Developing apparel sizing system using anthropometric data: Body size and shape analysis, key dimensions, and data segmentation

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4.1 Introduction: The body sizing system

Anthropometric data are obtained from a comprehensive anthropometric survey to understand the body shapes and sizes of certain population. When the body shapes and sizes are analyzed and understood, then the development of the right size clothing for good fitting garments can be achieved. It becomes especially significant when there is a need for mass-produced garments. These types of garments are mainly known as ready-to-wear where the sizes are set for certain body shapes and sizes.

The body sizing system is the method or system used to create a set of clothing for a variety of people in the target market (Xia and Istook, 2017). The most common sizing system in the apparel industry today uses a base size designed for a fit model and graded set of proportionally similar sizes derived from this base size. According to Xu et al. (2002) a size designation is “a set of garment sizes in a sizing system designed to reflect the body sizes of most individuals in a population” (Xu et al., 2002). On the other hand, RTW is the clothing that is manufactured in standard measurements and in size sets. It is designed to be purchased in an appropriate size and worn without further alterations. A sizing system can be as simple as “one size fits all” or S, M, L, or XL or as complex as a system that provides a custom-fitted garment for each individual. However, it has been noted that it is critical for any designer and manufacturer to provide clothing that fits all population (Goldsberry et al., 1996).

The purpose of a sizing system for apparel should be to make clothing available in a range of sizes that fit as many people as possible (McCulloch et al., 1998; LaBat, 1987). Standard sizing system should be able to help the apparel firms in categorizing garments of different sizes in a way that customers will recognize it (Hrzenjak et al., 2013). It also helps customers in identifying the garments that will provide them with a

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reasonable fit (Beazley, 1998a). It is very challenging to develop a size chart that can fit range of sizes for apparel. This size chart for clothing industry should effectively fit the variation of existing sizes and shapes of many different diverse population (Xia and Istook, 2017; Pei et al., 2017). Moreover, with different market segments, the problem also relies on accommodating the population for different ready-to-wear clothing stores that carry huge garment types and variations in which the right size and fit are usually compromised (Gill, 2015; Makhanya et al., 2014).

4.1.1 Size charts

The correct and reliable data collected from human measurements will provide real information for the industry about the sizes of their customers (Brownbridge et al., 2018). Individual companies may decide to put labels in their clothing with the bust, waist, and hip sizes, which will help consumers make better selections. Particularly in women's clothing the size label does not mean any particular measurement unless the company publishes a size chart. For women the body sizing systems are produced based on different combination of body measurements, proportions, and heights (Otieno and Fairhurst, 2000). For women's wear, sizes are labeled with numbers that correlate with height, bust, waist, hip, and other measurements. Skirts and pants are sold by size or by the waist measurement. Size categories for men are based on measurements on chest and length. Pants are sized at the waist and inseam. Shirt sizes are based on the measurement around the collar and the sleeve length. Most systems for sizing RTW garments have been based on very limited information. Thus a good sizing system should have detailed information of the key dimensions that are used to derive the size system, and this is called the size designation (Ashdown, 2014).

4.1.2 Size and fit

Size and fit are synonyms. It is reflected in the ready-to-wear (RTW) clothing as the product of a standard sizing system. To get a good fit, RTW clothing should be evaluated from the angle of individual *self and body*. The *self-evaluation* is called *body cathexis* (Manuel et al., 2010). Body cathexis is the evaluative dimension of body image and is defined as positive and negative feelings towards one's body. The dissatisfaction with body cathexis will result to the dissatisfaction with clothing fit (Kaiser, 1997). If one has higher body cathexis, the probability of satisfaction with the fit of clothing is higher (LaBat, 1987). The feeling of dissatisfaction of clothing fit can also be related to dissatisfaction with weight and lowered body cathexis (Song and Ashdown, 2013). A very important first step in determining correct sizing or creating well-fitted garments is obtaining accurate measurements of the specific human body. These measurements are considered the *body evaluation*, which is also known as the *anthropometry* (Gill, 2015). It is the science of human body dimensions. It deals with the methodical and precise measurement of the human body. The sizing systems that have been developed throughout the world are very small in numbers. Most of the world's clothing sizing systems are neither standardized nor related to the average human's body measurements. Therefore the needs for anthropometric studies are significant at this point for each country in the world. At the moment, there are only a handful of countries that have completed their national sizing system such as Korean size, Thailand size, Taiwan size, Japan size, Mexico size, Spanish size, Australia size, United Kingdom size, and North America size. Some of the countries now conducting the anthropometric research are India, the Philippines, and Malaysia.

4.2 Sizing system development and methodology

The process of developing the sizing system for any target market can be observed using the following procedure as shown in Fig. 4.1. The targeted sample for this methodology is demonstrated for the sample of female (7–12 and 13–17 years old). The illustrated procedure and process are conducted for children, and the original data were collected within 6 months. Anyhow the same process can be completed for the adult data too.

In this chapter, Fig. 4.1 illustrated the whole process to develop sizing system as shown later.

There are basically three important stages in sizing system development: Stages 1, 2, and 3. Stage 1 consists of the first process of anthropometric data collection, Stage 2 is the sizing data analysis, and Stage 3 consist of sizing system development. In general, it is imperative to identify important body dimensions for the development of sizing system. This is the first process after obtaining the data collection in which during the first stage of anthropometric survey, different body dimensions are measured on each person to develop sizing system. Then, from these body dimensions, only important body dimensions are selected to cluster sample population into similar body dimensions.

These important body dimensions are known as key dimensions or control dimensions. Key dimensions are the best representative of body shapes and sizes in which the sizing system is created (Adu-Boakye et al., 2012). Key dimensions consist of primary dimensions and secondary dimensions. Two distinct techniques to identify the

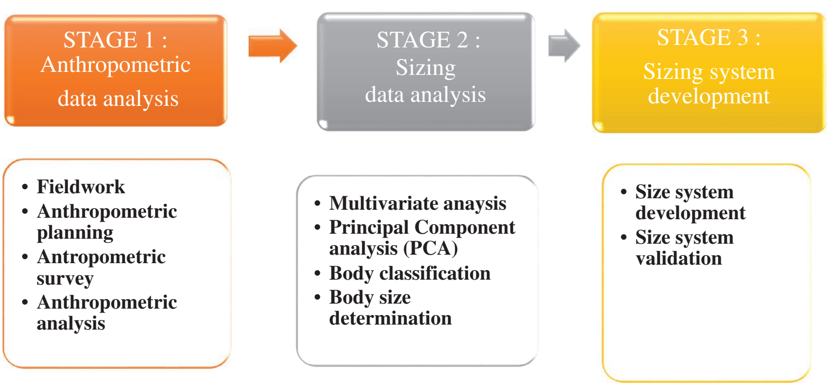

Fig. 4.1 Sizing system development process.

key dimensions are discussed in this chapter, which are the bivariate technique and principal component analysis, which is the multivariate technique. This chapter is designed to show how the anthropometric data are analyzed specifically using both techniques. Using bivariate technique will help to identify visual patterns of the dimensions as it only look at the relationships of two dimensions at one time. It will only give correlational relations between two variables. Using the principal component will give relative importance of the body dimensions. From the total body dimensions, this technique is able to classify them into important groups that suggest the group characteristics (Zakaria, 2011).

All steps and processes of obtaining the key dimensions are demonstrated in the bivariate and multivariate technique sections. In the subchapters the steps to identify the key dimensions are shown. These chapters practically showed the ways to analyze the anthropometric data and the ways to interpret data for the development of sizing system. Fig. 4.1 clearly shows how complex it is to develop a sizing system, encompassing three stages and ten steps from beginning to end. Stage 1 is anthropometric analysis, Stage 2 is sizing analysis, and Stage 3 is sizing system development. All ten steps are explained in the following sections.

