Customer Pairwise Fit Matrix Approach to Grouping of Customers for Garment Sizing

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Abstract

The garment manufacturing industry is reported to be experiencing customer complains of misfit. Studies on this problem seem not to have provided solutions that satisfy customers and manufacturers of clothing. In this study, Customer Pairwise Fit matrix (CPF) was explored to group a given customers population for the purpose of garment sizing. A mathematical fit function expressed as Percentage Fit (PF) between pair of customers was developed, CPF matrix for a number of customers indicating the degree of fit between any pair of customers was derived. A grouping algorithm from literature was adapted with the CPF matrix to divide a given population of customers to garment sizes, and demonstrated using garment anthropometric data related to trousers of 100 male potential customers in Nigeria. The results obtained for the PF between any pair of customers indicated 3 possible results of 'no fit' (PF = 0.0%), 'partial fit' (0.0% < PF <100%) and 'perfect fit' (PF=100%). The outcome of the adapted algorithm to the 100 potential customers led to 19 set of customers but 18 sizes appeared to give the 'best' possible fit of 99.31%. The procedure developed in this work may be useful for sizing of larger customer population and any garment type.

Keywords
Garment, Garment Anthropometric Dimension, Customer pairwise fit matrix, Perfect Tolerable Fit

1.0 Introduction

Production of garments in the past had been mainly based on Visit-the-Tailor hand-measurement-and-sew tailoring system. The approach is to satisfy the needs of an individual customer in one set-up. In the era of mass-produced clothing, garment sizing is the method used to create ready-to-wear garments meant to fit a range of people in the population (Petrova and Ashdown, 2012). In order to sustain mass production and to assist manufacturers to meet customers' different sizes; sizing systems were introduced. A 'size' for a clothing has specified measurements along certain dimensions and will fit perfectly a person with measurements equal to those on the specified size (Tryfos, 1986)

Kolawole and Charles-Owaba (2011) observed that the desires of customers to have appropriate fit and the need for manufacturers of garment to meet diverse population have led many nations of the world to develop sizing system and this has attracted many research works. Some of such studies include (Ashdown, 1998; McCulloch, *et al* 1998; Gupta and Gangadhar, 2004; Hsu and Wang, 2005; Chung et al, 2007; Zheng et al, 2007; Bagherzadeh, *et al*, 2010; Hsiao, 2013; Yang *et al*, 2015) with different solution approaches.

However, in spite of these efforts of developing garment sizing in relation to fit, getting a satisfactory sizing system has continued to be a challenge to researchers, manufacturers and customers. Hwang (2001) reported that most people have a problem with fit in the clothing that was available in the market place in one way or the other and argued that diverse and complexity in so many ways of human anthropometric dimensions might be responsible. Petrova and Ashdown (2012) suggested that the inadequacy of the sizing standards that is used in developing the system may have contributed. Lack of information on precise definition of the concept of garment fit may also be a factor. Another reason could be the means of developing garment sizing system which have generally relied on one or two control dimensions as the basis for obtaining sizes and use of aggregate loss between customers and developed prototype sizes to determine a suitable sizing system.

Since fit has become an issue in garment sizing and manufacturing, it appears further studies are required. In this study, the concept of customers pairwise fit matrix (CPF) is proposed for the grouping of customers for

garment sizing. The basis for this is the viewing of the assignment of customers who have close body dimensions into the same size as similar to grouping of objects on the basis of similarity. Kolawole (2016) observed that grouping objects on the basis of similarity has been identified in several disciplines such as information storage and retrieval, patients in hospitals and parts/machines grouping among others. Such studies include Charles-Owaba 2002; Agheli and Mehran 1981; Charles-Owaba 1981 and Elder 1981). Among these studies, a closer examination of the procedures of Charles-Owaba (2002) and Charles-Owaba (1981) in grouping of parts seems reasonable to be considered for the possibility of adapting it for grouping of customers into sizes. While for the grouping of parts, the basis was similarity of certain characteristics so as to reduce set-up cost; in the sizing system, the aim is to have customers whose dimensions are close to be in the same size category in order to obtain optimal number of sizes that would be produced for a given population and also ensure 'good' degree of fit. In this study, the method of Charles-Owaba (2002) and Charles-Owaba (1981) is to be adapted and would be used subsequently.

