Cluster Analysis based Segmentation of Shoe Last for Korean Footwear Industry

Nayeon Kim, Kyuyeon Kim, and Minsoo Kim

***Abstract*—**In this research authors present multiple shoe lasts for the same size of Korean customers. Instead of conventional foot length-based approach, multiple shoe lasts enable more customized footwear considering compounded dimensions such as foot breadth, instep circumference, and lateral malleolus height. By conducting Ward analysis, a hierarchical cluster analysis, authors found 3 optimized clusters, and then conducted K-means analysis for each cluster. The Human Body Measurements data (2010) from KATS (Korean Agency for Technology and Standards) is used for this analysis. For all size groups of shoes that are separated by 5mm-wise unitization, authors have found more than 2 shoe lasts that are customized for women and men independently. With the introduction of multiple shoe lasts that is suggested in this research, it is expected to have increased customer satisfaction in the footwear industry.

***Keywords*—**cluster analysis, footwear segmentation, shoe last, KATS

I. Introduction

As feet are the major part of a human body which support movements while bearing one's weight, so we normally protect our feet with shoes and socks. Contrary to the other clothing, unfit shoes can lead to huge inconveniences due to its relative rigid shapes and stiff materials. Shoes that are too small increase pressure on the foot, and those that are too large cause friction from sliding of the foot [1]. According to [2], it has been reported that out of 356 women, 80% have pain when wearing shoes and 76% have more than one deformity of foot. Therefore it is important to buy a suitable pair of shoes for the health of consumer and to provide more options for product dimension.

In Korea, the most of footwear are produced largely based on foot length while little considering their shapes. KATS (Korean Agency for Technology and Standards) has made a sizing system that uses a mixture of foot length and breadth for the prototype of shoes in Korean footwear industry. Even though this system has defined 21 foot length and 10 breadth dimensions for men (17 and 9 for women respectively), Korean companies still produce just one size for each shoe dimension, which causes huge inconveniences to customers. It is quite common in the footwear market that people with larger ball girth usually buy a bigger pair than their own foot length to comfort his/her feet. The main reason for this negligence to KATS system is considered as its wide range of dimensions and subsequent production costs for variants. In order for the sizing system to be more practical and applicable, it is needed to reduce those wide dimensions into much manageable numbers.

In this paper, we present another sizing system with a reduced number of dimensions from KATS system but still provide multiple choices for customer convenience. Proposed system also considers foot length and breadth like KATS system. It is expected that footwear industry can increase customer satisfaction level while restricting production cost within a manageable range by using suggested system.

The rest of this paper is organized as follows. Section 2 shows related researches on shoe sizing systems in the footwear industry. In section 3, our research design and experiment dataset are described in detail. Results are given in section 4 followed by conclusion in section 5.

II. Research Background

Many countries have their own shoe sizing system because the size specifications of shoe last are different between nations and peoples. And they have studied for long time to improve their sizing systems from the perspective of anthropometry. Thus the most of sizing systems focus to explain the full dimensions of people in size, but lack the configurations of options to produce consumer goods from the perspective of corresponding industries. Cheng and Perng [3] have proposed 17 classes of foot length and 5 classes of joint girth for shoe last design of Taiwanese men using a bi-variate normal distribution, to improve conventional sizing system. Furthermore, Chaiwanichsiria and Tantisiriwatb found proper shoe sizes for Thai elderly while studying foot and shoe size matching [4]. However, it is hard to adopt these results into Korea because the size specification systems of shoe last are different between countries and peoples [5], [6].

In Korea, Moon studied about foot type of college women [7] and men [8] in urban area. The author found 3 or 4 clusters by conducting factor analysis and cluster analysis for 17 variables [7], [8]. Park categorized KATS 2004 dataset for women, and identified 3 groups for foot shape and 4 groups for sole shape. Park also found that older group with ages of 40 and 50 tends to have wider foot breadth as well as greater lateral malleolus height [9].

These previous researches, however, have considered single

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dimensional clustering. In order to suggest more practical clusters of shoes, a shoe last that combines multiple measures of human foot into a shaping model of configuration is most needed for footwear industry. Thus, in this study, authors have suggested multiple shoe lasts for Koreans while considering 7 significant foot dimensions by cluster analysis.

III. Research Design and Dataset Description

A. Research Design

To find the optimal number of clusters, ward method is used, and then K-means analysis is conducted to classify the areas of combined dimensions for foot model, which are commonly used methods in the classification researches [10]-[12].

