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Original Article

Predicting Body Size and Shape for Vietnamese Males Using Fuzzy Logic

Mong Hien Thi Nguyen[1], Minh Dương Nguyen[2], Mau Tung Nguyen[3]

[1,2]*Faculty of Mechanical Engineering, University of Technology-VNU–HCM, Ho Chi Minh City, Vietnam.*
[3]*Faculty of Garment Technology-Fashion, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam*.

[1]*Corresponding Author : ntmhien14719@hcmut.edu.vn*

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Abstract - *The paper presents results of establishing a predictive model for body size and shape for Vietnamese males living in the Southern region. The study surveyed measurements on 353 men aged 18 to 60. They live in Southern Vietnam. The methods of principal component analysis, K-Mean cluster analysis, discriminant analysis, and ANOVA testing using SPSS software have identified six distinct body shape groups. The methods create objective functions that support the development of a sizing chart for Vietnamese males. The fuzzy logic technique is used to predict body size and shape. The feasibility of the predictive model was tested and evaluated on a sample of 30 men within the research age range. Results matched the sizes and body shapes of the test subjects. The predictive model for determining body size and shape using fuzzy logic techniques opens a new direction for the role of AI in modern fashion design and production. With a sizing system table that has many sizes, extracting the size will take a lot of time. This model will help customers minimize the time needed to determine their physical measurements and body shape. From there, they can make decisions on selecting appropriate clothing sizes and patterns when ordering custom-made garments or purchasing ready-made products, whether directly or through online sales channels.*

Keywords - *Body shape, Body size, Fuzzy logic, Fuzzy set, Sizing system table.*

1. Introduction

Currently, numerous studies worldwide are utilizing AI algorithms to keep pace with Industry 4.0 across various fields. The textile and garment industry is no exception, as many studies have applied fuzzy logic in this sector. For instance, in the study [1-4], the authors proposed an intelligent fashion selection system based on body measurements and basic sensory descriptions using fuzzy decision trees. For the manufacturer, there are many studies correlating arranged works inline, such as the study aims to measure and prioritize the primary causes of lean wastes and implement reduction methods by utilizing more effective waste cause identification methodologies [5]. In a study [6], fuzzy clustering was used to establish a clothing size system table.

This research only aims to develop men's trousers sizes, and the measurement data is collected from tailoring. Therefore, the measurement tolerance will be high, and the body shape has not been studied. The size set is subjective. Continuing the application of fuzzy logic in the garment industry, study [7, 8] utilized fuzzy logic to predict the drape of fabrics on different types of textiles. The other authors' study on garment fit to improve customer body fit of fashion design clothing by Artificial Neural Networks [9]. For the issue of garment fit when shopping, there is a study [10]. In this study, the authors investigate the preferences and needs of men when purchasing everyday clothing. The primary concern is the sizing chart specifications. Another study related to the fit of police uniforms [11]. This study did not analyze body shapes. So, it did not show the suitability between body shapes and sizes. For the fit clothes, the authors used a triangular fuzzy classification method to represent the lower body shape based on height, waist girth, and hip girth measurements from anthropometric data of 116 young women from Northeast China [12]. Regarding virtual garment fitting using 3D software for fit assessment, there is a second study [13]. For studies on body shape analysis and constructing size systems using traditional methods, some research has analyzed Body Mass Index (BMI). In studies [14-16], the authors used BMI to assess body thinness and obesity. Combining body shape analysis with BMI and a Waist-Hip Ratio (WHR) [17]. The study was conducted on adult men with a BMI over 25, waist circumference over 9cm, and a WHR over 0.85. The authors aimed at plus-size customers purchasing ready-to-wear clothing and sought to improve the fit of clothing by classifying the lower body of adult men based on two main measurements: waist circumference and hip circumference. Additionally, there is the study [18]. This study mentions the ideal male body shape as perceived by men themselves (BMI = 25.9, WHR = 0.87). For body shape classification based on the DROP index, there is a study [19]. In these studies, the authors used a 3D body scanner to analyze the body shapes of American men aged 26 to 35 based on the DROP index, resulting in four different shape groups: oval, rectangle, trapezoid, and triangle. Additionally, there is a study that analyzes male body shapes using principal component analysis combined with the DROP index, such as in the study [20]. The results identified three body shapes for overweight and obese men: rectangular, bottom hourglass, and top hourglass, as described in the study [21]. In a study [22], the authors analyzed 250 body measurement samples of Japanese males aged 2 to 70 and identified seven principal components influencing body shape analyzed.

In a study [23], the authors analyzed body measurement samples of Chinese males and identified six body shape groups. This research did not study the sizing system table. In the study [24], the authors discuss clothing size systems developed over the past 15 years, referencing the ISO 8559:2017 standard for the establishment of clothing sizing systems [25]. In 2012, author Jongsuk Chun presented an overview of male and female clothing size systems currently used around the world [26]. This document is valuable for designing size systems, as the author demonstrated that each body shape will have multiple sizes built and that each country will have its specific chest circumference ranges. The primary dimensions used in constructing size systems typically include bust girth, abdomen girth, hip girth, and height. These studies only present the creation of the sizing system table. The authors have not studied body shape analysis and the extraction of body shapes and sizes.

In Vietnam, in 2009, the General Department of Standards, Metrology, and Quality proposed that the Ministry of Science and Technology publish the TCVN 5782-2009 standards. This standard outlines a clothing sizing system table for a diverse range of subjects, from infants to adult men and women [27]. Through analyzing the above studies, the authors found that the research that combines body analysis, setting up a size system table, and using fuzzy logic algorithms has not been mentioned. This is also the reason why the authors conducted the “Predicting Body Size and Shape for Vietnamese Males Using Fuzzy Logic" study.

