An Approach to the Design of a Fuzzy Logic Model for the Ease Allowance Calculation in Loose Fitting Knee Length Ladies Trousers

Abher Rasheed, Xiany Zeng, Sebastien Thomassey,

ENSISA-Universite de Haute Alsace, Mulhouse, Alsace FRANCE

Correspondence to:
Abher Rasheed email: abher.rasheed@uha.fr

ABSTRACT
Consumers are getting more and more conscious about their clothing with each passing day. Everyone needs clothes of personalized design, fit, and color. The existing mass production system is not capable of handling this problem. Mass customization is a solution to this problem. This paper presents a new method of personalized ease allowance calculation using a fuzzy logic model. The model takes into account both the fabric properties and body morphology. The study is focused on a single product, namely,. loose fitting ladies trousers. Draping technique is used to determine the personalized ease allowance. Three fuzzy logic models are designed to calculate the ease allowance on three difference parts of the garment.

Keywords: Ease allowance, Fuzzy logic, Ladies trouser

INTRODUCTION
The apparel industry is undergoing rapid evolutionary changes that have resulted from the digital revolution, globalization, and consumer demands. Previously a lack of product availability required consumers to tolerate products that did not meet their expectations. However, this has changed, and consumers want and expect immediate personalized service and more variety in product offerings [1]**.** So these days, the consumers want personalized fit, color, and style of the garments they choose to buy. Keeping in mind the changing consumer demands, existing mass production systems are not capable of satisfying both consumers and manufacturers. Mass customization is the concept which can cope with the present day challenges [2][3]. Recently, mass customization has brought great benefits in many manufacturing sectors, including automotive, textiles, and cosmetics. Classically, this concept is defined as ‘‘producing goods and services to meet individual customer's needs with near mass production efficiency’’ [4]**.** Many researchers have studied mass customization in the apparel industry [2] [4] [5] [6].

A garment is assembled from different cut fabric elements. Each of these fabric elements is produced according to a pattern drafted on paper [7]. These patterns are obtained from one of two methods: direct drafting or draping. Direct drafting produces a pattern using body measurements with the help of a pattern construction procedure. This method is faster and systematic but less accurate [8]. This technique is commonly used in mass production. Draping is used in high level garment designing [9]. In this technique, the pattern makers drape the fabric directly on a model or a mannequin and trace out the fabric pattern. The patterns obtained from this technique are very accurate and have better fit.

But, draping is very time consuming and costly and thus cannot be used in mass manufacturing.

Each garment needs two types of ease allowance; functional ease allowance and design ease allowance. Functional ease allowance is the one which is necessary for the body movements such as breathing, and walking. While design ease allowance represents a certain type of design such as fitted or loose. The functional ease allowance depends on body measurements and the properties of the fabric being used. The direct drafting method cannot determine the ease allowance required for a certain fabric or body type. The objective of this research was to design a method of personalized ease allowance calculation using the designer's knowledge and taking into account the fabric properties and body measurements.

SELECTION OF FABRICS AND FABRIC PROPERTIES
Six fabrics made of different materials were taken from the market. Fabric properties are given in the *Table I.*

TABLE I. Fabric properties and %age of their contents.

Sample code	Fabric contents and %age			
	Cotton	Polyester	Wool	Elastane
S1	100	-	-	-
S2	97	-	-	3
S3	-	-	98	2
S4	65	33	-	2
S5	-	54	44	2
S6	-	-	100	-

These fabrics were draped on different models (real human beings not mannequins) at a later stage. The draping process is very time consuming, and it becomes very complicated if it has to be performed on real models. Due to these reasons, three fabrics were chosen for draping. The method which was used for fabric selection is explained in the following paragraphs.

With the help of physical testing and sensory evaluation, 13 different parameters of the sample fabrics were determined. A thickness meter was used to measure the thickness of the samples at zero pressure. A weighing balance was used to test the basis weight of the samples in GSM (grams per square meters). The bending length of the samples was determined with the help of a bending length tester. The sample size taken was 5 cm X 20 cm. The results of the physical testing are depicted in *Table II*.

TABLE II. Results of the physical testing.

