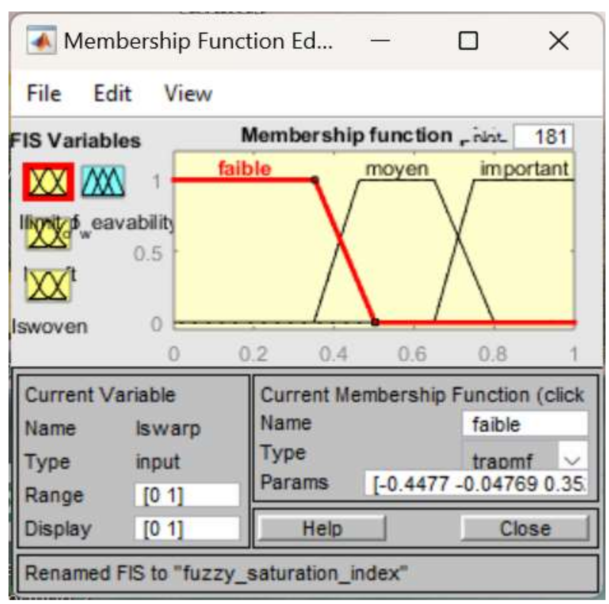
A fuzzy inference system is a system composed of three big bricks: the fuzzification, the inference engine and the defuzzification (Figure 3).

4. FUZZY LOGIC

4.1. *Fuzzification*

It is the operation of converting a classical (numerical) input into a linguistic value.
The membership function is a function that allows setting the degree of membership of a numerical data to a linguistic variable [9].

For example, fuzzification of warp saturation index:



The other indicators are modeled by the same method using the same membership functions characterizing the fuzzy subsets and using the following linguistic terms: □**Negligible, Medium, Important**□.

4.2 *Fuzzy inference*

The fuzzy inference allows us to develop a decision by using the decision rules. The decision rules are described by linguistic terms. [21]

For example:

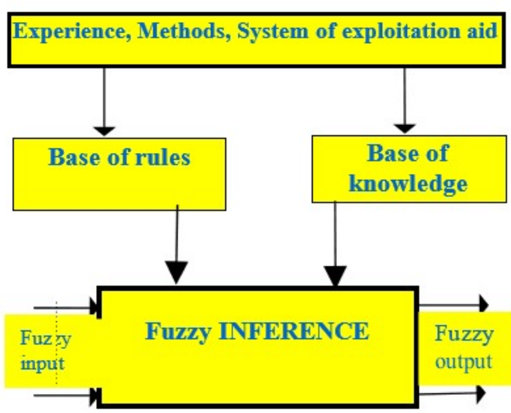
If *the warp saturation index is medium and the weft saturation index is negligible* ***and*** *woven saturation index is negligible* ***then*** *the limit of weavability is negligible.*

If *the warp saturation index is medium and the weft saturation index is medium* ***and*** *woven saturation index is medium,* ***then*** *the limit of weavability is medium.*

If *the warp saturation index is important and the weft saturation index is medium* ***and*** *woven saturation index is important,* ***then*** *the limit of weavability is important.*

Example of the rules base:

Iws: warp saturation index
Iwfs: weft saturation index
Iwos: woven saturation index
Lw: limit of weavability



Fuzzy INFERENCE

Rules of inference:

R_1 : if X_1 is A_{11} and X_2 is A_{12} ...and X_n is A_{1n} then y is C_1
.
.
R_m : if X_1 is A_{m1} and X_2 is A_{m2} ...and X_n is A_{mn} then y est C_m

$X = (X_1, X_2, \ldots\ldots X_n)$: *Vector of inference*
$A = [A_{m,n}]$: *Characteristic Matrix*
$C = (C_1, C_2 \ldots\ldots C_m)$: *Result Vector*

$$\mu_m = \prod_{j=1}^{n} \mu_{mj}(X_n)$$

μ_m : degree to belong of membership function decision class
μ_{mj}: degree to belong of membership function criterion

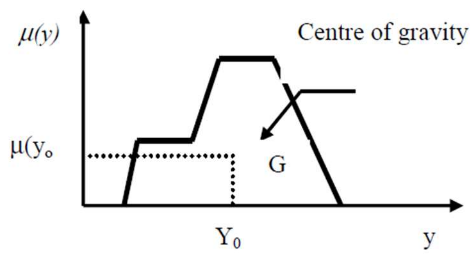
$A = [A_{m,n}]$ C

	Iws	*Iwfs*	*Iwos*		*Lw*
If	*Important*	*Negligible*	*Negligible*	Then	Negligible
	Important	*Important*	*Medium*		Medium
	.	.	.		.
	.	.	.		.

4.3 The defuzzification

The fuzzification is the Linguistic/Numerical conversion of different variables characterizing the global efficiency. The method which is used here is the method of the center of gravity. This method considers all available information.

$$Y_0 = \frac{\int_y y \times \mu(y)\,dy}{\int_y \mu(y)\,dy}$$



4. SIMULATIONS RESULTS

Several important special cases will be dealt with, helping to make the right decision of weaveability according to the warp and weft counts and their thickness.