2. Materials and Methods

This study focuses on analyzing male body shapes and constructing a sizing system table for individuals aged 18–60. Based on this, a model will be established to predict body sizes and body shapes. The research utilizes a cross-sectional survey method to collect measurement data. Classification of body shape groups is achieved through the use of PCA, ANOVA, and comparative assessments of BMI, DROP index, and WHR. Target functions are established to create the size system table. Fuzzy logic simulation techniques are employed using MATLAB software to develop an algorithm for predicting body sizes and body shapes. The age range for men, after reaching adulthood, from 18 to 60 years, is divided into three stages according to the body development cycle. The youth stage is from 18 to 25 years old. The prime adulthood stage is from 26 to 44 years old. The middle age stage is from 45 to 60 years old [28]. Through the analysis of four primary vertical dimensions and six primary horizontal dimensions from 30 measurement data points for each stage, it was found that in Stage 1, the primary dimension for determining the sample measurement is body height, with a standard deviation of S = 6.64cm. In stages 2 and 3, the primary dimension for determining the sample measurement is body weight. Therefore, the authors will combine Stages 2 and 3 into one age group, with a standard deviation of S2 = 6.9cm. The calculation results indicate the number of samples required for measurement in each age group, as Equation (1).

Group 1: For the group from 18 to 25 years old.

$$n = \frac{t^2 S^2}{m^2} \quad (1)\ [29]$$

Selecting the confidencel level 95%; m =1cm; t = 1.96; S= 6.64cm

$$n = \frac{1.96^2 x\ 6.64^2}{1^2} = 170\ (men)$$

Group 2: For the group from 26 to 60 years old.

Selecting the confidence level 95%; m =1cm; t = 1.96; S = 6.9cm

$$n = \frac{1.96^2 x\ 6.9^2}{1^2} = 183\ \text{(men)}$$

Total: 170 + 183 = 353 (men)

Regarding the testing of the program for predicting body size and shape using 30 measurement samples, there are two methods. Method 1: using the exact measurements from the sizing system table (Table 4), input these into the model (Figure 5), run the program, and then compare the results with the sizes in the table. The results show a complete match with the sizes in the table (Table 6). Method 2: using direct measurement samples involves inputting the measurements into the model. Then, the predicted results will be compared using the traditional table lookup method and the program extraction method. The results show a similarity in the predictions from both methods.

3. Results and Discussion

3.1. Define the Factors and Variables

The PCA results have four components with eigenvalues over 1, explaining 80.756% of the variance. These components form the basis for selecting key measurements. Table 1 shows that the first principal component, "Dimensions related to the primary horizontal dimension," explains

43.362% of the variance, with an initial eigenvalue of 6.504. The second component, "Dimensions related to the primary vertical dimension," represents 20.350%, with an initial eigenvalue of 3.053. The third component, "Dimensions related to center back," accounts for 10.231%, with an initial eigenvalue of 1.535, and the fourth, "Dimensions related to wrist girth," contributes 6.813%, with an initial eigenvalue of 1.022.

Table 1. The Principal Component Analysis

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.504	43.362	43.362	6.504	43.362	43.362	5.078	33.855	33.855
2	3.053	20.350	63.712	3.053	20.350	63.712	3.152	21.012	54.867
3	1.535	10.231	73.943	1.535	10.231	73.943	2.212	14.748	69.615
4	1.022	6.813	80.756	1.022	6.813	80.756	1.671	11.142	80.756
5	.716	4.773	85.529						
⋮									
15	.043	.285	100.000						

The survey data were analyzed using SPSS software [30]. Factors are extracted based on correlations across variables or within the structure of the variable matrix. Here, variables are the factors that result from factor analysis. The correlation r in the factor matrix in Table 2 is less than 0.3. This indicates that they are independent of each other, with no overlap or influence on each other.

Table 2. Correlations in the factor matrix for males aged 18-60

F1: Horizontal principal dimension	1			
F2: Vertical principal dimension	.000	1		
F3: Back waist length	.000	.000	1	
F4: Neck circumference	.000	.000	.000	1

3.2. The Results of the Body Shapes Analysis

In the initial step, the authors proposed seven body shape classification options: The option has two body shapes, the option has three body shapes, the option has four body shapes, the option has five body shapes, the option has six body shapes, the option has seven body shapes, and the option has eight body shapes. Concerning the results of ANOVA and K-Means clustering, the authors selected the classification option with six body shapes (Figure 1) for body shape categorization. The elements within the group were closely clustered together with minimal overlap between different groups. The body measurement dimensions for each group are presented in Table 3. The results show that the general group has a balanced rectangular body shape. Three indices, BMI, DROP, and WHR, are within the normal range (WHO).