	S1	S2	S3	S4	S5	S6
Thickness (mm)	0.78	0.5	0.76	0.75	0.64	0.67
Weight (GSM)	299	206	216	217	217	247
Warp bending-length (cm)	8.1	5.8	2.4	5.1	3.1	2.9
Weft bending-length (cm)	3.8	3.5	3.1	3	2.7	2.6
Average bending-length (cm)	5.9	4.7	2.7	4.1	2.9	2.8

A Kawabata compression tester was used to measure the linearity, compression energy, and resilience of the sample fabrics. *Table III* shows the Kawabata test results.

TABLE III. Kawabata compression tester results.

	S1	S2	S3	S4	S5	S6
Linearity	0.17	0.09	0.22	0.25	0.21	0.25
Compression energy (Nm/m)	0.16	0.22	0.32	0.17	0.17	0.17
Resilience (%)	64.97	40.57	60.51	50.24	54.3	68.06
Initial thickness (mm)	0.93	1.33	1.13	0.75	0.84	0.7
Final thickness (mm)	0.56	0.34	0.53	0.47	0.45	0.43

Five volunteers participated for the sensory evaluation of the fabrics. The minimum value of a certain property corresponds to 1 while 6 indicates the maximum value. *Table IV* shows the results of the sensory evaluation after data processing.

TABLE IV. Sensory evaluation results.

Sample code	S1	S2	S3	S4	S5	S6
Smoothness	2.4	4.8	2.8	4.4	3.8	2.8
Softness	1	3.2	4.8	2.4	3.8	5.8
Stretch	1	4.2	3	5	5.4	2.4
Bulkiness	4.4	1.4	5.4	2.4	3	4.4
Fall	1.2	3	5	2	4.4	5.4

Principle component analysis (PCA) was applied on the data given in *Table II*, *Table III*, and *Table IV*. The first part of *Figure 1* represents the six fabrics. We had to select three fabrics out of these six. The idea was to select the fabrics having different physical properties, so that the effect of the physical properties on the ease allowance could be studied later. It is clear from the PCA results that S1 (Obs1) is entirely different from the others. The rest of the fabrics make two groups corresponding to their eigenvectors. It can be assumed that the fabrics in one group are similar to each other. One group consists of S3, S6 and S5, while S2 and S4 make another group. One fabric from each group was selected, for example, S3 and S4. *Figure 1* shows the results of PCA.

N	P
6	13

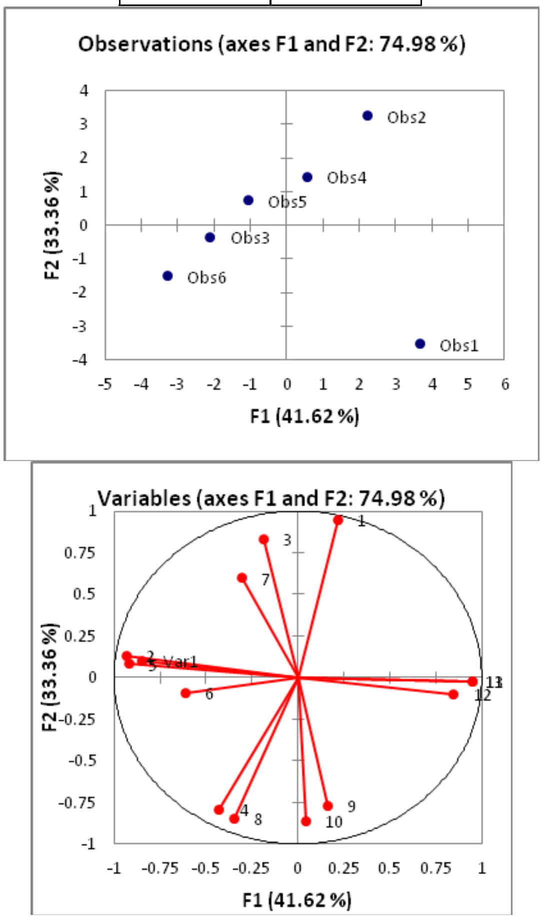

FIGURE 1. PCA for fabric samples and fabric properties.

