The Design of Shoe Sizes for Boys Aged 4-6 Years Old Based on Foot Anthropometric Data: Length Foot, Width Foot, and Foot Ball Circumference

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Abstract
Shoes are footwear that is useful for protecting feet. The right shoe sizes is the main factor of the functional aspect in comfort of wearing shoes. Shoes which had been sold massively still have different standard of the sizes between one brand and another, so that the consumers will find it difficult to determine which shoes are right for the foot. The purpose of this study was to design a shoe sizes for children aged 4-6 years based on foot anthropometry data, namely, foot length, foot width and foot ball circumference. Data collection was carried out on 100 boys aged 4-6 years. Anthropometric measurements of the feet were done manually using a ruler, measuring tape and calipers. K-means cluster was used to process data of foot anthropometric size and produce a shoe sizes reference with healthy allowance value from the foot growth chamber to design the size. The shoe sizes produced was 21 patterns of shoes sizes and could accommodate 87% of the total 100 respondents.

1. Introduction
Shoes are a type of footwear that functions as a wrapper to protect the feet when used. Shoes have several components of design consisting of soles, rights, hood, ropes and tongue. Shoes are foot wrappers that are usually made of leather, rubber, canvas, and denim. Shoes are one type of footwear that serves to protect the leg's foot. According to the Great Dictionary of the Indonesian Language, shoes are interpreted as rugs or foot wraps which are usually made of leather [5]. Shoes must be made as comfortable as possible to support human activities. The main factor of the functional aspects in the comfort of wearing shoes is size match [12].

If the function of the shoe is seen from the value of the functional aspect, the shape and dimensions of the shoe must be made according to the size of the human feet [9]. Shoes that are not based on anthropometric foot size will cause pain when used. In addition, improper shoe size will result in injury and deformity of the legs [10]. The dimensions of the shoes are very closely related to the morphology of the feet, because shoe making must use an anthropometric foot measurement. As for children, it is very important to pay attention to the size of the shoe dimensions compared to the size of the shoe dimensions used for adulthood [6]. Children are recommended to wear shoes at the age of 4 years, under the age of 4 years it is not recommended to wear shoes because the morphology of the leg bones is not yet fully formed. The child's feet are still growing in the shape and size, for that the dimensions of the shoe must loose enough to become a foot growth chamber [20]. Allowance for foot length must be 9-15
mm [4][11][12][16] and for allowance on the other foot must be 5-10 mm [14], these allowances are expressed as intervals on healthy shoe dimensions for a healthy foot growth.

The research on shoe size design was previously carried out by Wiryodiningrat and Basuki [18][18], in that study used an increase in the age interval every 4 months to produce shoe sizes. At the same age, it is uncertain that it will have the same anthropometric size. Anthropometric size is not only influenced by age, but anthropometric size is also influenced by geographical, gender, social and cultural factors. In this study, foot anthropometric data will be processed using K-means cluster method to produce shoe sizes, so that the shoe sizes produced will be in accordance with the size of the foot anthropometry.

Produce a shoe sizes is must be done by measuring the length and the width of the foot, and can be added with perimeter of the foot (SNI ISO 9407: 2013). Indonesia already has a shoe size standards contained in SNI 12-0655-1989. For the shoe sizes numbering on SNI 12-0655-1989, it uses two size notations, namely the size of foot length and foot ball girth. The size of the foot ball girth 108 mm is the smallest size in the shoe sizes notation contained in SNI 12-0655-1989, but the size is too wide when it is used on foot width of the children foot aged 4-6 years and if the size of 108 mm in SNI 12-0655-1989 is used for the size of the foot ball girth, it means that SNI 12-0655-1989 has only the notation of foot length and foot ball girth size on shoes, meaning that the standard shoe size in SNI 12-0655-1989 is not in accordance with rules on SNI ISO 9407: 2013. This study will produce 3 notation of shoe sizes dimension, namely length of shoes, width of shoes and circumference of shoes.

In this study, a field observation study was conducted interviews with parents who had children aged 4-6 years and they had difficulty choosing size of shoes that fit their child's feet. The problem encountered was the size of the shoe that fit with the length of the foot, but with a width of shoe that did not match to the foot width. Interviews with shoe manufacturers also found a problem that each of them had a different shoes size standards used to make shoes. This study was the need to design shoe sizes for boys aged 4-6 years based on foot anthropometry (foot length, foot width, and foot ball circumference). This study aimed to produce a shoe sizes for children aged 4-6 years which is expected to be an input for shoe manufacturers to make shoes based on the same size and as a reference for BSN in revising SNI 12-0655-1989.

2. Method
The subjects in this study were children aged 4-6 years. A hundred respondent of boys were selected to be measured on foot length, foot width and foot ball circumference.