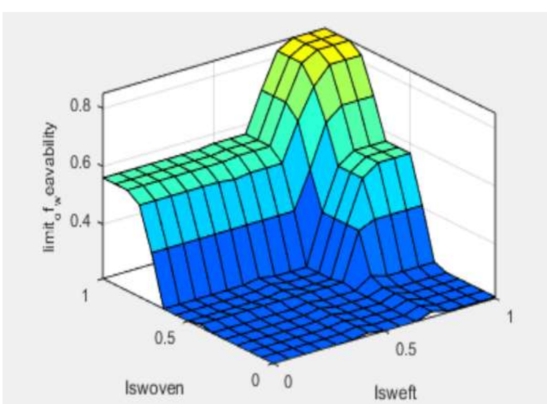
Example:

The warp saturation index is fixed in advance: Medium.

Case N°1: (MED, X, Z)

Woven saturation index
Weft saturation index
Warp saturation index

The curve of the case N°1 (MED, X, Z) result



The interpretation of the curve of the case N°1

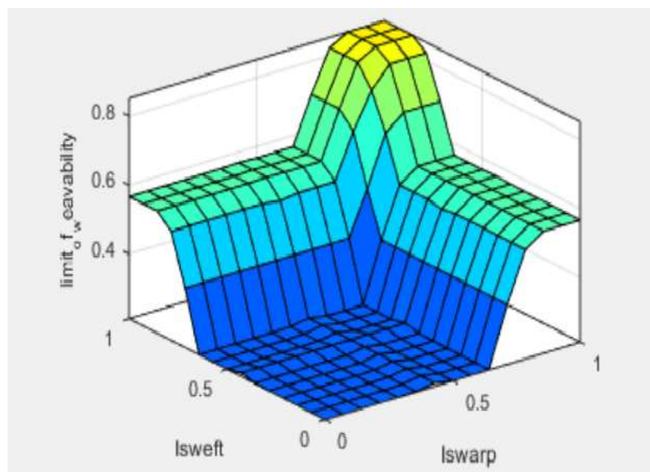
The above curve clearly shows us that this fabric can be woven easily (low weaveability limit) when both indicators (weft saturation index and woven saturation index) are low. On the other hand, it is an average when both are average. But when the two indicators (weft saturation index and woven saturation index) are important, the weaving will be difficult. The objective of this representation is to allow the modification of the result according to the decision rules. These rules are established according to the experts in the field.

Case N°2: (X, Y, MED)

Woven saturation index
Weft saturation index
Warp saturation index

The woven saturation index is fixed in advance: Medium.

The curve of the case N°2 (X, Y, MED) results



The interpretation of the curve of the case N°2

The above curve clearly shows us that weaveability can vary according to the inference rules. The weaveability becomes easy when one of them is weak and the other weak or average. It is average when one of them is weak and the other important or both are average. But when both are important, the weaveability becomes very difficult or impossible.

By using fuzzy logic to predict the weavability of a new fabric, it is possible to obtain more accurate estimates that are better adapted to the specific characteristics of the material and the weaving process. This approach offers an effective alternative to traditional prediction methods and can help to improve textile design and manufacturing processes.

There are other artificial intelligence (AI) methods that can be used to predict the weaveability of a new fabric:

1. Neural networks: Neural networks, particularly deep neural networks such as convolutional neural networks (CNN) or recurrent neural networks (RNN), are widely used in prediction and classification tasks. They can be trained on datasets containing examples of tissues and their characteristics to learn complex, non-linear models. Once trained, these neural networks can be used to predict the weavability of a new tissue based on its characteristics.

2. Expert systems: Expert systems are computer systems that use expert knowledge to solve specific problems. In the context of fabric weaveability prediction, an expert system could be developed by capturing the knowledge and rules of domain experts and using them to assess the weaveability of a new fabric. Expert systems can be based on conditional rules or use logical reasoning methods to make decisions.

It is important to note that the choice of AI method will depend on the data available, the complexity of the problem and the specific objectives of predicting weavability. In some cases, a combination of several methods can be used to obtain more robust and accurate results. In addition, a high quality and representative dataset is essential to train and evaluate the prediction models adequately.

5. CONCLUSION:

In this article, we have presented a new approach using artificial intelligence (fuzzy logic) that helps designers and creators of new fabric to know in advance the problems associated with the difficulty of weaving on looms and to avoid damage and loss of material. It also enables a priori assessment of production yield problems for items close to weaving limits.

We have shown the results of the simulation in different cases: the two diagrams easily show the ranges where weaving is easy and the cases where it becomes difficult or even impossible. This makes the information accessible thanks to inference rules based on the knowledge and expertise of weaving experts.

Our future research orientations and perspectives consist in carrying out an in-depth experimental study for confirmation and generalization.

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