A fuzzy model can take only a limited number of inputs. Hence all the fabric properties and body measurements cannot be taken into account. Therefore, it was decided to choose two fabric properties. It can be seen in *Figure 1* that all the fabric properties can be divided into four groups according to their corresponding eigenvector coefficients. The properties of group 1 (1, 3 and 7) have a negative correlation with the properties of group 3 (4, 8, 9 and 10). Similarly, the properties of group 2 (2, 5, 6 and 11) have a negative correlation with the properties of group 4 (12 and 13). This means that there is no need to choose the properties from the correlated groups. Therefore two fabric properties; stretch (3) and bending length (13) were chosen as inputs. Stretch (3) will represent group 1 and group 3 while bending length will represent group 2 and group 4.

GARMENT DESIGN

Three models participated in this research. A 3D body scanner of 'Human solutions' was used to obtain accurate body measurements of the participants. Some of the body measurements of the models can be seen in the T*able V*.

TABLE V. Body measurements of the participants.

	Model 1	Model 2	Model 3
	Measurement (cm)		
Height	163.3	154.6	164.4
Crotch length at waist band	66.6	66.5	63.2
Waist girth	73.1	80.3	72.5
Hip girth	99	93.3	99.5
Thigh girth at crotch	53.7	53.5	55.5

This study was conducted on a single garment, loose fitting knee length ladies trousers. Using the direct drafting method, patterns of the participants were drafted by using their body measurements. Then the three chosen fabrics were draped on the models and the 3D draped patterns were obtained. The preferences of the models for comfort were taken into account and were incorporated in the draped patterns. Ease allowances on different body parts were calculated by comparing the measurements on the drafted and draped patterns. Ease allowance can be calculated, simply, by taking the difference of the same measurement on the two patterns. The waist measurement of the drafted pattern was subtracted from the waist measurement of the draped pattern to get the measurement of the ease allowance at waist girth.

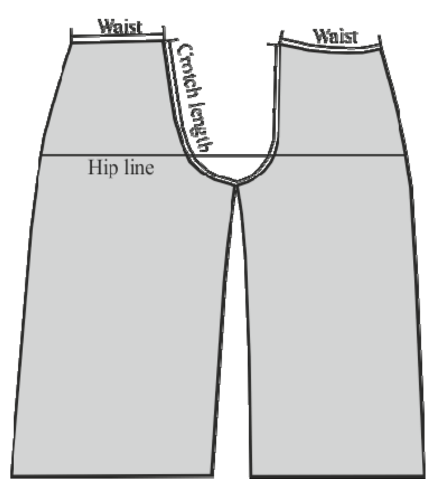

FIGURE 2. Draped pattern.

The ease allowance depends on the body morphology. There is no general rule, but more waist girth means more body surface area. Normally the functional ease allowance is added as the percentage of the body measurement, 2% of the waist girth. So more waist girth means, more ease allowance is required. To know the effect of the body morphology, waist was selected as an input for the model. For trousers, the functional ease allowance is required between waist and hip area: sitting, running. So it would be sufficient to have three ease allowance values, namely,. ease allowance at waist girth, ease allowance at hip girth, ease allowance at crotch length (*Figure 2*). *Table VI* illustrates some of the ease allowances calculated from the patterns.

TABLE VI. Ease allowance values determined by comparing the patterns of drafting and draping.

	Model 1		Model 2		Model 3
	S1	S3	S3	S4	S4
Waist girgh	5.0	0	-4.0	-3.0	-2.0
Hip girth	16.0	10.0	9.3	7.3	10.5
Crotch length	3.4	-0.6	-2.0	-2.0	0
* All the values are in centi-meters (cm)					

FUZZY MODEL

Figure 3 represents the general scheme of the experimental work. In the first part two fabric properties; Stretch and bending length and one body measurement; waist girth were chosen as the inputs for the models. Then ease allowances were calculated and three fuzzy models were designed to calculate the ease allowances at three different parts of the pattern.