2.1. Foot Measurement Tools and Techniques
The materials and equipment in this study were F4 size paper, pencil, eraser, ruler, measuring tape and calipers. This measurement was carried out based on measurements that have been made by Bata [3].

![Figure 1. Location of Foot Anthropometric Measurements](image-url)
Respondent was asked to stand, then the paper was placed on the floor and the feet stepped on the respective paper, then the foot was drawn along the edge of it using a pencil with an upright position. The results of the printed image were used to measure the length of the foot by a ruler.

Foot measurements are done at foot length (1), foot width (2), and foot ball circumference (3), as in figure 1. The width of the foot was measured by using a sliding length of the maximum horizontal width (direction of Y) on the foot of the part that was perpendicular to the most prominent part of the fifth metatarsal. For the foot ball circumference, the feet were measured using a measuring tape through the medial margin section of the head of metatarsal bone, the crest of the first metatarsal bone, and the lateral margin on the head of the fifth metatarsal bone [7].

2.2. Reference Sizes to Determine the Number of Clusters in the K-Means Cluster Method
Reference measures for shoe sizes were defined as narrow, medium and wide [8]. It means that in this study three references will be formed for designing a shoe sizes. Furthermore, data processing from foot anthropometric measurements was carried out using the K-Means cluster analysis and determined that three clusters to be formed, namely clusters with small foot size, cluster with medium foot size, and cluster with large foot size. The Elbow method was used to analyze whether these three clusters would be optimal for respondents with 100 boys.

2.3. K-Means Cluster Method Analysis
The objective of cluster analysis is to segment the sample population into homogeneous groups by applying the non-hierarchical K-means cluster method [13]. Different foot sizes are identified based on the grouping method in which subjects are grouped according to the similar foot size. The advantage of the K-Means Cluster method is that it has a fairly high accuracy on the size of the object, so this algorithm is relatively more measurable and efficient for processing data in large quantities. Step algorithm in K-Means [16]:

1. K non empty subsets of objects are partitioned (randomly)
2. The partitioning seed points of the clusters currently are the clusters centroids
3. The cluster with the nearest seed point is assigned with an object
4. Repeat step 2 until assignment does not change.

In this study foot anthropometric data will be processed using K-means cluster analysis. The results of the final cluster from K-means cluster analysis will be used as guidelines in the design of shoe sizes for children aged 4-6 years.

2.4. Designing a Shoe Sizes
The results of the final cluster and minimum as well as the maximum values in the descriptive analysis of each cluster group that had been formed will be used as a reference measure for designing a shoe sizes. The design of the length used size of looseness of 9-15 mm, which means using 6 mm intervals for each increase in shoe sizes and initial or minimum size on the length of shoes raised by 9 mm to obtain a healthy shoe for the children foot growth. For the width foot width and foot ball circumference, it used the looseness size of 5-10 mm, which means using 5 mm intervals for each increase in size of shoe width and shoe circumference and for the initial or minimum size of the width and circumference, the size would be increased by 5 mm to achieved the shoe looseness value for the children aged 4-6 years.

3. Result and Discussion
This section explained about data processing carried out and analysis of the results of processing data obtained. Data was analyzed using K-Means cluster analysis. After processing the data using the K-Means cluster analysis, the reference size were made using final clusters, those were narrow, medium and wide. From the results of the reference measurements that had been obtained, a shoe sizes was developed based on the reference sizes of narrow, medium and wide, and also noticed to the minimum and maximum values from the results of the descriptive analysis of each formed group.
3.1. Data Analysis Using K-Means Cluster

Processing data using K-Means cluster analysis, first determine the number of clusters to be formed. In this study three clusters formed and analyzed using the Elbow method whether these clusters were optimal to use in the anthropometric data clustering process of 100 boys aged 4-6 years. Through the screen plot from the results of the elbow method in Figure 2 it could be seen that the K value had the greatest decrease and then the result of the K value would decrease slowly until the result of the K value was stable. In the screen plot above, there was a large decrease in K1 to K2 then to K3 and the decrease was seen sloping at K3 to K4. At K3 to K4 and then followed by steady decline.

This result showed that the optimal cluster value formed from 100 respondents in this study was three clusters. After the number of clusters had been known, the clustering process was then carried out using the K-Means cluster method to get the final cluster center. The results of this final cluster center would be used to determine the reference size of shoes (narrow, medium and wide).