2.0 Theoretical Consideration

To come up with an appropriate garment sizing system for any clothing, it is necessary to identify garment sizing variables and parameters.

2.1 Garment Sizing Variables and Parameters

Garment sizing variables are the quantities in the tailoring industry whose values a garment designer may select and alter at will in the process of producing a garment fit desired by a customer. On the other hand, garment sizing parameters are quantities which are equally important as the variables to the industry but whose values cannot be altered at will by the garment designer. Knowledge of these quantities and respective differences will be very useful for understanding the analytical requirements of any tailoring industry.

From previous studies on garment sizing including (Kolawole, 2016; Ashdown, 1998; McCulloch *et al*, 1998; Tryfos, 1986) and visit to tailors to observe their business as they interact with customers, machines, clothes and other facilities, main variables and parameters related to garment sizing were identified and include tolerance, number of dimensions, customers' population and number of sizes required

2.2 Model Development

In this section, fit is defined quantitatively in terms of identified garment sizing parameters. A mathematical function that expresses this is stated as follows after the assumptions given.

To have a clearer picture of model developed, the following assumptions are made:

(a) A garment size that its dimension values perfectly fit a specific customer 'i' is known
(b) A customer 'k' whose fit is to be compared to that of customer 'i'
(c) A tolerance value on each dimension of the garment is known

Tolerance is a numerical value that a designer may add or subtract from the value of a particular dimension that would still make the garment within allowable fit to a customer

2.2.1 Garment Fit between Pair of Customers

It is assumed here that the garment size whose dimension values perfectly fit a specific customer captioned 'i' is known and let '*k*' be the customer whose fit is to be compared to that of customer 'i'. Also, let ω_{ikj} be a binary state of fit between '*i*' and '*k*' on dimension '*j*' such that:

$$\omega_{ikj} = \begin{bmatrix} 1, \text{ if } |x_{ij} - x_{kj}| \leq t_j \\ \\ 0, \quad \text{otherwise} \end{bmatrix} \tag{1}$$

Where: $x_{ij,}$ the value of the anthropometric dimension *j* of customer *i* for a particular garment; $x_{ik,}$ the value of the anthropometric dimension *j* of customer *k* for the same particular garment;

and t_j is the tolerance on dimension j.

If considered over *m* dimensions for a particular garment with m dimensions, the relative fit of '*i*' to '*k*', B_{ik} expressed as a binary vector is defined as follows:

$$B_{ik} = \begin{bmatrix} \omega_{ik1} \\ \omega_{ik2} \\ \omega_{ik3} \\ \omega_{ikj} \\ \vdots \\ \omega_{ikm} \end{bmatrix} \tag{2}$$

Where,

$$\omega_{ikj} = \begin{cases} 1, & \text{if i and k have a tolerable fit with respect to dimension j} \\ \\ 0, & \text{otherwise} \end{cases} \tag{3}$$

Hence for a perfect tolerable fit in all the garment dimensions:

$$B_{ik} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ \vdots \\ \vdots \\ 1 \end{bmatrix} \quad (4)$$