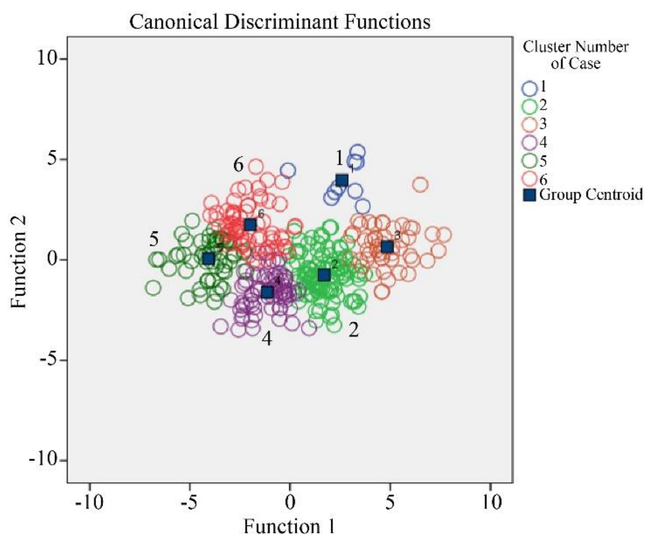
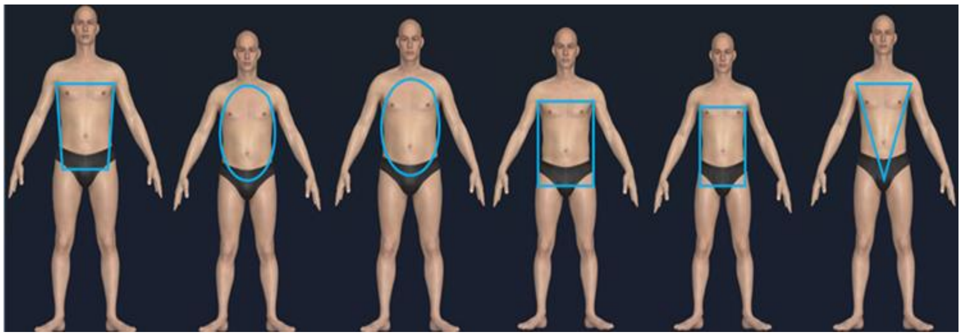


Fig. 1 Chart showing the distribution of elements in the 6-group classification option

Table 3. The results of the ANOVA for the 6-body shape group classification

Dimension	General group (men)	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
	N= 353	N = 9	N = 102	N = 50	N = 69	N = 56	N = 67
Height (cm)	168.49	182.57	166.61	172.23	164.57	164.12	174.34
Weight (kg)	63.72	79.80	65.71	78.86	56.73	53.48	63.00
Neck girth (cm)	39.76	43.51	39.95	41.81	37.89	38.54	40.39
Bust girth (cm)	90.14	95.48	93.81	99.96	85.34	81.97	88.28
Waist girth (cm)	79.66	85.06	85.25	91.92	77.12	68.75	73.00
Abdomen girth (cm)	83.06	87.61	88.71	95.91	80.73	71.54	76.27
Hip girth (cm)	94.60	103.98	96.94	103.54	91.76	87.88	91.68
Center back (cm)	42.32	42.41	42.71	45.33	40.65	40.87	42.40

Back width (cm)	32.22	35.70	33.09	36.11	32.08	28.28	30.99
Shoulder width (cm)	42.72	45.39	43.73	47.11	42.71	38.29	41.25
Armhole depth (cm)	25.66	26.83	26.57	28.18	24.54	23.41	25.29
Sleeve length (cm)	56.68	61.52	56.03	58.43	55.31	55.08	58.44
Wrist girth (cm)	20.68	17.66	22.88	25.13	20.53	16.21	18.29
Outseam (cm)	96.70	110.56	92.85	95.25	91.74	100.59	103.62
Inseam (cm)	75.41	82.09	74.33	76.67	72.86	75.01	78.17
BMI (kg/m2)	22.43	23.94	23.67	26.59	20.95	19.86	20.73
DROP (cm)	7.09	7.87	5.10	4.06	4.61	10.43	12.01
WHR	0.87	0.84	0.92	0.93	0.88	0.81	0.83



Group 1 Group 2 Group 3 Group 4 Group 5 Group 6

Fig. 2 Images of the 6 body shape groups

There are six groups of body shapes (Figure 2). Group 1 has an inverted triangle body shape. This group represents the smallest percentage (2.55%) and has the tallest body shape among the 6 groups, with a large hip but a small wrist. The BMI and DROP indices of Group 1 are higher than those of the general group (7.87 > 7.09), indicating a significant difference between the bust and abdomen measurements in Group 1. However, the WHR index for Group 1 is smaller than that of the general group (0.84 < 0.87), indicating that the difference in waist and hip measurements between Group 1 and the general group is quite large. Additionally, with a BMI greater than 23, Group 1 is classified as overweight.

Group 2 has an oval body shape with an average height. It represents the highest sample percentage (28.9%), and the average values for this group are close to those of the general group, but the body shape is different. The BMI for Group 2 is 23.67, while for the general group, it is 22.43. The DROP index for Group 2 is 8.55, compared to 10.49 for the general group. The WHR index for Group 2 is 0.88, whereas for the general group, it is 0.84. These three indices indicate that Group 2 has a slightly larger abdomen. Additionally, with a BMI greater than 23, Group 2 is classified as overweight.

Group 3 has an oval body shape with a tall stature. This is indicated by the highest BMI among the 6 groups. Additionally, the DROP index for Group 3 is the smallest among the groups (4.06), showing that the waist does not differ much from the bust. The WHR for Group 3 is 0.93, the highest among the 6 groups, indicating that the waist is not much smaller than the abdomen. According to WHO, a WHR greater than 0.9 in men is a warning of excessive abdominal fat. Additionally, a BMI greater than 25 indicates that Group 3 is classified as obese according to WHO standards [31].

Group 4 has a rectangular body shape, with slightly shorter height and narrow shoulders. The body width is balanced, as indicated by the BMI of 20.95. A DROP index of 0.83 suggests that the bust and waist dimensions are relatively similar. The WHR for Group 4 is like that of the general group (0.88; 0.87), indicating a relatively similar difference between abdomen and hip measurements.