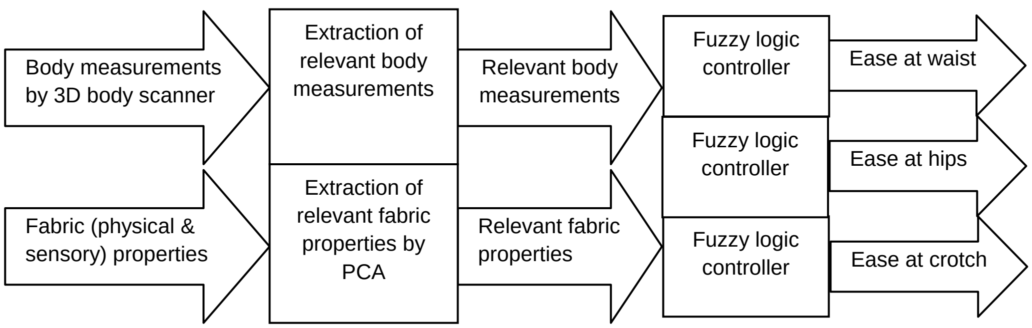

FIGURE 3. General scheme of the model.

All three fuzzy models have the same inputs but the rules and outputs are different for each fuzzy model. By using the data from physical testing, sensory evaluation, drafted patterns, draped patterns and calculated ease allowances, the fuzzy rules for the fuzzy models were extracted. *Figure 4* presents a fuzzy model having three inputs and an output

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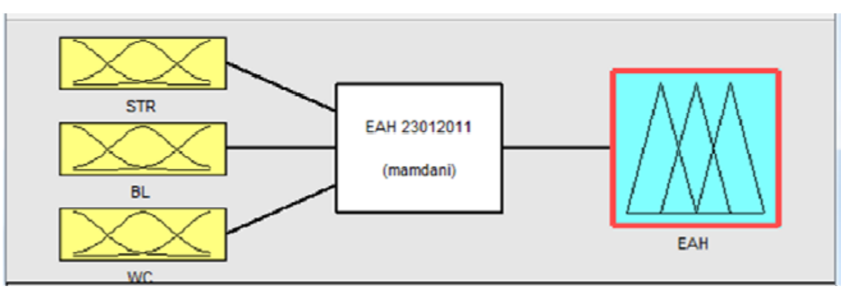

FIGURE 4. Fuzzy logic model.

The range of the stretch (STR), bending length (BL) and waist girth (WC) was 1 – 6, 2.4 cm – 6 cm and 65 cm – 85 cm respectively. The range of ease allowance at waist girth (EAW), ease allowance at hip girth (EAH) and ease allowance at crotch length (EACL) was -4 cm – 5 cm, 4 cm – 16 cm and -2 cm – 4 cm respectively. All the inputs and outputs were divided into four membership functions. All the membership functions were triangular (trimf). The linguistic values of these functions were very small

(VS), small (S), medium (M) and large (L). The fussy rules of the models are given in *Figure 5*, *Figure 6* and *Figure 7*.

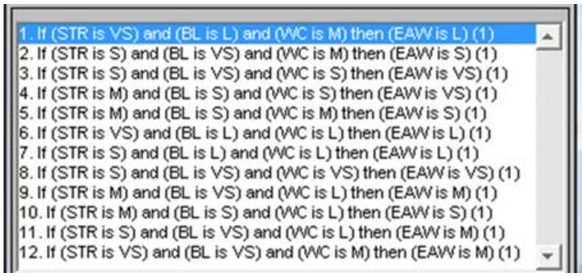

FIGURE 5. Fuzzy rules for ease allowance at waist (EAW).

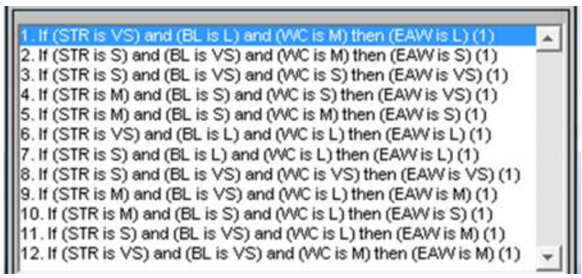

FIGURE 6. Fuzzy rules for ease allowance at hips (EAH).

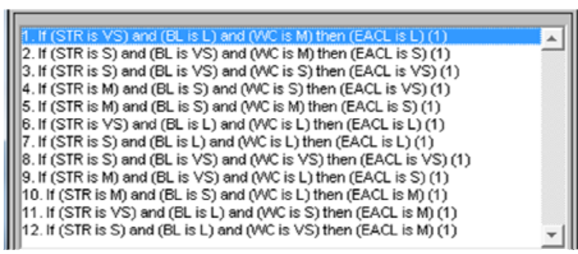

FIGURE 7. Fuzzy rules for ease allowance at crotch length (EACL).