For a partial tolerable fit, it may be represented as follows:

$$B_{ik} = \begin{bmatrix} 0 \\ 1 \\ . \\ . \\ 1 \\ 1 \end{bmatrix}; \quad (5)$$

and for "no fit" situation:

$$B_{ik} = \begin{bmatrix} 0 \\ 0 \\ . \\ . \\ 0 \\ 0 \end{bmatrix} \quad (6)$$

It should be noted that expressions of equations (2), (4), (5) and (6) represent the binary vector of fit for any pair of customers. Alternatively, the fit between any pair of customers in any population may also be expressed as a scalar. Thus, let r_{ik} be the scalar expression of fit between customers '*i*' and 'k' defined as follows:

$$r_{ik} = {}^{[(B_{ik})^T B_{ik}]}\Big/_{[(B_{ii})^T B_{ii}]} \quad (7)$$

Where $(B_{ik})^T$ is the transpose of binary vector B_{ik}
Let B_{ii} theoretically be the identity of a customer compared to himself defined as follows:

$$B_{ii} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} \quad (8)$$

Hence r_{ik} of equation (7) may be re-written as:

$$r_{ik} = \begin{bmatrix} w_{ik1}, w_{ik2} \cdots w_{ikm} \end{bmatrix} \begin{bmatrix} w_{ik1} \\ w_{k2} \\ \vdots \\ w_{ikm} \end{bmatrix} \Big/ \begin{bmatrix} 1,1, \cdots 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \quad (9)$$

The following important property of expression of equation (7) and (9) may be noted:

$$0 \leq r_{ik} \leq 1 \quad (10)$$

Comparing expressions (9) with (4), (5) and (6), it is clear that:

$$r_{ik} \begin{cases} = 1, & \text{i and k have perfect tolerable fit in the particular gament of interest} \\ < 1, & \text{i and } k \text{ have partial tolerable fit} \\ = 0, & \text{i and k have no fit situation} \end{cases} \quad (11)$$

While the scalar and binary vector expressions are stating the same thing, the scalar appears to have some mathematical and information storage advantage. The scalar shows the degree of fit which can be expressed in either proportion or percentage. Considering the percentage representation, it may be observed that customers *i* and *k* can have 0.0%, 10%, 20% … 90%, 100% fit with respect to the use of a particular garment.
In terms of percentage fit, PF_{ik} may be expressed as follows:

$$PF_{ik} = 100r_{ik} = 100\ {[(B_{ik})^T B_{ik})]}/{[(B_{ii})^T B_{ii}]} \quad (12)$$

For a population or group of *N* customers, an *N* x *N* matrix of fit can be generated. Let 'L' denote this matrix. Thus:

$$L = \begin{pmatrix} PF_{11} & PF_{12} & PF_{1k} & \cdots & PF_{1N} \\ PF_{21} & PF_{22} & PF_{2k} & \cdots & PF_{2N} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ PF_{k1} & PF_{k2} & PF_{ki} & \cdots & PF_{kN} \\ PF_{N1} & PF_{N2} & PF_{Nk} & \cdots & PF_{NN} \end{pmatrix} \quad (13)$$

2.2.2 Garment Fit for a Sub-group of Customers

Another advantage of the scalar representation is its ease for expressing the degree of fit for a group of customers who may likely wear the same garment size. Let l be the fit matrix of *n* customers in size 'α'.

$$l = \begin{pmatrix} PF_{11} & \cdots & PF_{in} \\ PF_{21} & PF_{22} & PF_{2n} \\ \cdots & \cdots & \cdots \\ PF_{ni} & \cdots & PF_{nn} \end{pmatrix} \quad (14)$$

Also let h_α be the degree of fit of the set of customers (g_α) in size α

$$h_\alpha = {[\sum_{j=1}^{g_\alpha} \sum_{k=1}^{g_\alpha - 1} PF_{ik}]}/{n_\alpha(n_\alpha - 1)} \quad (15)$$

$i, k \in g_\alpha$; $i \neq k$

Where n_α is the number of customers in size α, and PF_{ik} is the scalar expression of fit between customers *i* and *k*.