Stage 1 is anthropometric analysis. The goal of Stage 1 is to collect body measurements of the sample population and analyze those using simple statistical methods. The purpose of this analysis is to understand the body ranges and variations present in the sample population. This stage consists of four steps—fieldwork preparation, anthropometric planning, the anthropometric survey itself, and anthropometric analysis—each of which is described in the following sections.

4.2.1 Step 1: Fieldwork preparation

This is the first process under anthropometric data analysis. Before obtaining the data the planning on how to conduct the anthropometric survey must be planned carefully. There should be careful consideration to select the team groups for better cooperation and understanding to work together.

4.2.1.1 Paperwork

Fieldwork preparation refers to the preparation that must be done before conducting the anthropometric survey. Preparation activities could include getting permission from the authorities, developing the anthropometric protocol, and training the measurers. When conducting an anthropometric survey, the process of preparing paperwork and getting the access from the authorities might involve asking formal permission from government bodies or agencies or from various related management of companies that owned spaces for public to go like the malls and town hall. The paperwork granting permission to work with different target populations can be challenging, which needs persistence and patience with the process of waiting for authorities to organize them. However, once the permission is granted, it will be a really good experience to conduct the anthropometric survey because you will have a chance to mingle and meet with many people of different walks of life.

4.2.1.2 Training the measurers

The next task is to prepare the measurers, if the anthropometry survey is conducted manually. If the survey is to be done using digital methods, such as a 3-D body scanner, then training will be focusing on using the sophisticated machine. The training for an anthropometric survey for clothing purposes is based on the standard ISO 8559/1989, which defines the terms used for each different body dimension. Under this ISO standard, there are 51 body dimensions to be measured for a clothing system. These body dimensions are divided into three groups: vertical length, width, and girth, as shown in Table 4.1. These dimensions are also divided into the upper and lower body. The 29 dimensions suitable for the upper body or whole body are marked with superscript "a", while the other 20 dimensions (not marked) are categorized as lower body dimensions.

First the measurers have to be briefed about the objectives of the anthropometric survey. They can be introduced to the topic using a PowerPoint presentation, and the objectives were clearly explained laying emphasis on the consistency and precision of measurement process. Each of the trainees should be provided with a copy of the anthropometric manual giving pictures of all the body dimensions. This is followed by a detail explanation of each body dimension followed by a demonstration on a real body.

The measurers should ideally work in pairs and perform hands-on practice on their partners for some days till they are comfortable and familiar with each body dimension. Each measurer uses a form, which lists all the body dimensions to record the measurements. The measurement practice should be continued until the measurers gained confidence and started getting consistent readings.

4.2.1.3 Anthropometric measurement protocols

Anthropometric protocols demonstrate how a manual anthropometric survey can be conducted. The measurement process starts with the subject changing into a tight-fitting garment for better and more accurate body measurements. In every anthropometric survey activity, a team of workers will attempt to finish the targeted number of measurements per day to achieve their daily goal. Manual measurement takes an average of 40 min per subject, and the goal is to measure at least seven people daily. Using the 3-D body scanner, it is much faster: the time from changing clothes to completion of measurement is about 5–10 min per person.

A consistent set of procedures should be employed for the manual measurement process, such as

- fill out demographic data (name, age, gender, and ethnic group),
- measure height,
- measure weight,
- measure upper body dimensions,
- measure lower body dimensions.

One member of the team can measure, while the other records the measurements. All measurements should be taken from one side of the subject's body consistently. After

Table 4.1 List of body dimensions according to ISO8559/1989

Length (vertical)	**Width (vertical)**	**Girth (horizontal)**
Height		Weight
1. [a]Under arm length	1. [a]Shoulder length 2. [a]Shoulder width	1. [a]Head girth
2. [a]Scye depth	3. [a]Back width	2. [a]Neck girth
3. [a]Neck shoulder point to breast point	4. [a]Upper arm length	3. [a]Neck-base girth
4. [a]Cervical to breast point	5. [a]Arm length	4. [a]Chest girth
5. [a]Neck shoulder to waist	6. [a]Seventh cervical to wrist length	5. [a]Bust girth
6. [a]Cervical to waist(front)	7. [a]Hand length	6. [a]Upper arm girth
7. [a]Cervical to waist(back)	8. Foot length	7. [a]Armscye girth
8. [a]Cervical height(sitting)		8. [a]Elbow girth
9. [a]Trunk length		9. [a]Wrist girth
10. [a]Body rise		10. [a]Hand girth
11. [a]Cervical to knee hollow		11. Waist girth
12. [a]Cervical height		12. Hip girth
13. Waist height		13. Thigh girth
14. Outside leg length		14. Mid-thigh girth
15. Waist to hips		15. Knee girth
16. Hip height		16. Lower knee girth
17. Crotch		17. Calf girth
18. Trunk circumference		18. Minimum leg girth
19. Thigh length		19. Ankle girth
20. Inside leg length/crotch		
Height		
21. Knee height		
22. Ankle height		

Lower body dimensions.
[a]Upper body dimensions.

completing the measurements of the day, the forms should be counted and the overall quality of anthropometric measurements checked. Forms with missing data are considered not valid and discarded. The number of subjects measured each day is recorded to ensure that the target number of samples has been achieved and that results are accurate.

4.2.2 Step 2: Anthropometric planning

Anthropometric planning comprises the preliminary study, sample size calculation, and fieldwork coordination. The first purpose of the preliminary study is to test the whole process of measuring, to understand the nature of the survey, and to solve any potential problems before undertaking the real anthropometric survey. The second purpose is to take the measurements needed to calculate the sample size for the anthropometric survey.

4.2.2.1 Preliminary survey

The preliminary survey can be conducted on a small scale and is usually called the pilot study. The sample size can range from 30 to 100 people. The main objective is to collect sufficient body measurements to calculate the sample size needed for the real anthropometric survey.

One common technique that can be used to calculate the sample size for a study is the proportionate stratified random sampling technique (Hair et al., 1998; Bartlett et al., 2001). Proportionate stratified sampling refers to taking the same proportion (sample fraction) from each stratum (Tabachnick and Fidell, 2007). For example, say there are three groups of students: group A with 100 people, group B with 50 people, and group C with 30 people. These groups are referred to as strata. The sample units are randomly selected from each stratum based on proportion. For example, a proportion of 10% from each group (strata) would mean that 10 people were taken from group A, 5 people from group B, and 3 people from group C. The stratum group for this study was based on two groups, age (7–17 years old) and gender (female and male).

A study can have, for example, four demographic variables: age, gender, ethnic group, and geographical area (rural and urban). If the study is focused on two factors such as age and gender, then the proportionate sample size will reflect the distribution of age and gender groups in the real population. The other two parameters, ethnic group and geographical area, can be selected according to simple random technique with the targeted number of subjects calculated from the proportionate sample size (Bartlett et al., 2001).

Data obtained from the preliminary study can be analyzed to calculate the total sample size using the stratified random sampling formula (Eq. 1.1). Then the number of subjects to be sampled from six gender and age groups can be calculated using proportionate sampling based on the actual number of subjects present in the geographical area of interest. The steps are given in detail later.

4.2.2.2 Sample size determination

The sample size for a survey can be calculated using the stratified random sampling formula as shown in Eq. (1.1) (Scheaffer et al., 2005):

$$n = \frac{\sum_{i=1}^{l} N_i^2 \sigma_i^2 / a_i}{N^2 D + \sum_{i=1}^{l} N_i^2 \sigma_i^2} \tag{1.1}$$

where

N = total number of target population.
X_i = input for sample i.
Y_i = output for sample i
x = mean value of input data
y = mean value of output data

The body dimensions used to calculate the sample size are the common key dimensions for a sizing system: height, chest girth, bust girth, waist girth, and hip girth. After figuring the total sample size, the sample size for each of the strata can be calculated using Eq. (1.2), and then the total number of subjects for each age range and gender can be calculated based on the proportionate method formula (Eq. 1.3).