![Figure 2. Screen Plot Graph (Elbow Method)](image)

| Variable                  | Cluster 1 | Cluster 3 | Cluster 2 |
|---------------------------|-----------|-----------|-----------|
| Foot Length (mm)          | 167.39    | 178.84    | 197.11    |
| Foot Width (mm)           | 70.43     | 76.59     | 84.42     |
| Foot Ball Circumference (mm) | 172.96   | 187.84    | 207.63    |

Judging from the final cluster results in table 1, we could determine the characteristics of the size of each cluster. For Cluster 1, it had a small foot size, for cluster 3 was medium size and for cluster 2 was group with wide and large legs. The results of the final cluster couldn’t be used as a reference measure for making a shoe sizes yet, because the dimension of shoes in children must had a looseness value for the foot growth chamber. The looseness value of the length was 9-15 mm, the width and the circumference of the shoe was 5-10 mm. The length of the shoe was added by 9 mm and the width and circumference were added by 5 mm.

| Shoes Length (mm) | 176.39 | 187.84 | 206.11 |
| Shoes Width (mm)  | 75.43  | 81.59  | 89.42  |
| Circumference of Shoes (mm) | 177.96 | 192.85 | 212.63 |
3.2. Reference Size for Making a Shoe sizes

The reference size was formed from the final cluster results that had been added to the looseness value for foot growth.

**Table 3. Reference Size for Narrow, Medium, and Wide**

| Variable                        | Narrow | Medium | Wide |
|---------------------------------|--------|--------|------|
| Shoes Length (mm)               | < 188  | 176-206| >188 |
| Shoes Width (mm)                | < 81   | 75-89  | >81  |
| Circumference of Shoes (mm)     | < 193  | 178-213| >193 |

The reference size in the table 3 was used to determine the limit in designing a shoe sizes for children aged 4-6 years. The minimum and maximal values of the descriptive analysis of each cluster group that has been formed must be determined. In cluster 1 there were 23 respondents, cluster 3 there were 58 respondents, and cluster 2 there were 19 respondents, the results of the descriptive analysis of each cluster seen in table 4.

**Table 4. Descriptive Analysis Statistic of Cluster 1, Cluster 2 and Cluster 3**

| Size   | Variable                        | N  | Range | Min. Value with Allowance | Max. Value with Allowance |
|--------|---------------------------------|----|-------|----------------------------|----------------------------|
| Cluster 1 | Foot Length (mm)              | 23 | 13    | 161                        | 170                        |
|         | Foot Width (mm)                | 23 | 11    | 65                         | 70                         |
|         | Foot Ball Circumference (mm)   | 23 | 18    | 165                        | 170                        |
| Cluster 3 | Foot Length (mm)              | 58 | 25    | 166                        | 175                        |
|         | Foot Width (mm)                | 58 | 13    | 70                         | 75                         |
|         | Foot Ball Circumference (mm)   | 58 | 20    | 180                        | 185                        |
| Cluster 2 | Foot Length (mm)              | 19 | 24    | 184                        | 193                        |
|         | Foot Width (mm)                | 19 | 13    | 77                         | 82                         |
|         | Foot Ball Circumference (mm)   | 19 | 23    | 197                        | 202                        |

Based on the minimum value and maximum value that had been added to the looseness value for the foot growth and based on the reference size, a shoe sizes could be prepared for children aged 4-6 years.

**Table 5. Shoe Sizes (narrow)**

| Size Label | Shoes Length (mm) | Shoes Width (mm) | Circumference of Shoes (mm) | Cover Rate |
|------------|-------------------|------------------|-----------------------------|------------|
| N1         | 170-176           | 70-75            | 170-187                     | 8 %        |
|            |                   | 76-81            | 170-187                     | 3 %        |
| N2         | 177-183           | 70-75            | 170-187                     | 6 %        |
|            |                   | 76-81            | 170-187                     | 4 %        |

Narrow has 4 shoe sizes . Narrow has 2 variations in shoe length, 4 variations in shoes width, and 4 variations in shoe circumference. Narrow accommodates 21% of 100 respondents.
Table 6. Shoe Sizes (medium)

| Size Label | Shoes Length (mm) | Shoes Width (mm) | Circumference of Shoes (mm) | Cover Rate |
|------------|-------------------|------------------|----------------------------|------------|
| M1         | 177-183           | 76-81            | 182-205                     | 5 %        |
| M1         | 76-81             | 182-205          | 10 %                        |
| M2         | 184-190           | 82-87            | 188-205                     | 8 %        |
| M2         | 76-81             | 188-205          | 10 %                        |
| M3         | 191-197           | 82-87            | 188-205                     | 6 %        |
| M3         | 76-81             | 188-205          | 1 %                         |
| M4         | 198-204           | 82-87            | 188-205                     | 3 %        |
| M4         | 6 %               | 3 %              | 15% of 100 respondents      |

Medium has 8 shoe sizes. Medium has 4 variations in shoe length, 8 variations in shoes width, and 8 variations in shoes circumference. Medium accommodates 51% of 100 respondents.