Notice that h_α is the average of the fit in l matrix. This h_α shares the same property as PF_{ik}. That is:

$$0 \leq h_\alpha \leq 100 \quad (16)$$

Interpreted as follows:

$$h_\alpha \begin{cases} = 100, & \text{perfect tolerable fit i. e. all member in each group can wear the size} \\ < 100, & \text{only some may wear the same size} \\ = 0, & \text{none can wear the same size} \end{cases} \quad (17)$$

2.3 The Garment Fit for a Population of Customer

In the previous section, the degree of fit of a size for a set of customers has been shown. In any given population, a single size may not likely satisfy all, hence there may be need for more than one size. Then a number of sizes as $1, 2, \ldots \alpha \ldots q$, which would accommodate a given population with corresponding degree of fit of $h_1, h_2 \ldots h_\alpha \ldots h_q$

Let $V(h_\alpha)$ represents the overall degree of fit for the garment sizing system, this degree of fit is a function of number of dimensions (*m*), population (*N*), tolerance (*t*) and the number of required size (*q)* as well a set of customers (g_α) in size α

Notationally; $V(h_\alpha) = f(g_\alpha, q;\ t, m, N) = {[h_1 + h_{2+} \ldots h_\alpha + \cdots h_q]}/{q}$ (18)

Where;

g_α = a set of customers in size α
q = number of sizes
t = tolerance
m = number of dimensions
N = customers population

A close observation shows that '$V(h_\alpha)$' shares the same property with 'h_α' i.e.

$$0 \leq V(h_\alpha) \leq 100 \quad (19)$$

This can also be interpreted as:

$$V(h_\alpha) \begin{cases} = 100, & \text{perfect tolerable fit i.e. all in each group can wear the same size} \\ < 100, & \text{partial tolerable fit, only some can wear the same size} \\ = 0, & \text{none can wear the same size} \end{cases} \quad (20)$$

A solution to a sizing problem whose $V(h_\alpha)$ equals 100% is a perfect solution with low likelihood for customers complaining. That is, every customer in the population would be able to find a suitable size.

2.4 Garment Sizing Problem and Solution Procedure

To define and solve a sizing problem, Customers Anthropometric Dimension (CAD) related to specific garment would have to be transformed into a Customer-pairwise Fit Matrix (CPF) shown in expression (13) using expressions (1) to (12). The CPF matrix has the characteristics of indicating the cluster of customers likely to wear the same size of garments. By observing the matrix elements, the information in expression (13) may provide some clue as to those customers who may wear the same size. Indeed, the cluster of customers whose average of the set $\{PF_{ik}\}$ is equal to 100 or very close to 100 are likely to wear the same size. Hence, the CPF matrix serves as an input into an algorithm which further transforms the sample of customers into those who will wear the same size of garments. First, the problem is hereby defined.

Given the matrix, $L = \begin{pmatrix} PF_{11} & PF_{12} & PF_{ik} & \cdots & PF_{iN} \\ PF_{21} & PF_{22} & PF_{2k} & \cdots & PF_{2N} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ PF_{k1} & PF_{k2} & PF_{ki} & \cdots & PF_{kN} \\ PF_{N1} & PF_{N2} & PF_{Nk} & \cdots & PF_{NN} \end{pmatrix}$ i = 1, 2, 3, 4, 5... N-1, N

Maximize:

$$V(g_\alpha, q;\ t, m,\ N) = \left(\sum_{\alpha=1}^{\alpha=q} h_\alpha\right)_{/q} \quad (21)$$

Subject to:

$$g_1 \cap g_2 \cap g_3 \cap \ldots\ldots\ldots\ldots g_\alpha \cap \ldots\ldots\ldots g_{\alpha+1} \cap g_q = \{\Theta\} \quad (22)$$

$$\sum_{\alpha=1}^{q} n_\alpha = N \quad (23)$$

where g_α is the set of customers in size α, n_α is the number of customers in size α, q is number of sizes, Θ is an empty set of customers and *N* customers population.

Stating descriptively, the problem is that of segregating a given customers population with known relevant tailoring anthropometric dimensions into sub-groups who will use the same size such that "best fit" per person and subsequently the whole population is attained.