First step:

$$\bar{y}_{st} = \frac{1}{N}[N_1\bar{y}_1 + N_2\bar{y}_2 + \ldots + N_l\bar{y}_l] \tag{1.2}$$

where

N = total population age 7–17
N_1 = total population age 7–12
N_2 = total population age 13–17
$\bar{y}$ = mean of variables for each age group

Second step:

$$\mathrm{D} = \left(\frac{0.01 \times \bar{y}_{st}}{2.326}\right)^2 \tag{1.3}$$

Third step:

Calculating the sample size using stratified random sampling (Eq. 1.1)

To calculate the sample size, the age range for the sample population is calculated, and then the total population in the geographical area is calculated. For example, the total population in one state is 823,071[N]. The number of subjects in each age group is then tabulated. Each age group forms a stratum, and the sample for each stratum is calculated using the proportionate method according to the ratio of the real population. Each stratum age [h] is given by

$$n_{h=(N_h/N)*n} \tag{1.4}$$

where n_h *is* the sample size for stratum h, N_h is the population size for stratum h, N is total population size, and n is the sample size.

For example, the male-to-female ratio in the real population in one state is 51% male and 49% female. For each age range the sample is divided into the corresponding ratio (n) of male and female:

$$n_m = N_h * n \tag{1.5}$$

$$n_f = N_h * n \quad (1.6)$$

where n_m is the sample size for the male stratum, n_f is the sample size for the female stratum, $N_h$is the population size for stratum h *(age)*, and n is the total sample size.

4.2.3 Step 3: Anthropometric survey—Manual method

A preliminary study is conducted before the main anthropometric survey to check the feasibility of the research approach and to improve the design of the research. ISO standard 8559:1989 (garment construction and anthropometric surveys—body dimension) can be used as a guideline for taking body measurements. In the traditional manual technique, measurement tools to be used include calibrated nonstretchable plastic measuring tapes, height scale with movable head piece, long ruler, elastic 5-meter tapes, and digital weight scale. Since measuring a single subject can take from 20 to 40 min, provision for refreshments for measurers and the subjects should be made to incentivize them. The survey data collected in the form of categorical (demographic data) and continuous data were screened and stored in a standard format.

4.2.3.1 Data entry

All the collected data are keyed into a software such as SPSS or MS Excel. The usual format is to key in the subject's name and data into a row, which is known as a case. The body variables are keyed into the columns. The demographic information (categorical data), gender, ethnic group, age, and geographical area (urban or rural), comes first followed by columns containing numeric body measurements (continuous data).

4.2.3.2 Data screening

Data screening consists of examination for data entry errors, missing data, or outliers. The entire data set is filtered to ensure that there are no errors or missing data. Errors can creep in due to mistakes in keying in the data; these can be rectified by cross-checking with the raw data. The distribution of data can be tested using graphical and numerical methods. The graphical method makes use of histograms, while the numerical assessment is based on values of mean, median, skewness, and kurtosis. Histograms provide a useful graphical representation of the data. Data are normally distributed if the histogram shows a Gaussian distribution. This involves evaluating the bell shape of the data distribution. When tabulating common key dimensions like height, chest girth, bust girth, waist girth, and hip girth, the mean and median values should be the same, while the skewness and kurtosis should show values of 0 and 3, respectively; this indicates that the data are normal (Tabachnick and Fidell, 2007). Skewness refers to the asymmetry of the distribution. If the skew has a negative value, this means the data are skewed to the left; if positive the skew is to the right. Kurtosis refers to the peakness or the flatness of the graph (Hutcheson and Sofroniou, 1999).

4.2.4 Step 4: Anthropometric analysis

The final step of Stage 1 is to analyze the data. The statistical method generally applied at this stage is the descriptive analysis also known as univariate analysis based on simple statistics. Categorical and continuous data can be analyzed as follows:

4.2.4.1 Categorical data

The categorical data are analyzed to understand the demographic profile of the sample population. The first classification to be made often is to divide the population into gender-based subsets, namely, male and female. Frequency distribution curves are plotted by quantity and percentage, and results can be illustrated using tables and bar graphs.

4.2.4.2 Continuous data

Continuous data analysis based on descriptive statistics includes calculation of frequency distributions, range, mean, median, mode, standard deviation, coefficient of variation, and Pearson correlation coefficients to determine the interrelationships between the various body dimensions.

The objective of anthropometric analysis is to profile the demographic data and the continuous data in such a way that the overall patterns of body dimensions are described and one can distinguish between genders and different age groups for selection of key dimensions.

The next section deals with Stage 2—the sizing data analysis.

In this stage the objective is to divide the sample population into smaller groups composed of individuals who have similar key body dimensions. The center panel of Fig. 4.1 shows the phases of Stage 2, which consists of four steps (Steps 5–8). The analysis shown in Stage 2 is only one possible method of determining key dimensions and clustering the sample population. Besides the three methods shown here (PCA, cluster analysis, and decision tree analysis), other methods like bivariate analysis, neural networks, and artificial intelligence can also be used (Kim et al., 2018; Doustaneh et al., 2010).

Step 5 is multivariate analysis, the purpose of which is to test the sampling adequacy of the collected data. In Step 6, principal component analysis (PCA) is employed to reduce all the variables into significant components. In Step 7, cluster analysis is used to segment the sample subjects into homogenous groups with similar body shapes and sizes. In Step 8 the decision tree technique can be applied to classify sample subjects into groups based on profiles and to validate the cluster groups.

4.2.5 Step 5: Multivariate analysis

Prior to applying a PCA, a sampling adequacy test needs to be performed on the data to confirm the appropriateness of conducting PCA to ensure that the data can be factored well (Tabachnick and Fidell, 2007). In addition, Bartlett's test of sphericity can also be used to add a significant value to support the factorability of the correlation matrix obtained from the items.

4.2.6 Step 6: Principal component analysis (PCA)

The objective of using PCA is to reduce the number of variables and to cluster these variables into a more parsimonious and manageable number of groups. Parsimonious means to summarize most of the original information (variance) in a minimum number of components for prediction purposes (Pallant, 2001).

4.2.7 Step 7: Cluster analysis

Cluster analysis is an exploratory data analysis tool used to segment a population into homogenous subgroups. This means that each person in a group shares similar physical traits with others in the group and that people in one group differ from those in other groups.

4.2.8 Step 8: Classification analysis (decision tree)

Decision tree analysis is a data mining technique that is effective for classification (Lin et al., 2008). The classification and regression tree (CRT) technique can be used to verify and classify the sample population according to cluster groups; CRT is used where the data are continuous. The profile of the tree is useful when interpretation of the data set is required. By doing the classification analysis, important variables can be obtained, and a simple profile can easily be extracted from the tree diagram (Viktor et al., 2006).

The last stage described in Fig. 4.1 is Stage 3—the sizing system development.

4.2.9 Step 9: Size system development

The purpose of developing the sizing system is to create sizes for each cluster group that are appropriate to the individual group's range. Two important decisions must be made. The first is to estimate the size roll, which will accommodate most of the target population, and the second is to determine which samples go into the cluster groups obtained from the cluster analysis technique (Bairi et al., 2017). The goal is to accommodate as many people from the target population as possible using one intersize interval.

For the development of the sizing system, the following elements have to be calculated: size range, size interval, size scale, and size roll.

After the selection of the interval range, the classification profile obtained from the decision tree analysis is used as a guide to select samples matching the right body size and shapes. Using this profile the samples are classified according to the body sizes and shapes. The last step is to validate the efficiency and accuracy of the sizing system thus developed.

4.3 Body dimension profiling

Body dimension profiling is the first process of anthropometric data analysis. From the data, simple statistical analysis was conducted to analyze the data, and the data illustrated the mean of height, weight, and important girth measurements such as bust, waist, and hip. This table is important to give a general outlook of the data of certain population as it represents the real sizes and shapes of the population of each country. For the purpose of analysis and details of the anthropometric procedure to develop sizing system, a sample population of female aged 13–17 years old is used for demonstration.