Group 5 has a trapezoidal body shape and consists of lean, small-statured individuals. This is reflected in the BMI of 19.86. It is the group with the shortest height among the 6 groups. The waist is much smaller compared to the bust and hips, resulting in a relatively large DROP index of 10.43. The WHR is the smallest among the 6 groups (0.81), indicating a significant difference between waist and hip measurements.

Group 6 has an inverted triangle body shape with tall stature, flat abdomen, and slightly broad shoulders. The body is well-proportioned, as indicated by a BMI of 20.73. There is a significant difference between bust and abdomen measurements compared to all other groups, resulting in the highest DROP index (12.01). There is also a significant difference between the waist and hip measurements, as reflected by a WHR of 0.83.

3.3. Results from principal component analysis

Table 4 shows that the first principal component consists of 7 dimensions, in the following order: abdomen girth, shoulder width, back width, bust girth, waist girth, hip girth, and weight. The measurements have loadings ranging from 0.678 to 0.868, with an initial eigenvalue of 6.504 and a variance of 40.61%. Shoulder width has the highest loading at 0.868. Therefore, abdominal girth is selected as the primary measurement. The second principal component includes dimensions related to the vertical principal dimensions of the body, consisting of 4 dimensions: height, inseam, sleeve length, and outseam. The measurements have loadings ranging from 0.739 to 0.900, with an initial eigenvalue of 3.053 and a variance of 20.35%. Height has the highest loading at 0.88. Therefore, height is selected as the second primary dimension. The third principal component includes dimensions related to the back waist drop, consisting of 3 dimensions: center back, wrist girth, and armhole depth.

The measurements have loadings ranging from 0.609 to 0.875, with an initial eigenvalue of 1.535 and a variance of 10.231%. The back waist drop is selected as the third primary measurement. The fourth principal component includes dimensions related to neck girth with a loading of 0.799, an initial eigenvalue of 1.022, and a variance of 6.813%. This is the fourth primary measurement. Additionally, factors are extracted based on the correlation among variables or within the matrix of variables.

Table 4. Loading of the principal component analysis

The name of the principal component analysis	Characteristic parameters	Principal Component			
		1	2	3	4
Parameters related to the horizontal principal dimension	Abdomen girth	0.868	0.135	0.128	-0.130
	Shoulder width	0.848	-0.126	0.126	0.302
	Back width	0.844	0.150	-0.008	-0.138
	Waist girth	0.836	-0.147	0.239	0.312
	Hip girth	0.779	0.211	0.067	0.323
	Bust girth	0.679	0.029	0.411	0.458
	Weight	0.678	0.331	0.245	0.478
Parameters related to the vertical principal dimension	Height	0.197	0.900	0.138	0.075
	Inseam	0.002	0.889	0.058	0.091
	Sleeve length	0.268	0.830	0.075	-0.007
	Outseam	-0.390	0.739	-0.216	0.272
Parameters related to the center back	Center back	-0.088	.182	0.875	0.049
	Wrist	0.392	-.118	0.821	0.029
	Armhole depth	.0473	.096	0.609	0.420
Parameters related to neck girth	Neck girth	0.135	.170	0.071	0.799
Initial eigenvalues		0.504	3.053	1.535	1.022
% Variance		43.362	20.350	10.231	6.813
% Cumulative		43.362	63.71	73.943	80.756

3.4. Determine the Step Intervals of the Primary Dimensions

Find the primary measurements: Through principal component analysis from a sample of 353 men, it was found that the abdomen girth has the highest coefficient among the horizontal principal variables of the four principal components and is the primary measurement of the first principal component.Therefore, the abdominal girth is selected as the primary measurement for the first principal component. Regarding vertical dimensions, height has the highest coefficient and is the primary measurement for the second principal component. Height is chosen as the second primary measurement. These two primary measurements will serve as the basis for calculating the dependent measurements to design the sizing system table. Determine the step intervals between sizes: The size range is determined based on the primary dimension of height, which ranges from 150 to 193cm. The average height is 168.49cm, with a standard deviation of 6.91cm. Due to the study's focus on adult males, whose height is relatively stable, the author chooses a height step interval equivalent to the standard deviation, which is 7cm. The size range is determined based on the primary dimension of abdomen girth, which ranges from 63 to 107.10cm. The average abdominal circumference is 83.06 cm, with a standard deviation of 9.02. Given the broad age range in the study, the author chooses a step interval for abdomen girth equivalent to half the standard deviation, which is 5cm.

Establishing a linear regression Equation (2)

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad (2)$$

Where:

- Y: Value of the dependent variable (outcome)
- X_1(Abdomen girth), X_2 (Height): Values of the independent variables. X_1 and X_2 are fixed variables with no measurement errors.
- β_0: Constant
- β_1 (Abdomen girth), β_2 (Height): Adjustment coefficient for each independent variable.
- ε: residuals. Assume that the residuals have a mean value of zero and constant variance for all values of X_1 and X_2.

After analyzing the coefficients in SPSS, a sizing system table will be established as presented in Sig values in the F tests of the ANOVA table, which are less than 0.05, indicating that the regression equations for these measurements are completely appropriate (Table 5).

Size symbols: Body shape group-code number/abdomen girth measurement. For example, A1-4/65.5, where A represents the height's body shape, 1 is the size code number, 4 is the body shape code number, and 65.5 is the abdomen girth measurement. Based on the standard deviation of two dimensions, including the abdomen girth and height, combined with the dimensions of the common group, the waist girth is divided into nine different levels, and height is divided into six levels.