This problem can be solved using any of the several existing computer programmes applied to solving similar grouping problems in parts/machines grouping (Charles-Owaba, 2002; and Charles-Owaba, 1981). The entire solution for a given N customers, tolerance (t), number of dimensions (m) and number of sizes (q) may be presented in the format shown in Table 1.

Table 1: Garment Sizing Solution Format: t=; m=; and N=

Number of Sizes	Size (α)	Set of Customers ($g_{\alpha i}$) to wear the same size	Fit of a Size (h_α)	Fit of a Sizing System
2	1		h_1	$V(h_2)$
	2		h_2	
3	1		h_1	$V(h_3)$
	2		h_2	
	3		h_3	
α	1		h_1	$V(h_\alpha)$
.	2		h_2	
	.		.	
	.		.	
	α		h_α	
Q	1		h_1	$V(h_q)$
	2		h_2	
	3		h_3	
	.		.	
	.		.	
	.		.	
	Q		h_q	

3.0 Model Application

In order to test possible application of the model developed, anthropometric data related to men's trousers for a population of 100 men in Nigeria was used. This data (Table 2) were collected by Kolawole (2016) in a previous study and five dimensions (Length, Waist, Thigh, Hip and Bottom girth) as used by tailors in making trousers were obtained. The values of the dimensions for each of the customers are shown in Table 2.

To transform the anthropometric data into Customer Pair-wise Fit Matrix (CPF) using the procedure explained in the previous sections, the value of tolerance should be known. From literature and interaction with tailors in Nigeria, value of tolerance could vary from less than ±2.54cm (±1 inch) to as much as over 20.00cm depending on the type of garment. Many traditional wears in Nigeria and other African countries generally have loose fit and hence high value of tolerance. For this study, 5.08cm as adopted by Kolawole (2016) is used.

With tolerance set 5.08cm, the anthropometric data were transformed into CPF using the procedure explained in the section 2.2.1 and combined expression (1) to (13). For limited space, a sample of CPF matrix for customer population of 25 is presented in Table 3. With each of the CPF matrices and varying number of garment sizes, q = 2, 3, 4, 5, 6, ……, 19, 20, the garment sizing problems stated in section 2.4 are solved using an adapted Charles-Owaba's (2002) modified machine parts grouping algorithm written in Fortran 90 computer code and run on personal computer (HP model G6.1). The resulting set of solutions for N=100, t=5.08 and m=5 are presented in Table 4.

Table 2: Customer- Garment Anthropometric Dimension Matrix (Trousers)