4.3.1 Size and shapes of female (13–17 years old)

Table 4.2 summarizes the data of the critical body dimensions for upper and lower body garments. These tables represent statistics for the measured sample population of female (13–17 years old). From Table 4.2 the tallest teenage girls (13–17 years old) from the sample are 170.6 cm, and the shortest of height is approximately at 131.1 cm. The heaviest girl in is about 96.6 kg, and the thinnest weighs only at 20 kg. The SD of the height and other variables are lower as compared with the girls (7–12 years old), which means that the variation of height and other body dimensions in this age group is lower. Moreover, hip girth and bust girth showed higher variations as compared with height. The 5th to 95th percentiles of the measurement for the sample size are also shown in the table.

4.3.2 Growth distribution of female

In Fig. 4.2 the description of growth was illustrated. Growth trend for teenage girls showed that the growth in vertical body dimensions started from age 13 and becomes steady at the age of 15. From age 15 onwards the teenage girls have stopped growing. Nonetheless, for horizontal dimensions, there is slight growth from age 13 to 15 years old but becomes steady from age 15 and above.

Table 4.2 Extreme values, SD, and percentile values of anthropometric measurements for 13–17-year-old Malaysian female children

Body dimensions		Height (cm)	Weight (kg)	Bust girth (cm)	Hip girth (cm)	Waist girth (cm)
Minimum		131.1	20	58.5	65	49
Maximum		170.6	96.2	121.5	121.5	117
Percentiles	5th	142.61	33.51	69	76.10	55.74
	50th	154.25	47.95	79.5	88	64
	95th	165.01	76.54	98.5	108.44	86
Std. Deviation		6.80	13.07	9.60	9.69	9.80

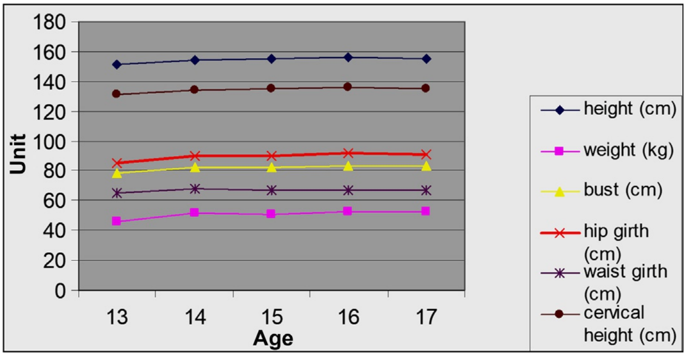

Fig. 4.2 Growth trend of female (13–17 years old).

4.4 Key dimensions and control dimensions' identification using multivariate data techniques

In this chapter, principal component analysis (PCA) technique is used to select key dimensions. The main objective of using PCA technique is to reduce all the variables into small sets of components, which then only significant components are analyzed and named. From the components, key body dimensions will be selected based on the highest relationship with the components. Before running the anthropometric data using the PCA technique, there is a need to do multivariate data examination shown later.

PCA was used to reduce the variables into new significant variables called principal components (PC). In 1985 Salusso-Deonier et al. (1985) developed a sizing system known as principal component sizing system (PCSS) using the PCA technique. However, their application of PCA differed from that of O'Brien and Shelton (1941). In previous research, PCA was applied to reduce the data, and then the components were analyzed for the selection of only one key dimension from each component. But in Salusso-Deonier et al.'s (1985) research, PCA components were applied to the classification of the population. Here the relationship of variables is looked upon in terms of the loading of factors of those variables on each component (correlation between a variable and a component).

If the loading is high, it means that the variable is highly associated with the component. This sizing analysis showed that two components were most important, namely, PC1 as laterality, associated mainly with body girth, arcs, and widths, and PC 2 as linearity, associated with heights and lengths. PCSS also known as principal component sizing system is based on partitioning the PC1 and PC2 geometrically (Salusso-Deonier et al., 1985). PC1 and PC2 behave like the control dimensions in conventional sizing system construction. The height and weight distribution is used to identify the PCSS sizes.

Salusso-Deonier et al. (1985) concluded that PCSS represents better relationship for the sample studied, which classified correctly 95% of subjects within <30 size categories. All the methods described earlier are based on a linear structure that has an advantage of easy grading and size labeling (O'Brien and Shelton, 1941). Multivariate analysis—specifically the PCA technique—is still widely used by many researchers to detect the relationships between variables and in turn find key dimensions by which to classify the population (Chung et al., 2007; Hsu et al., 2006; Gupta and Gangadhar, 2004). PCA was also used to identify the key dimensions for the population (Chung and Wang, 2006). They classified each population according to key dimensions using simple univariate analysis. Height dimension resulted in three height ranges, and bust girth gave six bust ranges. For this chapter, only one group of anthropometric data is used to show how key dimensions were selected using PCA method. The data used here are the male and female 13–17 years old

4.4.1 Multivariate data examination

There are two main measurements conducted in this section prior to PCA, namely, the validity and percentile analysis. All the 50 body dimensions taken from the samples (female age 13–17) are tested for validity and reliability. These measurements are examined prior to PCA. Bartlett's test of sphericity and Kaiser-Meyer-Olkin (KMO) test are performed to ensure the adequacy of sampling for PCA analysis. In addition, Cronbach's alpha is used to determine the consistency and unidimensionality of the data.

The KMO result shows all values are >0.9, and Bartlett's test of sphericity is highly significant since the observed significance level is 0.0000 ($P<.005$). For factor analysis, KMO is supposed to be $>.5$ and Bartlett test $<.05$. As shown in Table 4.3, KMO values are 0.973 for male (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997) and 0.965 for female (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997). According to Raykov (Raykov and Marcoulides, 2008), KMO >0.9 falls into the range of superb or marvelous. Thus it can be concluded that the relationship between the variables is very strong and factor analysis can be carried out. In addition, the results also confirm that the data show sampling adequacy, which means it is likely to factor well for PCA analysis.

4.4.2 Principal component analysis (PCA)

The body dimensions of each sample group are extracted using PCA and varimax rotation. This is a common technique applied on anthropometric data to describe variations in human body in a parsimonious manner by many previous sizing studies

Table 4.3 Sampling adequacy and reliability tests for all sample populations

Tests	Female
KMO of sampling adequacy	0.97
Bartlett's test of sphericity approx. Chi-squared df sig. ($P<.005$)	31,437.00 1378 0.000

(Field, 2005; Hsu et al., 2007). Parsimonious means the variation of body dimensions are described using the fewest principal components (PCs) possible (Salusso-Deonier et al., 1985).

4.4.3 The results of components analysis

The results of the extracted components for each sample group are recorded. In general, 50 components are extracted from each sample group to explain 100% of the variance in the data. The summarization of variables proves to be very good as the number of principal components is the same with the number of original variables. This indicates that the original information is not neglected as a variation factor (Salusso-Deonier et al., 1985).

According to Hair et al. (1998) the first few components should extract at least 50% of the variance to prove the usefulness of PCA technique. The study shows that female samples between 13 and 17, with less percentage value, are observed, at 54%. Thus this result indicates variance of >50% in the first component. This indicates that PCA technique is an effective method for this study to obtain a parsimonious solution in describing the variations of body shapes in this sample group.

Furthermore, the extracted factor should at least be 90% of the explained variance to show efficiency (Hair et al, 1998; Salusso-Deonier and DeLong, 1982). From this finding, 90% variance was explained by fourteen principal components for female samples age between 13 and 17. In contrast, study conducted by Hsu et al. (2006) shows that only 60% of total variance for 15 components are found in the study, which is considered low. However, in 2006, the same researcher improved her studies by obtaining a 60% total variance accounted for two components (Gupta and Gangadhar, 2004).