The body shape groups are categorized according to increasing levels of abdomen girth, numbered from 1 to 9. The height groups are categorized according to increasing levels of height and are labeled with the characters A, B, C, D, E, and F.

3.5. Determining the number of sizes

Since there are six height size groups and nine waist circumference size groups, there will be 54 sizes. The interval for height is 7 cm, while that for waist girth is 5 cm.

The smallest size has a height measurement of 150cm and an abdomen of 63cm. The largest size has a height measurement of 193 cm and an abdominal girth of 108cm. (Table 6).

Table 5. The linear regression equations for the dimensions

Measurement positions	Average body shape measurements (kg; cm)	Correlation functions (kg; cm)	Sig
Weight (kg)	63.72	$Y = -90.872 + 0.687 \times X_1 + 0.579 \times X_2$	0.000
Neck girth	39.76	$Y = 16.259 + 0.075 \times X_1 + 0.102 \times X_2$	0.000
Bust girth	90.14	$Y = 9.528 + 0.560 \times X_1 + 0.202 \times X_2$	0.000
Waist girth	79.66	$Y = 5.727 + 0.884 \times X_1 + 0.003 \times X_2$	0.000
Hip girth	94.60	$Y = 5.139 + 0.513 \times X_1 + 0.278 \times X_2$	0.000
Center back	42.32	$Y = 7.018 + 0.025 \times X_1 + 0.197 \times X_2$	0.000
Back width	32.22	$Y = -3.425 + 0.222 \times X_1 + 0.102 \times X_2$	0.000
Shoulder	42.72	$Y = 2.501 + 0.246 \times X_1 + 0.117 \times X_2$	0.000
Armhole depth	25.66	$Y = 1.731 + 0.127 \times X_1 + 0.079 \times X_2$	0.000
Sleeve length	56.68	$Y = -4.776 + 0.024 \times X_1 + 0.353 \times X_2$	0.000
Wrist	20.68	$Y = -4.499 + 0.243 \times X_1 + 0.030 \times X_2$	0.000
Outseam	96.70	$Y = 34.607 - 0.321 \times X_1 + 0.527 \times X_2$	0.000
Inseam	75.41	$Y = 10.304 - 0.036 \times X_1 + 0.404 \times X_2$	0.000
BMI	22.43	$Y = 13.384 + 0.240 \times X_1 - 0.065 \times X_2$	0.000
DROP	7.08	$Y = 9.538 - 0.44 \times X_1 + 0.202 \times X_2$	0.000
WHR	0.84	$Y = 0.801 + 0.006 \times X_1 - 0.003 \times X_2$	0.000

Table 6. Size notation for each height group (Unit: cm)

Abdomen girth Height	65.5 [63-68]	70.5 [68-73]	75.5 [73-78]	80.5 [78-83]	85.5 [83-88]	90.5 [88-93]	95.5 [93-98]	100.5 [98-103]	105.5 [103-108]
A [150-157]	A1-4/65.5	A2-4/70.5	A3-3/75.5	A4-2/80.5	A5-2/85.5	A6-2/90.5	A7-2/95.5	A8-2/100.5	A9-2/105.5
B [157-164]	B10-5/65.5	B11-5/70.5	B12-4/75.5	B13-4/80.5	B14-2/85.5	B15-2/90.5	B16-2/95.5	B17-3/100.5	B18-3/105.5
C [164-171]	C19-5/65.5	C20-5/70.5	C21-4/75.5	C22-4/80.5	C23-2/85.5	C24-2/90.5	C25-3/95.5	C26-3/100.5	C27-3/105.5
D [171-178]	D28-5/65.5	D29-5/70.5	D30-6/75.5	D31-4/80.5	D32-2/85.5	D33-1/90.5	D34-1/95.5	D35-3/100.5	D36-3/105.5
E [178-185]	E37-5/65.5	E38-5/70.5	E39-5/75.5	E40-6/80.5	E41-6/85.5	E42-1/-90.5	E43-1/95.5	E44-3/100.5	E45-3/105.5
F [185-193]	F46-5/65.5	F47-5/70.5	F48-6/75.5	F49-6/80.5	F50-3/85.5	F51-3/90.5	F52-1/95.5	F53-3/100.5	F54-3/105.5

3.6. Encoding the Sizing System Table

The sizing system tables are encoded in the sequence of sizes from A1/65.5 to F54/105.5. The encoded numbers will be used as the output for body shape and body size measurements.

Specifically, the body shape encoding output consists of the numbers 1, 2, 3, 4, 5, and 6, corresponding to the six body shape groups analyzed in section 3.2. The size encoding output will be the numbers from 1 to 54, as shown in Table 7.