Customer	Length(cm)	Waist(cm)	Thigh(cm)	Hip(cm)	Bottom girth(cm)
1	107.95	76.2	71.12	101.6	45.72
2	99.06	86.36	73.66	105.41	44.45
3	105.41	83.82	73.66	100.33	44.45
4	106.68	83.82	71.12	97.79	45.72
5	106.68	78.74	73.66	96.52	45.72
6	106.68	78.74	68.58	99.06	45.72
7	116.84	86.36	73.66	102.87	45.72
8	114.3	101.6	76.2	110.49	45.72
9	104.14	78.74	69.85	97.79	44.45
10	105.41	80.01	69.85	100.33	45.72
11	109.22	80.01	71.12	100.33	45.72
12	101.6	77.47	73.66	97.79	45.72
13	104.14	93.98	73.66	107.95	45.72
14	110.49	81.28	69.85	96.52	45.72
15	105.41	81.28	71.12	96.52	45.72
16	102.87	76.2	69.85	95.25	45.72
17	99.06	85.09	71.12	95.25	45.72
18	110.49	78.74	71.12	96.52	45.72
19	99.06	74.93	68.58	93.98	44.45
20	100.33	76.2	68.58	95.25	43.18
21	106.68	81.28	69.85	97.79	45.72
22	104.14	74.93	68.58	93.98	45.72
23	99.06	87.63	71.12	93.98	45.72
24	109.22	71.12	69.85	95.25	45.72
25	116.84	81.28	69.85	100.33	45.72
26	104.14	78.74	68.58	96.52	45.72
27	107.95	81.28	72.39	97.79	46.99
28	107.95	78.74	71.12	100.33	45.72
29	100.33	73.66	69.85	96.52	43.18
30	104.14	82.55	71.12	99.06	45.72
31	102.87	72.39	68.58	95.25	44.45
32	110.49	77.47	71.12	101.6	45.72
33	101.6	73.66	69.85	95.25	44.45
34	104.14	85.09	69.85	97.79	45.72
35	101.6	83.82	69.85	93.98	45.72
36	104.14	83.82	73.66	102.87	45.72
37	101.6	77.47	69.85	100.33	45.72
38	109.22	78.74	71.12	100.33	45.72
39	114.3	86.36	73.66	101.6	45.72
40	105.41	78.74	68.58	101.6	45.72
41	111.76	78.74	69.85	100.33	45.72
42	105.41	81.28	71.12	100.33	45.72
43	111.76	78.74	69.85	97.79	45.72
44	105.41	81.28	71.12	100.33	45.72
45	113.03	92.71	71.12	105.41	45.72
46	109.22	91.44	71.12	107.95	45.72
47	106.68	86.36	71.12	97.79	45.72
48	106.68	81.28	69.85	97.79	45.72
49	101.6	76.2	76.2	101.6	43.18
50	104.14	78.74	71.12	99.06	43.18
51	96.52	71.12	73.66	96.52	43.18
52	109.22	74.93	71.12	96.52	43.18
53	104.14	76.2	63.5	93.98	40.64
54	110.49	81.28	76.2	99.06	43.18
55	104.14	81.28	66.04	96.52	38.1
56	109.22	91.44	76.2	109.22	43.18
57	106.68	72.39	71.12	99.06	43.18
58	114.3	88.9	76.2	106.68	43.18
59	109.22	83.82	76.2	101.6	43.18
60	106.68	76.2	71.12	96.52	40.64
61	104.14	78.74	71.12	99.06	43.18
62	101.6	76.2	71.12	99.06	43.18
63	104.14	85.09	71.12	106.68	43.18

Customer	Length(cm)	Waist(cm)	Thigh(cm)	Hip(cm)	Bottom girth(cm)
64	109.22	78.74	71.12	101.6	40.64
65	101.6	68.58	71.12	101.6	40.64
66	109.22	85.09	73.66	101.6	45.72
67	106.68	73.66	73.66	96.52	43.18
68	107.95	78.74	73.66	96.52	43.18
69	109.22	78.74	66.04	99.06	38.1
70	111.76	73.66	66.04	99.06	38.1
71	104.14	71.12	71.12	96.52	40.64
72	104.14	76.2	73.66	96.52	40.64
73	106.68	78.74	76.2	101.6	45.72
74	99.06	71.12	73.66	101.6	43.18
75	109.22	76.2	73.66	96.52	43.18
76	106.68	73.66	71.12	101.6	40.64
77	109.22	73.66	71.12	99.06	40.64
78	109.22	81.28	71.12	101.6	43.18
79	106.68	76.2	71.12	96.52	45.72
80	109.22	78.74	68.58	99.06	45.72
81	97.79	71.12	66.04	96.52	40.64
82	111.76	77.47	71.12	99.06	45.72
83	100.33	71.12	68.58	96.52	43.18
84	106.68	78.74	68.58	99.06	40.64
85	114.3	80.01	81.28	106.68	45.72
86	110.49	82.55	71.12	99.06	43.18
87	116.84	80.01	71.12	101.6	45.72
88	101.6	73.66	71.12	96.52	43.18
89	111.76	77.47	78.74	96.52	45.72
90	106.68	81.28	71.12	99.06	40.64
91	106.68	78.74	73.66	96.52	43.18
92	100.33	74.93	71.12	96.52	40.64
93	104.14	78.74	73.66	96.52	43.18
94	101.6	76.2	73.66	99.06	43.18
95	106.68	76.2	76.2	99.06	43.18
96	106.68	78.74	76.2	101.6	40.64
97	104.14	78.74	76.2	101.6	43.18
98	114.3	92.71	76.2	111.76	45.72
99	104.14	74.93	76.2	101.6	43.18
100	106.68	69.85	71.12	96.52	40.64