To reduce the numbers of components for a more parsimonious solution, the criterion of retaining components is applied, which are latent root, scree plot, and percentage of accumulated variance. Table 4.4 showed all the components that have been extracted with an eigenvalue greater than one (with bold values), which implies that these components are suitable to be retained.

For the female population aged between 13 and 17 years old, the result is shown in Table 4.4. In this table, six components (Components 1, 2, 3, 4, 5, and 6) show an eigenvalue >1. The first component shows eigenvalue of 27.0% followed by 7.5%, 2.0%, 1.9%,1.1%, and 1.0% in which the total rotation sums of squared loadings account for 81.1%.

For criteria 2, which is the scree plot, the results are shown in Fig. 4.3. An elbow where the curve merges into a straight line can be seen at Components 2 and 3 (which are marked by red circles). The component at that merge location is the point to stop. From Fig. 4.3, the elbow is obvious from PC2 and PC3, and thus PC1 to PC3 are retained.

The third criteria for retaining values depend on the percentage of accumulated variance. Based on the examination of eigenvalue and scree plot, three components are retained for sample's group with rotation sums of value of 76.7% for female (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997).

Table 4.4 Principal component analysis extraction for female (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997)

Component	Initial eigenvalues			Rotation sums of squared loadings	
	Total	% of variance	Cumulative %	% of variance	Cumulative %
1	27.0	54.0	54.0	39.3	39.3
2	7.5	15.0	69.0	20.8	60.0
3	2.0	4.1	73.1	7.5	67.6
4	1.9	3.7	76.9	6.6	74.1
5	1.1	2.3	79.1	3.6	77.8
6	1.0	2.0	81.1	3.4	81.1

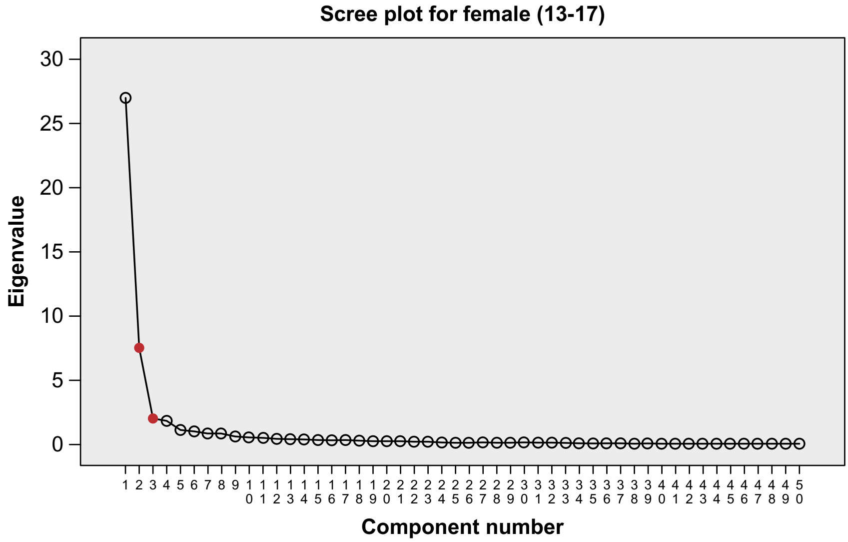

Fig. 4.3 Scree plot of female (13–17 years old).

It can be observed that the cumulative percentage is reduced when fewer components are retained. However, at this point, the numbers of components are not finalized yet until all the factor loadings of each component are examined, which clearly distinguish those variables that correlate highly with each component.

In general, previous studies have shown that body dimensions are accumulated into its own component, which can be interpreted as one type of measurements such as the length, girth, or width. These tables show the results of extracted variable components that show the factor loadings for all the 50 anthropometric dimensions.

After analysis of factor loading, the current findings yield two significant components, which consist of variables of the highest factor loading. Thus two components are retained, namely, the principal component 1 (PC1) and principal component 2 (PC2) for each sample groups. For sample group male and female (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997), 44 variables and 42 variables, respectively, are grouped into two components. PCA technique has successfully achieved the goal of getting a parsimonious group of variables, which extracted almost all of the variables in two components.

The two retained components gave cumulative percentage as follows: female (LaBat, 1987; Otieno and Fairhurst, 2000; Ashdown, 2014; Manuel et al., 2010; Kaiser, 1997) with 60.0%. The present findings seem to be consistent with other research, which commonly retained two final components. However, the cumulative percentage for these two components was found differently in different studies ranging from 65% to 81% (Xia and Istook, 2017; Xinzhou et al., 2018).

Consequently, it was found that the first component (PC1) consists of all girth dimensions including bust girth, chest girth, upper arm girth, hip girth, and waist girth and few width dimensions like back width and shoulder width. The second component (PC2) consists of all length dimensions such as height, cervical height, upper arm length, and arm length. This finding is found similar to many previous sizing studies where two components represent the girth and length factors (Hsu, 2008, 2009; Beazley, 1998b).

4.4.4 The results of factor loadings analysis

In this section, all the body dimensions with high factor loading ($\geq$0.75) are listed in Table 4.5 for one sample female group. The aim of this section is to select the key dimensions. It is apparent from this table that most of the variables are highly correlated to the individual components, which can be seen from the high factor loadings. Overall, almost all variables are reduced into two factors.

As can be seen from Table 4.5, upper arm girth and waist girth are distinguished as the strongest variables correlated to girth factor for male samples (age 13–17). In contrast, bust girth has the highest factor loading for female samples age 13–17. Under arm length and inside leg length are noted to have the highest factor loading correlated to length in males aged 13–17 as compared with arm length and hip height in females aged 13–17. Hence PCA analysis for each sample group is shown later.

4.4.4.1 Female samples (age 13–17)

For female samples, as can be seen from Table 4.5, 28 variables were found correlated to the girth and length component as compared with 26 variables in female samples. On the other hand, 16 and 15 variables are loaded on length girths for males and females, respectively.

Table 4.5 Principal component analysis with varimax rotation for females (13–17 years old)

Body types	Variables	PC 1 (girth)	PC 2 (length)
	Height		0.77
	Weight	0.93	
Upper body (girth)			
	1. Neck girth	0.81	
	2. Back width	0.81	
	3. Bust girth	0.93	
	4. Upper arm girth	0.93	
	5. Armscye girth	0.90	
	6. Elbow girth	0.85	
	7. Wrist girth	0.83	
Lower body (girth)			
	8. Waist girth	0.94	
	9. Hip girth	0.93	
	10. Thigh girth	0.92	
	11. Mid-thigh girth	0.91	
	12. Lower knee girth	0.91	
	13. Calf girth	0.88	
	14. Knee girth	0.84	
	15. Crotch	0.78	
Upper body (length)			
	16. Arm length		0.84
	17. Under arm length		0.82
	18. Cervical to breast point		0.8
	19. Neck shoulder to breast point		0.76
	20. Trunk circumference		0.77
Lower body (length)			
	21. Hip height		0.91
	22. Waist height		0.87
	23. Knee height		0.84
	24. Inside leg length		0.84
	25. Out leg length		0.83
	26. Thigh length		0.82
	Total proportion (%)	39.3	60.0

4.4.5 Identifying key dimensions

From the table earlier, PCA method confirms that those variables shown in Table 4.5 prove to be the significant dimensions often taken in any anthropometric survey. The key dimensions commonly acknowledged in other literatures are also found significantly in this study, namely, waist girth, bust girth, chest girth, and height. For example, bust girth has the highest factor loading for female sample age 13–17. However, in other studies, upper arm girth is noted as the strongest variable correlated to girth factor for male samples (age 13–17) that has not previously been described in any sizing studies. Moreover, under arm length and inside leg length are noted to have highest factor loading correlated to length in males aged 13–17 and as compared with arm length and hip height in females aged 13–17. Under arm length is also another variable found to have high relationship with length, which is not common to other sizing studies.