Table 7. Encoded sizing system

Size	A1-4/65.5	A2-4/70.5	A3-3/75.5	A4-2/80.5	A5-2/85.5	A6-2/90.5	A7-2/95.5	A8-2/100.5	A9-2/105.5
Encoded numbers	1	2	3	4	5	6	7	8	9

Size	B10-5/65.5	B11-5/70.5	B12-4/75.5	B1-4/80.5	B14--2/85.5	B15-2/90.5	B16-2/95.5	B17-3/100.5	B18-3/105.5
Encoded numbers	10	11	12	13	14	15	16	17	18
Size	C19-5/65.5	C20-5/70.5	C21-4/75.5	C22-4/80.5	C23-2/85.5	C24-2/90.5	C25-3/95.5	C26-3/100.5	C27-3/105.5
Encoded numbers	19	20	21	22	23	24	25	26	27
Size	D28-5/65.5	D29-5/70.5	D30-6/75.5	D31-4/80.5	D32-2/85.5	D33-1/90.5	D34-1/95.5	D35-3/100.5	D36-3/105.5
Encoded numbers	28	29	30	31	32	33	34	35	36
Size	E37-5/65.5	E38-5/70.5	E39-5/75.5	E40-6/80.5	E41-6/85.5	E42-1/90.5	E43-1/95.5	E44-3/100.5	E45-3/105.5
Encoded numbers	37	38	39	40	41	42	43	44	45
Size	F46-5/65.5	F47-5/70.5	F48-6/75.5	F49-6/80	F50-3/85.5	F51-3/90.5	F52-1/95.5	F53-3/100.5	F54-3/105.5
Encoded numbers	46	47	48	49	50	51	52	53	54

3.7. Algorithm for Choosing the Size and Body Shape by Fuzzy Logic

In this study, the MIMO model is chosen for the Sugeno fuzzy controller. The model uses the Max-Min rule. The MIMO model and Sugeno Fuzzy Controller enable the system to handle complex relationships between body measurements and the predicted body shape or size. With Sugeno rules, each input variable (abdomen, height) influences two outputs (shape and size) through a constant, allowing faster and more streamlined processing. This approach ensures that each body measurement contributes efficiently to accurately predicting both body shape and size. In this, there are 2 input variables: abdomen girth (X_1) and height (X_2). These variables must fall within the value ranges specified in the size chart, which are listed: $62.80 \leq X_1 \leq 108.20$cm; $149.80 \leq X_2 \leq 193.20$cm. The two output results are the body shape and the size that need to be predicted. There are 9 membership functions for the first input variable (Figure 3). Each function represents a range of measurements for each body shape.

The first output result is the number of the 6 body shape groups (Table 8). There are a total of 6 membership functions for the second input variable (very short, short, average, high, and very high) (Figure 4). Each function represents a range of waist circumference measurements (Table 9). The second output result is the predicted body size, with a total of 54 sizes. The model predicts body shape and body size, as shown in Figure 5.

Table 8. Characteristics of the membership functions for the abdomen girth

The group of abdomen girth	Membership functions (cm)	Characteristics	Acronym
1	[62.8 65.5 68.2]	Very Small Abdomen	VSA
2	[67.8 70.5 73.2]	Quite Small Abdomen	QSA
3	[72.8 75.5 78.2]	Small Abdomen	SA
4	[77.8 80.5 83.2]	Slightly Small Abdomen	SSA
5	[82.8 85.5 88.2]	Medium Abdomen	MA
6	[87.8 90.5 93.2]	Slightly Large Abdomen	SLA
7	[92.8 95.5 98.2]	Large Abdomen	LA
8	[97.8 100.5 103.2]	Quite Large Abdomen	QLA
9	[102.8 105.5 108.2]	Very Large Abdomen	VLA

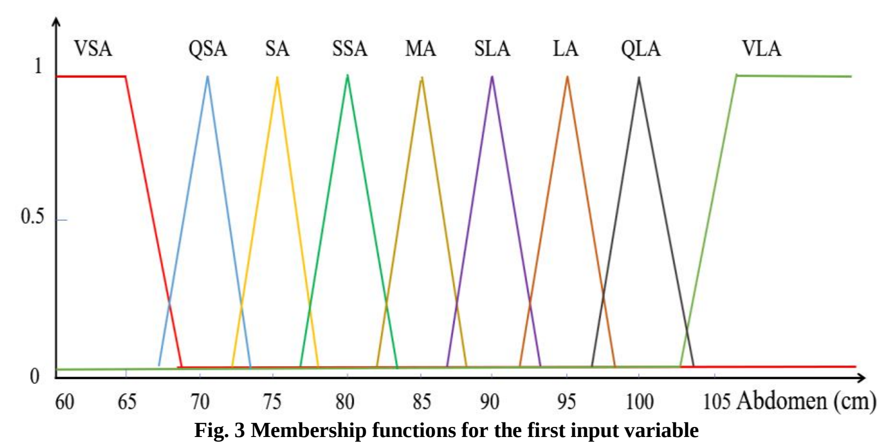


Fig. 3 Membership functions for the first input variable

Table 9. Properties of the height variable's membership functions

The group of abdomen girth	Membership functions (cm)	Characteristics	Acronym
A	[149.8 153.5 157.2]	Quite Short	QS
B	[156.8 160.5 164.2]	Short	S
C	[163.8 167.5 171.2]	Medium	M
D	[170.8 174.5 178.2]	Tall	T
E	[177.8 181.5 185.2]	Quite Tall	QT
F	[184.8 188.5 193.2]	Very Tall	VT