Table VII indicates a few results obtained from the fuzzy models.

TABLE VII. Some results of the Fuzzy models.

Sr. no.	Stretch	Bending length	Waist girth	EAW (cm)	EAH (cm)	EACL (cm)
1	3.5	4.2	70	-2.9	8.0	-1.2
2	3.5	4.2	80	-1.0	12.2	0.7
3	3.5	3.3	72.5	-2.1	8.8	-0.7
4	3.5	5.1	72.5	0.5	10	1.0
5	2	3	74.5	0.0	8	-0.3
6	3	3	74.5	-1.4	9.2	-0.3

The patterns obtained show that the ease allowance is different if a fabric is draped on two different models or two different fabrics are draped on the same model. This verifies the fact that both the fabric parameters and body measurements influence the ease allowance.

Generally, fabric stretch has an inverse relationship with the ease allowance. More the fabric stretch, requires less ease allowance needs to be added. Bending length, on the other hand, has a direct relationship. More bending length means the fabric has less softness and requires more ease allowance. Waist girth has a direct relationship with the ease allowance, if all the other factors are kept constant. This is so because wider waist means more surface area. Therefore more ease allowance is required for bigger waists.

However, the combined effect of these factors on the ease allowances is complex and difficult to understand. Fuzzy models make it easier to understand their combined effect on ease allowance. The Fuzzy models showed the same behavior with a few exceptions. The models illustrated that, for a medium waist person the EAH remains almost constant, even if the stretchablity and the bending length are changed. It seems to be logical, because this is the widest part of the lower body and the trousers should fit on this part of the body.

The results also showed that the maximum ease allowance was added at hip girth for all the models. It is because; the hip is the widest lower body part having the maximum surface area. For a stretch fabric, ease might be negative which means the fabric is subtracted and this subtracted difference is accommodated by the stretch of the fabric.

CONCLUSION

A new method for optimizing garment design is proposed. The method takes into account the expert's knowledge to estimate a more suitable value of ease allowance at different body landmarks for loose fitting knee length ladies trousers. Both fabric properties and body measurements are considered. The experimental work showed that the ease allowance not only depends on the fabric properties but the body morphology as well. Two fabric properties and one body measurement were chosen as the inputs. Principle Component Analysis (PCA) was used to extract these input parameters from a bigger set of parameters.

Three fuzzy models were designed to determine the ease allowances at three body landmarks, namely, ease allowance at waist (EAW), ease allowance at hips (EAH), and ease allowance at crotch length (EACL). Each model uses the same inputs and calculates the combined effect of the input parameters on the ease allowance. The effect of each input parameter can easily be estimated but the fuzzy models are necessary to understand their combined effect.

Fuzzy models depicted that the fabric stretch has an inverse relationship with the ease allowance. More the fabric has stretch; less ease allowance is required at all three body landmarks. Bending length, on the other hand, has a direct relationship. More bending length means the fabric has less softness and requires more ease allowance. Waist girth also showed a direct relationship with the ease allowance if all the other factors are kept constant. The fuzzy models also displayed that, for a medium waist person the EAH remains almost constant, when the fabric stretch and the bending length are changed.

The garment patterns obtained by using this method would be more personalized and would have better fit. The process is rapid like direct drafting but provides a better fit like draping at the same time. This method could help fulfill the demands of the customers for more and more personalized garments. Other methods can also be used but the fuzzy logic has some advantages over other techniques e.g. artificial neural network. It is very easy to convert human knowledge into the fuzzy rule, the simulation is very accurate and it can work with a reasonably small knowledge base [10].

In the next part the study will be conducted on more models and the linear regression equations will be derived for each body part. So that these equations can be used to write software capable of making the changes in a flat pattern automatically, taking into account the fabric properties and body measurements.

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AUTHORS' ADDRESSES

Abher Rasheed
Xiany Zeng
Sebastien Thomassey
ENSISA-Universite de Haute Alsace
11 Rue Alfred Werner
Mulhouse, Alsace 68100
FRANCE