Overall the girth variables chosen as the key dimensions are chest and bust girths for the upper body. In contrast, hip girth is chosen for the lower body key dimensions. The selection of these body dimensions as the key dimensions confirms the findings from other research conducted in which the same common dimensions' girth is found to be significant as the key dimensions for the upper body while for the lower body the hip girth is chosen instead of waist girth. The hip was a better choice as compared with waist girth for some of these reasons; it was mentioned as a variable that has a variety of relationship with the upper and lower torso (Gordon, 1986). It was found out that the hip was a better selection for lower garment simply because this dimension cannot be easily adjusted after it has been made (Gordon, 1986; Otieno and Fairhurst, 2000). From previous studies it has been noted that the hip was a more stable measurement and found to have high correlation with girth component and therefore determined to be the key dimensions for the lower body (Ashdown, 1998).

In general, for example, Table 4.5, height was selected as the key dimensions for both the upper and lower body. Height is selected based on the high factor loading. The current study found that height represents almost 77%, 0.77 for length component for female samples between age 13 and 17. This is consistent with the result from correlation analysis in the other studies that shows height is very strongly correlated with other length variables. From the opinion of other researchers, height is a must to be incorporated in a sizing system (James and Stone, 1984). In addition, according to James and Stone, height was found an advantage especially for teenagers as it could be easily measured in retail shops where a height chart could easily be obtained. As for adults the body dimensions that can be considered the key dimensions are the chest, bust, waist, and legs. Height is also regarded as a better estimator of size rather than age for children as compared to adults (Simmons and Istook, 2003). Hence height is the most suitable dimension to cluster the samples into different groups.

All the key dimensions mentioned earlier are finally selected for the classification of the sample population. These key dimensions are selected based on the high relationship with the main body measurements, girth, and length. Furthermore, it has been mentioned in previous studies that key dimensions must be convenient to take (Winks, 1997). This indicates that the selected key dimensions should be the ones that can be measured easily and practical especially when it comes to children (Xinzhou et al., 2018). In addition, it is also being stated that if these measurements will be used as the size coding, the customers should be very familiar with the key dimensions, for example, chest girth or bust girth for the upper body as compared with upper arm girth.

The next step after determining the key dimensions will be to classify the sample population into the same sizes using the key dimensions. Key dimensions are selected because those body dimensions are significant, very convenient, and familiar for consumers to measure.

Table 4.6 Cluster groups for the upper body: female samples (age 13–17)

	Cluster 2	**Cluster 3**	**Cluster 1**
n	**120**	**101**	**80**
Mean height (cm)	150.1	159.0	155.2
Range (cm)	142.7–156.0	153.3–164.5	145.0–164.0
Mean bust girth (cm)	76.6	79.6	91.8
Range (cm)	69.5–86.7	70.6–86.7	85.7–98.5
Body type	*Small*	*Medium*	*Large*

4.5 Body size classification using cluster analysis

The objective of doing cluster analysis is to group the sample population into homogenous groups. Two variables were calculated using the PCA method and then were used as the key dimensions to group the sample subjects. Six separate cluster analyses were run generating participant cluster membership from two to seven grouping categories. Each K-means cluster result was evaluated to determine the ideal number of grouping categories. It is found that three and four are the most ideal because the cluster groups were distinct from each other. However, for this research, three groups were chosen and considered practical for size clustering of the children's wear. K-means cluster technique successfully extracts three distinct cluster groups (Table 4.6). Fig. 4.4 illustrated the distribution of height (y-axis) versus bust girth (x-axis) for all three clusters. The profile of each cluster is defined as this: Cluster 1 with 134 samples, tall stature with medium to big bust; Cluster 2 with 194 samples, average height with small to medium bust; and Cluster 3 with 197 samples, short with small bust.

4.5.1 Female sample size (13–17 years old): Clustering for upper body

Table 4.6 shows the distribution of females (age 13–17) according to height and bust girth, which is meant for the upper body. This table shows that most of the sample population falls under Cluster 2, small size. The second highest distribution of sample size is in Cluster 3, medium size. The last cluster group, Cluster 1, is the large size.

The division of female samples (age 13–17) is depicted in Fig. 4.4. Three clusters are evident. Cluster 1, large size, contains samples that are short to tall with large bust measurements. For Cluster 2, the samples belong to the small-size body type with short to average height and small to average bust. In Cluster 3, medium size, the samples are average to tall with small to average size bust.

Generally, from cluster analysis, three distinct groups were obtained. As can be seen from Table 4.7, the small-size cluster (Cluster 2) has most of the sample size, and most of this cluster is age 13. Ages are evenly distributed in the medium body type, whereas females age 16 are mostly found in the large-size cluster group.

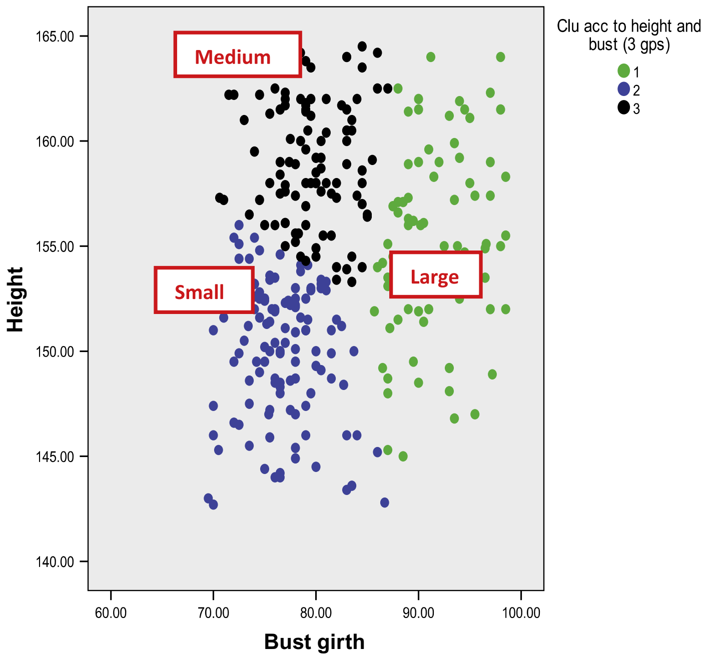

Fig. 4.4 Scatter plot of age groups according to height and bust for females age 13–17.

Table 4.7 Age versus cluster groups for the upper body (females age 13–17)

Age	Cluster according to height and bust (three groups)			Total
	Small	*Medium*	*Large*	
13	36	14	15	65
14	22	24	18	64
15	25	19	13	57
16	17	20	23	60
17	20	24	11	55
Total	120	101	80	301

The next step is to verify that these cluster groups are distinct from each other by using the decision tree technique.

4.6 Decision tree analysis

In this study the decision tree is obtained using the regression tree since all the data are continuous. The objective of doing decision tree is to verify whether the cluster groups are classified properly and the profile of the clusters can be easily and accurately obtained from the tree diagram. The decision tree (refer to Fig. 4.5) classified the cluster groups with correctness of 90% for age 13–17. Hence this confirms that the sample groups are classified correctly into cluster groups using k-means technique.

For this section the same dependent and independent variables are used to classify the cluster groups. The dependent variables are the cluster groups for each individual sample group. The independent variables are the primary control variables (key dimensions) of each sample group specific to either the upper body or lower body. The observations are seen in this female sample group for the upper body where the rule of this tree model is as follows: the maximum depth of the tree extends two levels beneath the root node at the minimum sample; the parent node is 100, and the child node is 50; all is the same for sample groups. The same observation is also seen in the predictive variables where the girth variables are identified as the predictive variables for female age 13–17.

4.6.1 Decision tree for female (13–17 years old) upper body

The results of the tree (Fig. 4.5) show that bust girth is the only predictor for the large size. The female samples in this group were split into two bust measurements. Those with bust measurements >86.3 cm are most likely to be clustered under the large size. Those with bust measurement <86.3 cm and >161.4 cm tall are likely to be grouped as the medium size. Those <154 cm tall with bust <86.2 cm are likely to be grouped under small size. The profile of the clusters is shown in Table 4.8.