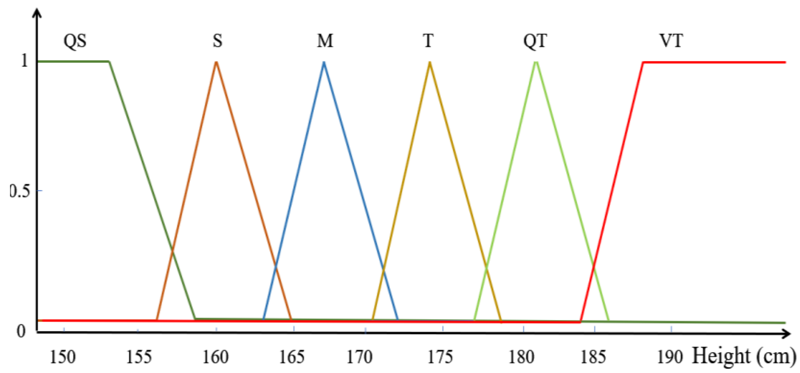


Fig. 4 Membership functions for the second input variable

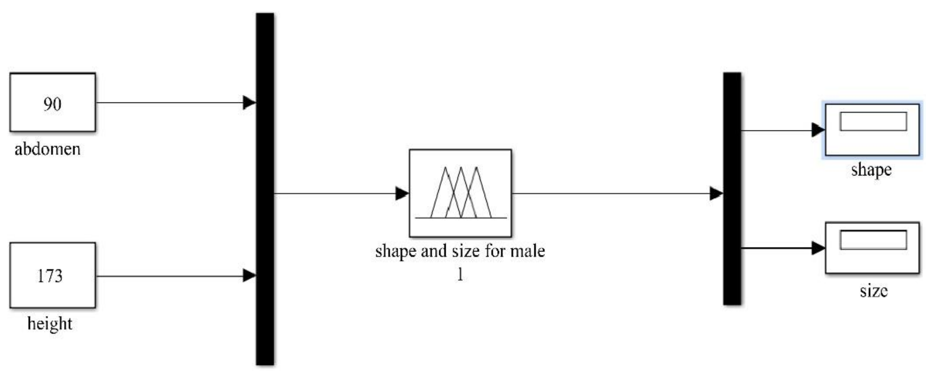


Fig. 5 Model for predicting body size and shape

3.8. Fuzzy rules

The fuzzy rule set of the study is presented in Table 10. There are 54 fuzzy rules used in this study.

The fuzzy rules established are in the following structure:

If (x1 is A_1^m) and (x2 is B_1^n) then (y_1 is C^p)(y_2 is D^q)

Table 10. Fuzzy rule set

Fuzzy Rules	Abdomen Girth	Height	Body Shape	Size	Fuzzy Rules	Abdomen Girth	Height	Body Shape	Size
1	VSA	QS	G4	A1-4/65.5	28	VSA	T	G5	D28-5/65.5
2	QSA	QS	G4	A2-4/70.5	29	QSA	T	G5	D29-5/70.5
3	SA	QS	G3	A3-3/75.5	30	SA	T	G5	D30-5/75.5
4	SSA	QS	G2	A4-2/80.5	31	SSA	T	G4	D31-4/80.5
5	MA	QS	G2	A5-2/85.5	32	MA	T	G2	D32-2/85.5
6	SLA	QS	G2	A6-2/90.5	33	SLA	T	G1	D33-1/90.5
7	LA	QS	G2	A7-2/95.5	34	LA	T	G1	D34-1/95.5
8	QA	QS	G2	A8-2/100.5	35	QLA	T	G3	D35-3/100.5
9	VLA	QS	G2	A9-2/105.5	36	VLA	T	G3	D36-3//105.5
10	VSA	S	G5	B10-5/65.5	37	QSA	QT	G5	E37-5/65.5
11	QSA	S	G5	B11-5/70.5	38	QSA	QT	G5	E38-5/70.5

12	SA	S	G4	B12-4/75.5	39	SA	QT	G5	E39-5/75.5
13	SSA	S	G4	B13-4/80.5	40	SSA	QT	G6	E40-6/80.5
14	A	S	G2	B14-2/85.5	41	A	QT	G6	E41-6/85.5
15	SLA	S	G2	B15-2/90.5	42	SLA	QT	G6	E42-6/90.5
16	LA	S	G2	B16-2/95.5	43	LA	QT	G6	E43-6/95.5
17	QLA	S	G3	B17-3/100.5	44	QLA	QT	G3	E44-3/100.5
18	VLA	S	G3	B18-3/105.5	45	VLA	QT	G3	E45-3/105.5
19	VSA	M	G5	C19-5/65.5	46	VSA	VT	G5	E46-5/65.5
20	QSA	M	G5	C20-5/70.5	47	QSA	VT	G5	E47-5/70.5
21	SA	M	G4	C21-4/75.5	48	SA	VT	G6	E48-6/75.5
22	SSA	M	G4	C22-4/80.5	49	SSA	VT	G6	E49-6/80.5
23	MA	M	G2	C23-2/85.5	50	MA	VT	G3	E50-3/85.5
24	SLA	M	G2	C24-2/90.5	51	SLA	VT	G3	E51-3/90.5
25	LA	M	G3	C25-3/95.5	52	LA	VT	G1	E52-1/95.5
26	QLA	M	G3	C26-3/100.5	53	QLA	VT	G3	E53-3/100.5
27	VLA	M	G3	C27-3/105.5	54	VLA	VT	G3	E54-3/105.5

3.9. Input Results for Running the Program with Two Input Variables

The program requires inputting two variables: abdomen girth and body height measurements. From these specific input values, the controller performs "fuzzification" at the membership functions to assess which level the signal belongs to among the pre-classified levels (Column 2, Table 8 for abdomen girth) and (Column 2, Table 9 for height). Subsequently, the input signal is converted into characteristic values for abdomen girth such as " Quite Small Abdomen", “Small Abdomen”, "Slightly Small Abdomen", "Medium Abdomen", "Medium", “Slightly Large Abdomen”, “Large Abdomen”, “Quite Large Abdomen”, “Very Large Abdomen”, “Quite Short”, “Short”, “Medium”, “Tall”, “Quite Tall”, “Very Tall”. Next, these abdominal and height characteristics are processed according to the rules of the controller. Through the "defuzzification" block of the controller, they are converted back to obtain a specific output value. This result is the predicted body shape and body size.