Source: Kolawole (2016)

Table 3: Customers' Pair-wise fit (CPF) matrix for N=25, t=5.08 and m=5

CUSTOMERS	CUSTOMERS																								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
1	-	60	80	80	100	100	60	40	100	100	100	80	60	100	100	80	40	100	60	60	100	80	40	80	80
2	60	-	80	60	40	40	80	60	60	60	60	60	80	60	60	60	80	40	60	60	60	60	80	40	80
3	80	80	-	100	100	100	80	40	100	100	100	80	60	100	100	80	80	100	40	80	100	60	60	80	80
4	80	60	100	-	100	100	80	40	100	100	100	80	60	100	100	80	80	100	60	60	100	80	80	80	80
5	100	40	100	100	-	100	40	40	100	100	100	100	60	100	100	100	60	100	80	80	100	100	60	80	80
6	100	40	100	100	100	-	60	20	100	100	100	100	60	100	100	100	60	100	80	80	100	100	60	80	80
7	60	80	80	80	40	60	-	60	60	60	60	60	60	60	60	40	60	40	40	40	80	40	60	40	100
8	40	60	40	40	40	20	60	-	20	20	60	40	60	40	40	20	40	60	20	20	20	20	40	40	40
9	100	60	100	100	100	100	60	20	-	100	100	100	60	80	100	100	80	80	100	100	100	100	80	80	80
10	100	60	100	100	100	100	60	20	100	-	100	100	60	100	100	100	80	100	60	100	100	80	40	80	80
11	100	60	100	100	100	100	60	60	100	100	-	80	60	100	100	80	80	100	60	80	100	80	40	80	80
12	80	60	80	80	100	100	60	40	100	100	80	-	60	80	100	100	80	80	100	100	100	100	80	60	80
13	60	80	60	60	60	60	60	60	60	60	60	60	-	40	60	60	60	40	60	60	60	60	60	60	40
14	100	60	100	100	100	100	60	40	80	100	100	80	40	-	100	80	80	100	60	80	100	60	60	80	80
15	100	60	100	100	100	100	60	40	100	100	100	100	60	100	-	100	80	100	60	100	100	80	60	80	80
16	80	60	80	80	100	100	40	20	100	100	80	100	60	80	100	-	80	80	100	100	100	100	80	80	80
17	40	80	80	80	60	60	60	40	80	80	80	80	60	80	80	80	-	60	80	80	80	80	100	60	80
18	100	40	100	100	100	100	40	60	80	100	100	80	40	100	100	80	60	-	80	80	100	80	60	80	80
19	60	60	40	60	80	80	40	20	100	60	60	100	60	60	60	100	80	80	-	100	60	100	80	80	40
20	60	60	80	60	80	80	40	20	100	100	80	100	60	80	100	100	80	80	100	-	80	100	80	80	80
21	100	60	100	100	100	100	80	20	100	100	100	100	60	100	100	100	80	100	60	80	-	80	60	80	80
22	80	60	60	80	100	100	40	20	100	80	80	100	60	60	80	100	80	80	100	100	80	-	80	100	40
23	40	80	60	80	60	60	60	40	80	40	40	80	60	60	60	80	100	60	80	80	60	80	-	60	40
24	80	40	80	80	80	80	40	40	80	80	80	60	60	80	80	80	60	80	80	80	80	100	60	-	60
25	80	80	80	80	80	80	100	40	80	80	80	80	40	80	80	80	80	80	40	80	80	40	40	60	-

Table 4: Garment Sizing Solution (t= 5.08; m= 5; and N= 100)