This tree verified that the cluster groups were correctly segmented using the cluster analysis method. The next step is to develop sizing system based on these cluster groups.

4.7 Body size determination for sizing system

In this study the sizing system was designed according to the design limit that accommodated 90% of the population. Using design limit means taking into consideration the values that might have an impact on the total reliability and practicality of clothing production for manufacturers (Abtew et al., 2017). Designing according to limit also prevents sizes to be produced unnecessarily and impractical use for only few people. The sizing system is built according to the percentile values of 5th and 95th.

4.7.1 Female sizing system 13–17 years old for upper body garments

Fig. 4.6 showed the distribution of sizes according to the body types for female aged between 13 and 17 years old; the control variables for upper body are height and bust girth. The size interval for height is 8 cm and for bust and girth is 6 cm. The range for height in this population is 142–166 cm, which is the same for the upper and lower body. The range is divided into five subgroups using an interval of 6 cm, which is 142, 148, 154, 160, and 166 cm. For the bust the range is from 70 to 98 cm; this range

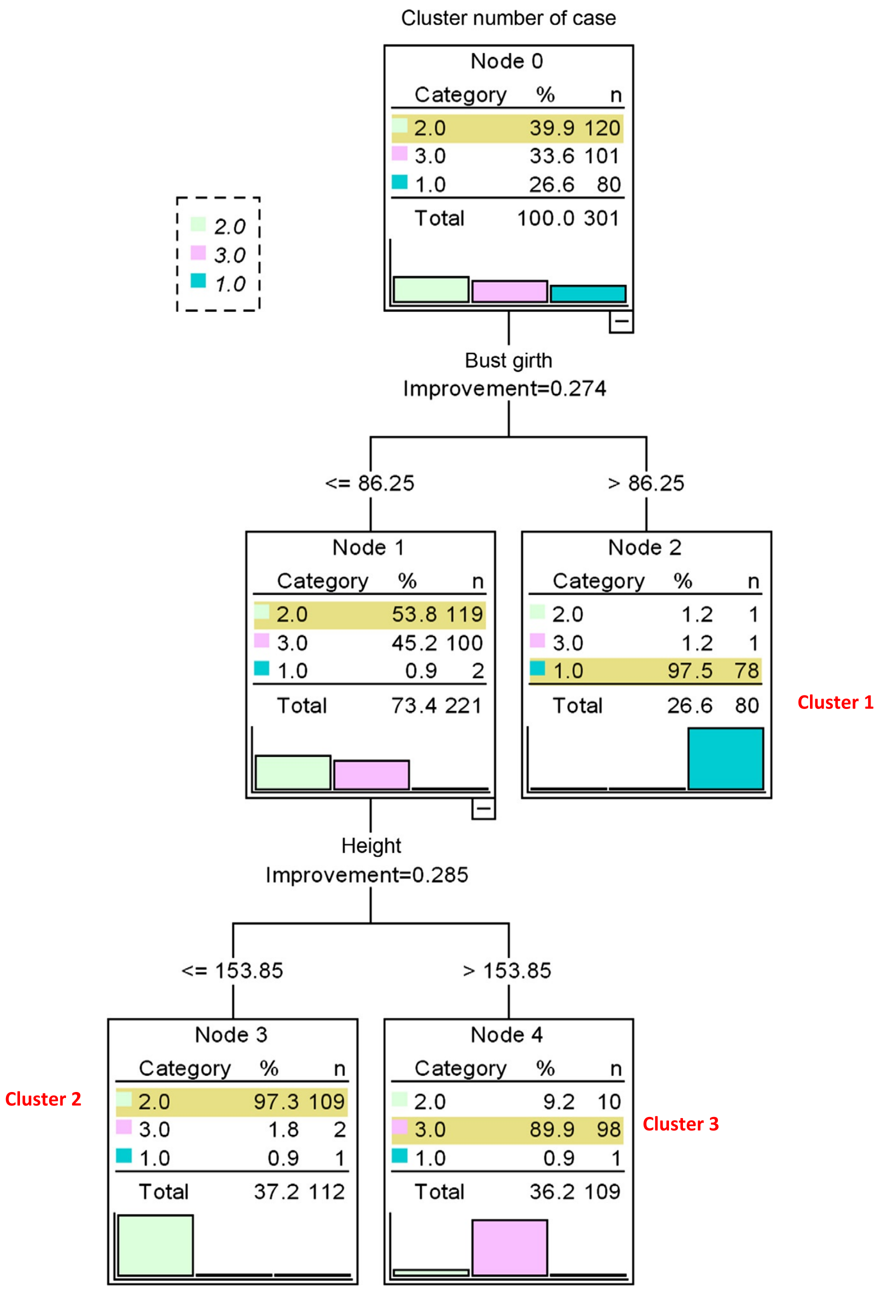

Fig. 4.5 Decision tree for female (13–17 years old) upper body.

Table 4.8 Profile of upper body types for female 13–17

Node	Body type	Classified rule	n =
1 and 3	Small	Bust girth $\leq$86.3 cm and height $\leq$ 153.9 cm	109
1 and 4	Medium	Bust girth $\leq$86.3 cm and height $\geq$ 153.9 cm	98
2	Large	Bust girth $\geq$86.3 cm	78

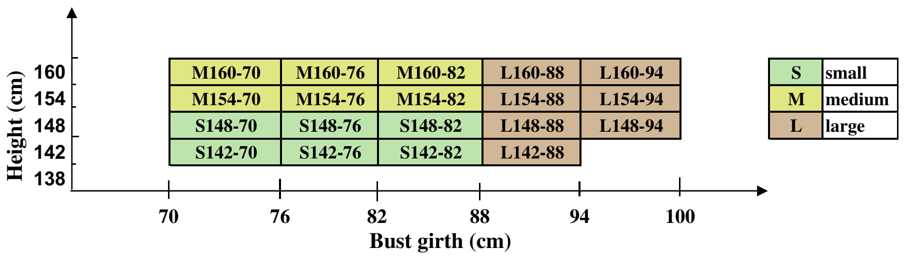

Fig. 4.6 Distribution graph of height versus bust girth for upper body, females (13–17 years old).

is divided using an interval of 6 cm: 70, 76, 82, 88, 94, and 100 cm. With the size interval, the height gives five subgroups, whereas the hip gives six subgroups totaling to 30 sizes designed to accommodate the female samples (age 13–17).

Fig. 4.6 indicates the outcome of the body type selection based on the classified rules. In total, there are 19 sizes suitable for the sample population. Six sizes are developed for small-size samples, six sizes for medium-size samples, and another seven sizes for large-size samples.

There are 30 sizes designed to accommodate this entire sample size, but the outcome indicates that only 19 sizes can cover the whole samples in which it means that the samples are found to be in one of these 19 sizes. This result is proof that the size interval is accurate and so does the rule that dictates which samples get into what sizes based on the IF/THEN statement. However, the coverage of the samples is not known yet as it is calculated in the next section. Lesser size rolls can indicate the size system is good if only the coverage of the samples is high above 80% as compared to lesser size rolls and less percentage of coverage.

4.7.2 Female size validation 13–17 years old for upper body

Table 4.9 proposes 19 sizes to accommodate the entire sample population for this group: six each for small and medium body types and seven for the large body type. Almost 40% of the samples were accommodated in the small body type, 37.5% in the medium, and 21.9% in the large. The result shows 99.3% coverage for this sample group. In addition, the aggregate loss for each body type is excellent as they show much lower values than the ideal, and the average aggregate loss of fit is excellent at 2.5 cm.