Table 7. Shoe Sizes (wide)

| Size Label | Shoes Length (mm) | Shoes Width (mm) | Circumference of Shoes (mm) | Cover Rate |
|------------|-------------------|------------------|----------------------------|------------|
| W1         | 198-204           | 82-87            | 200-223                     | 1 %        |
| W1         | 88-93             | 200-223          | 4 %                         |
| W2         | 205-211           | 94-99            | 206-223                     | 1 %        |
| W2         | 82-87             | 206-223          | 0                           |
| W3         | 212-218           | 88-93            | 206-229                     | 1 %        |
| W3         | 94-99             | 206-229          | 6 %                         |

Wide has 9 shoe sizes. Wide has 3 variations in shoe length, 9 variations in shoes width, and 9 variations in shoes circumference. Wide accommodates 15% of 100 respondents.

3.3. Designing Shoes Sizes Patterns

The design of this size pattern later be used to label size information on shoes according to the rules made in SNI ISO 9407: 2013. Write label the shoe size based on the size pattern in figure 2 it could be written as N176/75/175 which the length of 176 mm, the width of 75 mm, and the circumference of 175 mm.

![Shoe Size Patterns for Boys Aged 4-6 Years Old](image)

Figure 3. Shoes Size Patterns for Boys Aged 4-6 Years Old
3.4. Analysis

From the size pattern that had been formed, the results analysis was then carried out by knowing the foot size which could be accommodated from the size pattern in Figure 2.

| Shoes Length (mm) | Accommodating Foot with Length (mm) |
|-------------------|-------------------------------------|
| 176               | 161-167                             |
| 183               | 168-174                             |
| 190               | 175-181                             |
| 197               | 182-188                             |
| 204               | 189-195                             |
| 211               | 196-202                             |
| 218               | 203-209                             |

Accommodation for foot length is shown in table 8. For shoes length has a size of 176 mm, 183 mm, 190 mm, 197 mm, 204 mm, 211 mm, and 218 mm. Each size accommodates 7 size of foot length.

| Shoes Width (mm) | Accommodating Foot with Width (mm) |
|------------------|------------------------------------|
| 75               | 65-70                              |
| 81               | 71-76                              |
| 87               | 77-82                              |
| 93               | 83-88                              |
| 99               | 89-94                              |

Accommodation for foot width is shown in table 9. For shoes width has a size of 75 mm, 81 mm, 87 mm, 93 mm, and 99 mm. Each size accommodates 6 size of foot width.

| Shoes Circumference (mm) | Accomodating Foot with Foot Ball Circumference (mm) |
|--------------------------|-----------------------------------------------------|
| 187                      | 165-182                                             |
| 205                      | 183-200                                             |
| 223                      | 201-218                                             |
| 229                      | 201-224                                             |

Accommodation for foot ball circumference is shown in table 10. For shoes circumference has a size of 187 mm, 205 mm, 223 mm, 229 mm. Each size accommodates 18 size of foot ball circumference.

The results of the shoe sizes grading in table 5, table 6 and table 7 was a measure that had used leg looseness for healthy growth space of children feet aged 4-6 years. The size in this study produced 21 pattern size that accommodate 87% of 100 respondents. This shoe sizes also produced three dimensions of shoes length, shoes width and shoes of circumference. So that this shoe sizes was in accordance to SNI ISO 9407: 2013 which stated that in the notation, the shoe size must had a shoe length and width.

The difference in the size produced by SNI 12-0655-1989 was located in a smaller number of sizes. The produced 21 of size patterns, while SNI 12-0655-1989 had a larger size but did not show foot width notation in the existing size.

4. Conclusion and Suggestion

This section will explain the conclusions that can be drawn from the results of the study. In addition, this section will also provide suggestions for developing further research.

4.1. Conclusion

The design of shoe sizes grading for boys aged 4-6 years was the result of this study. The study produced 21 size patterns, of these 21 sizes could accommodate 87% of 100 respondents. The size for shoe width
had been produced, different from SNI 12-0655-1989 which only used shoe length and shoes circumference notation.

The results of this shoe sizes were in accordance with SNI ISO 9407: 2013 standards, that there should be a shoe sizes and width notation to determine the shoe dimensions. The results of this sizes could be written with the label N1/75/187 which means that the shoe had a length of 176 mm, width of 75 mm, and shoes of circumference of 187 mm.

4.2. Suggestion

The size of shoes produced in this study was only be used for mass shoe making. To make shoes based on individual orders, measurements need to be done but not only on the foot length, foot width and foot ball circumference. The foot measurements must be more specific to the anthropometry of other human legs, which can be added by measuring the anthropometry section on heel width, circumference fat foot, width fat foot, the height of the deep bone, the height of outer bone, and ankle circumference.

5. Reference

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