Number of Sizes	Size (α)	Set of Customers (g_{α_i}) to wear the same size	Fit of a Size (h_α)	Fit of Sizing System
2	1	58;98	100%	88.99%
	2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 49, 50, 51, 52, 53, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79,80,81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 99, 100	77.98%	
3	1	58;98	100%	92.85%
	2	19, 53, 83	100%	
	3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49, 49, 50, 51, 52, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79,80,81, 82, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 99, 100	78.56%	
4	1	45; 46; 58	100%	95.07%*
	2	19; 81; 83	100%	
	3	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 47, 48, 49, 50, 51, 52, 53, 54, 55, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79,80, 82, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 99, 100	80.26%	
	4	56; 98	100%	

4.0 Results and Discussions

From the result shown in Table 3, it could be observed that the percentage fit between any pair of customer (i, k) varies from 0.0% to 100%. This indicates that the degree of fit can be in three categories; "no fit" (PF_{ik} = 0.0%), "partial fit" (0.0% < PF_{ik} < 100%) and "perfect fit" (PF_{ik} =100%). The reason for this variation in several pairs of customers could be attributed to whenever the difference in garment related anthropometric dimension (j) is not within tolerance limit for all the 'm' dimensions, PF_{ik} would be 0.0%. But when the difference is within tolerance for some dimensions and not all, then PF_{ik} lies between 0.0 and 100% i.e. partial fit, however, when the difference is within tolerance for all the 'm' dimensions, PF_{ik} would be 100% i.e. perfect fit.

Furthermore from Table 3, Customer 1 has perfect fit with 9 customers (5, 6, 9, 10, 11, 14, 15, 18 and 21) as PF_{ik} = 100.0% but partial fit with remaining 15 customers (0.0% < PF_{ik} < 100%). Customers 2, 8 and 13 do not have perfect fit with any other customers, these customers are perhaps outliers. The sizing problem was however solved with the goal of having those customers whose PF_{ik} relationships are 100% are in the same size/group as much as possible.

In addition, from the results partly shown in Table 4, the 100 customers are grouped into 2, 3, 4…18, 19 and 20 sizes. If there are two sizes, size 1 would have 2 customers with a tolerable fit of 100% and size 2 would have 98 customers with a tolerable fit of 77.98% but overall tolerable fit of 88.99%. For 3 sizes; size 1 and 2 have tolerable fit of 100% but consist of 2 and 3 customers respectively while the third size with tolerable fit of 78.56% has 95 customers. Overall fit for the 3sizes is 92.85%. Complete results for the first 4 groups of the

sizes are shown in Table 4 and for space limitations, results for all the sizes are summarised in Table 5. It may be seen that 18 sizes with overall sizing fit of 99.31% appears to be the best possible number of sizes, hence for this population, 18 sizes would satisfy the customers better than other number of sizes.

Table 5: Summary of Garment Sizing Solution (t= 5.08; m= 5; and N= 100)

Number of Sizes	Fit of Sizing System
2	88.90%
3	92.85%
4	95.07%
5	96.20%
6	96.92%
7	96.09%
8	85.35%
9	98.03%
10	98.16%
11	98.60%
12	98.55%
13	98.90%
14	98.33%
15	91.70%
16	92.14%
17	92.82%
18	99.31%
19	94.16%
20	99.28%

5.0 Conclusions

In this study, the possibility of solving garment sizing problem through Customer Pairwise Fit (CPF) matrix was explored. An attempt was made to identify garment sizing parameters and variables which led to a quantitative definition of fit formulated as CPF matrix indicating the degree of fit between any pair of customers in terms of the garment sizing parameters. The sizing problem was then defined as that of segregating a given customers population with known garment anthropometric data into sub-groups who will use the same size with the goal of maximizing fit. To test the feasibility of this approach, a sizing system for 100 potential customers population in Nigeria was developed. The results gave 99.31% fit which appears reasonable enough. The proposed method could be applied to larger customers population and different clothing.

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