Table 4.9 Size validation for upper body, female (age 13–17)

Body type	Size group	n (%)	Mean aggregate loss (cm)
Small	6	120 (39.9)	2.6
Medium	6	113 (37.5)	2.7
Large	7	66 (21.9)	2.6
Total	19	299 (99.3)	2.6

Table 4.10 Size distribution for upper body, female (age 13–17)

		Key dimensions (cm)		Accommodation rate		
Size roll	**Body type**	**Bust girth**	**Height**	**n**	**%**	**Aggregate loss (cm)**
1	Small	70–75.9	142–147.9	12	4.0	2.7
2			148–153.9	32	10.6	2.7
3		76–81.9	142–147.9	10	3.3	2.6
4			148–153.9	45	15.0	2.6
5		82–87.9	142–147.9	7	2.3	2.5
6			148–153.9	14	4.7	2.6
7	Medium	70–75.9	154–159.9	14	4.7	2.9
8			160–165.9	5	1.7[a]	2.8
9		76–81.9	154–159.9	38	12.6	2.7
10			160–165.9	23	7.6	2.6
11		82–87.9	154–159.9	18	6.0	2.7
12			160–165.9	15	5.0	2.6
13	Large	88–93.9	142–147.9	2	0.7[a]	2.5
14			148–153.9	10	3.3	2.5
15			154–159.9	21	7.0	2.7
16			160–165.9	6	2.0	2.6
17		94–99.9	148–153.9	8	2.7	2.6
18			154–159.9	13	4.3	2.8
19			160–165.9	6	2.0	2.7
TOTAL				299	99.3	2.05

[a]Percentage is too low to be considered as a size to manufacture.

Table 4.10 shows an efficient size table as most of the samples were assigned to one of the proposed sizes. The efficiency of the table is confirmed high as only two sizes were <2% coverage. In addition, the aggregate loss for the entire size table shows an excellent value of 2.5 cm, well below the ideal value, meaning that the proposed sizes are accurate for this group.

Table 4.11 Summary table of size measurements for female (7–17 years old)

Gender—female Age range—13–17 years old		
Category		Upper
Key dimensions		Height and bust girth
Cover rate		**99.30%**
Size interval (cm)		8
Number of sizes in each body type	Big Medium Small	7 9 8
Total of sizes		**24**

4.8 Summary of sizing system

The whole process of developing the sizing system showed the result for the female aged between 13 and 17 years for upper body garment as shown in Table 4.11.

Table 4.11 finally presents the summarized results for the sizing system developed for teenage girls between 13 and 17 years old. From the table the coverage of each sizing system is high with >95%. The total number of sizes developed to cover 99% of the measured sample is 24. This is the final process of a sizing system in which the whole flow was demonstrated using a sample data. The success of a size system can be measured by statistical analysis and wearable analysis. The research conducted from this chapter has shown the statistical analysis only. The future development will be conducting the wearable test on the selected data to prove the sizing system is workable to be implemented.

4.9 Future trends

This chapter has successfully shown how to conduct analysis of the anthropometric data in which to develop an accurate garment sizing system for the RTW garment industry. The purpose of developing a sizing system is to produce garments in sizes that can accommodate a majority of customers within a set of fixed sizes. Without a sizing system that is able to generate an appropriate range of sizes for each size designation, producing good-quality well-fitting garments is impossible, and the overall objective of mass production cannot be met. When a sizing system is introduced, researchers must relate it to the understanding of fit. An accurate sizing system must be built based on actual anthropometric data as the understanding of body sizes and shapes is the only way to cater to the needs of consumers. The method of producing a sizing system impacts the efficiency of that sizing system.

The research that is based on theory and practice of sizing system development has progressively evolved from 1940 to the present. This means that a sizing system needs a lot of improvement to be efficient. For mass production purposes the sizing system must be flexible in nature; if there is a need to reduce the number of sizes to make mass production more efficient, the accommodation rate should not be negotiated. Every manufacturer understands that there is a need to accommodate most of their customers with a high-coverage sizing system.

Sizing system development began decades ago using only simple bivariate methods. As time went on the sizing systems evolved to incorporate many highly intelligent methods such as data mining, neural networks, and SOM (Ng et al., 2007). This was made possible by the experience of >70 years of exploring and understanding how to develop sizing systems that are efficient for manufacturers, customers, and retailers. It is amazing that the study of sizing systems is still ongoing today—it seems that the study of anthropometric data, sizing systems, and size designations never stops (Otieno et al., 2016; Yang et al., 2015). Many discoveries have been made, and the weaknesses of different sizing systems are being discussed to develop new methods as old methods become obsolete. It is anticipated that newer sizing systems using newer advanced analysis techniques will produce better and better sizing systems resulting in a greater goodness of fit for clothing customers (Hsu et al., 2010).

Moreover, researchers are still actively searching for ways in which to improve the efficiency of clothing sizing systems, many of which lie in the improvement of sizing validation. The key efficiencies lie between the accommodation rate and size roll. New advanced intelligent techniques are being applied to produce better sizing systems with higher accommodation rates and lower size rolls. New methodology like artificial neural networks and genetic algorithms is some of the intelligent machine learning techniques that may prove useful in creating a predictive model for finding the right sizes for the right body shapes (Adu-Boakye et al., 2012). This is very important to garment manufacturers, as a better model means that they can produce fewer sizes and still accommodate a majority of the population. This would yield tremendous benefits for both consumers and retailers, since such a model satisfies both parties.

Lastly the global issues of today have taken a toll on the whole concept of manufacturing garments. With the initiative of the sustainable development goals from UN, we are moving towards a better world. Most of the countries in the world are already realizing the concept of "sustainable fashion" or "ethical fashion." In driving towards this initiative, sizing system development is considered one of the most important agenda for every country if we are adopting the concept of ethical fashion. Understanding the body size and shapes of one nation will result to developing the right sizing system to ensure the garment fits the body well and thus will reduce the wastage of fabrics. Wastage of fabric can happen because the sizes that we develop for different master blocks are not based on the anthropometric data. Thus the garments will need alterations, and more fabric wastage will be produced (Adu-Boakye et al., 2012; Naveed et al., 2018).

4.9.1 The importance of fit and sizing system

Commercial market trends indicate that consumers today expect better fitting products and sizing systems that address niche market needs (Yang et al., 2015). A garment that catches your eyes in the store may seem like a good choice to you for that instance, but you cannot be sure until you try it on for the right fit and size. This situation is very common when it comes to buying the RTW clothing. Sometimes it could be frustrating and challenging. Sizes are not always consistent even within the same brand. Why does this happen? Each of RTW manufacturers has its own standard size measurements because of several factors. No matter what size is marked on the label, what really counts is how the garment fits. How do you recognize that your clothes don't fit you well? Check for wrinkles and bulges that indicate a poor fit. A garment that fits well is more likely to be worn and more comfortable (Hsu et al., 2010). Regardless of how one might perceive "fit" to be good or bad, it is impossible to meet the consumer's perception of good fit without a set of accurate measurement (Adu-Boakye et al., 2012). This calls for a good body sizing system that is based on human measurements considering the different body shapes, sizes, and proportions. As a conclusion, in this competitive market, retailers and manufacturers must be responsive to rapidly changing consumer demands. One of the consumers' demand today is the need of garment sizes that fit them well.

4.9.2 Benefits of fit and body sizing system

- Fit is the highest determinant for apparel purchase in today's market; therefore the ability of the manufacturers to produce a well-fitted garment will definitely enhance sales.
- Manufacturers will be more successful in this increasingly competitive global environment by offering quality clothing with good fit and size.
- Customers no longer need to spend long hours trying garments for good fit or finding the right size when shopping for clothes.
- Shopping for clothes will be much easier and fun; shoppers do not have to guess the size and fit because with the right size, it should fit well.
- Improved customer satisfaction will be resulted to less exchange and returns of clothing.
- A good fit will lead to satisfied customers and therefore will ensure customer loyalty in the long run and ultimately will enhance business performance of the retailers.
- Majority of shoppers are willing to pay higher for quality clothing with good fit and size.

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