3.10. Discussion

A comparison of Table 2 and Table 5 indicates the following recommended sizes for each body shape group:

Group 1 has five sizes: D33-1/90.5, D34-1/95.5, E42-1/90.5, E43-1/95.5, F52-1/95.5.

Group 2 has twelve sizes: A4-2/80.5, A5-2/85.5, A6-2/90.5, A7-2/95.5, A8-2/100.5, A9-2/105.5, B14-2/85.5, B15-2/90.5, B16-2/95.5, C23-2/85.5, C24-2/90.5, D32-2/85.5.

Group 3 has fourteen sizes: A3-3/75.5, B17-3/100.5, B18-3/105.5, C25-3/95.5, C26-3/100.5, C27-3/105.5, D35-3/100.5, D36-3/105.5, E44-3/100.5, E45-3/105.5, F50-3/85.5, F51-3/90.5, F53-3/100.5, F54-3/105.5.

Group 4 has seven sizes: A1-4/65.5, A2-4/70.5, B12-4/75.5, B13-4/80.5, C21-4/75.5, C22-4/80.5, D31-4/80.5.

Group 5 has eleven sizes: B10-5/65.5, B11-5/70.5, C19-5/65.5, C20-5/70.5, D28-5/65.5, D29-5/70.5, E37-5/65.5, E38-5/70.5, E39-5/75.5, F46-5/65.5, F47-5/70.5.

Group 6 has five sizes: D30-6/75.5, E40-6/80.5, E41-6/85.5, F48-6/75.5, F49-6/80.5.

The sizing system table includes 54 body size measurements across 353 people, divided into 6 height-based groups, each with 9 sizes. Since the groups differ only in height, for industrial applications, businesses should use the group whose measurements best represent the overall sample. As shown in Table 6, Group C meets this criterion. Thus, Group C sizes (C19-5/65.5, C20-5/70.5, C21-4/75.5, C22-4/80.5, C23-2/85.5, C24-2/90.5, C25-3/95.5, C26-3/100.5, C27-3/105.5) are recommended for production. When comparing the Vietnamese body shape with the results of anthropometric research conducted in three others Southeast Asian countries, as presented in Table 11 [32, 33], it becomes evident that there are no significant differences in height.

Vietnamese people weigh the lightest among the four countries. These similarities may have important implications for various fields, including fashion design, ergonomics, and health assessments within Southeast Asian countries. From the result of the analysis of the body shapes, the sizing system table is established. Compared with the size table [27], the height group was divided into three groups. As a result, compared with the Vietnamese size system, the size set in this research has 42 more sizes. In addition, the measurement ranges of the primary dimensions also increased. The height has increased by 19cm, the bust girth increased by 11.47cm, and the hip girth increased by 12.25cm (Table 12). This shows that since 2009, the adult Vietnamese male stature has become taller and larger. This study achieved good results in proposing a model for extracting a sizing system table for body shape groups because the measurement data was carefully collected with little measurement error. This will give a reliable body shape analysis result in establishing a size chart with a size chart of 54 sizes. It can be quite slow to manually select a size that fits your body shape accurately. To solve this problem, the fuzzy logic algorithm is a good solution and is easy to apply to choose the right size in a short time.

Table 11. The mean anthropometric data for three asian countries

	Vietnamese	Chinese	Malaysian	ThaiLand
Height (cm)	168.5	167.7	168.1	168.6
Weight (kg)	63.7	71.4	68.4	65.4

Table 12. Comparing the sizes and body shapes in this research with TCVN 5782:2009 [27]

	Total Size	Body Shape	Height (cm)	Bust Girth (cm)	Hip Girth (cm)
This research	54	A, B, C, D, E, F	152-176	76-94	66-84
TCVN 5782:2009	12	A, B, C	150-193	77.22-106.69	81.41-111.66

4. Conclusion

The study analyzed 353 Vietnamese men in Ho Chi Minh City, aged 18-60, using SPSS software, including principal component analysis and factor analysis, K-Mean Cluster. Six different groups of male body shapes were selected after conducting an ANOVA. These are trapezoid-shaped, round-shaped, oval-shaped, wide rectangle-shaped, narrow rectangle-shaped, and inverted triangle-shaped.

Additionally, the study produced a table of linear regression equations to determine dependent measurements based on the two main measurements, abdomen girth and height, as well as the interval. Based on this, the research results established a sizing system table consisting of 54 sizes, serving 6 body shapes: A, B, C, D, E, and F, with each body shape having 9 abdomen girth groups. The results of the body shape analysis and the establishment of the sizing system table are used as the two input variables and the program's output for predicting body size and body shape using fuzzy logic techniques.

The fuzzy logic model has 2 input variables: abdomen girth and body height. There are 2 output results: body shape and body size. There are a total of 9 membership functions for the input variable abdomen girth and 6 membership functions for the input variable body height. The model uses the Max-Min composition rule. There are a total of 54 fuzzy rules.

The program will allow customers to determine their body shape and size, providing a basis for selecting clothing that suits their body shape in a short amount of time. The program was tested using measurement data and body shape for 30 samples. This research result will serve as a useful database in the practical production of pattern design in the garment industry and applications in teaching courses related to men's clothing design. Specifically, this prediction model will meet the needs of remote clothing shopping through e-commerce platforms. This research direction will be expanded to the research subject of overweight men and women and adult women in many other countries.

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