Based on our preliminary survey, shoes with the size of 245-280mm for men and 220-250mm for women are mostly produced from the top 10 companies in Korean footwear industry. With this result, we have conducted cluster analysis for 15 size groups as is given in the TABLE I.

TABLE I
Definition of Size Group

Size Group (Male/Female)	Length Range (mm)	Sample Size
220 (F)	216-220	F: 146
225 (F)	221-225	F: 231
230 (F)	226-230	F: 348
235 (F)	231-235	F: 339
240 (F)	236-240	F: 269
245 (M, F)	241-245	M: 240, F: 141
250 (M, F)	246-250	M: 303, F: 55
255 (M)	251-255	M: 269
260 (M)	256-260	M: 272
265 (M)	261-265	M: 195
270 (M)	266-270	M: 113
275 (M)	271-275	M: 73
280 (M)	276-280	M: 25

B. Dataset and Key Variables

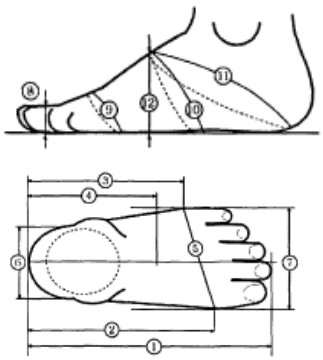
Data Item	Measure in Shape
1. Foot length 2. Pternion to Metatarsophalangeal I length 3. Pternion to Metatarsophalangeal V length 4. Pternion to Instep length 5. Metatarsophalangeal I to Metatarsophalangeal V breadth 6. Heel breadth 7. Foot breadth 8. Max toes height 9. Ball girth (Foot circumference) 10. Instep circumference 11. Pternion to Instep circumference 12. Instep height	

Fig. 1 The items for last design [13]

From 1979, KATS has measured 316 anthropometric data items from Koreans for every 6 years, and has built a database for public use. Authors have used 43 data items that are related to feet dimension like sex, age, length, breadth, instep circumference, lateral malleolus height, ball girth (i.e. foot circumference), pternion to metatarsophalangeal length and so forth from the 2010 year's dataset, which is the most recent update of this database.

A shoe last is a wooden or metal model of the human foot on which shoes are shaped [4]. Amongst above 43 chosen data items, shoe last is defined with 12 data items [13] that is depicted in the Fig. 1.

The 12 measures of shoe last, however, have not been fully recorded in the KATS dataset, though they are included in the original 46 data items. So authors have to remove 6 measures from the analysis which are mostly lacked in the dataset. And authors additionally included lateral malleolus height in the analysis that is depicted in the Fig. 2. In our preliminary survey, more than 8% of customers have answered improper length of this measure causes severe inconvenience. This, thus, leads to 7 key measures — 2, 3, 7, 9, 10, 12 in the Fig. 1, and lateral malleolus height in the Fig. 2 — for the analysis of this research.

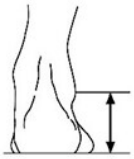


Fig. 2 Lateral malleolus height

Outliers with the deviation of ±3σ are removed from the analysis for better result, and thus total 3019 effective data records are used in the cluster analysis. Detailed number of data records for each size groups that are used for this study is summarized in the TABLE I.

IV. Results

TABLE II
Overall Clusters Result

Size Group	Clusters [a]	Inter(Intra)-clusters Distance		Ratio
		Within [b] (W)	Between [c] (B)	(B÷W)
220 (F)	2	13.54	21.50	1.59
225 (F)	2	12.60	21.00	1.67
230 (F)	2	12.14	21.73	1.79
235 (F)	2	12.11	21.51	1.78
240 (F)	2	12.84	21.79	1.70
245 (F)	2	13.00	19.57	1.50
250 (F)	2	17.00	27.86	1.64
245 (M)	2	16.67	22.99	1.38
250 (M)	2	15.62	22.92	1.47
255 (M)	3	15.62	22.63	1.45
260 (M)	2	16.59	21.45	1.29
265 (M)	2	15.44	22.16	1.43
270 (M)	2	16.00	22.35	1.40
275 (M)	2	15.82	24.95	1.58
280 (M)	2	15.55	28.83	1.85

F = Female, M = Male.
[a]Cluster is the optimal number of clusters calculated for each size group.
[b]Within stands for the average distance within clusters.
[c]Between is for average distance between clusters.

As we can see in the TABLE II, the optimized number of cluster is 2 except for size group 255(M). The proportions of average distances between clusters (B) over within clusters (W)

are all above 1, which demonstrate valid results. This relatively small number of clusters for each size groups can be more helpful for the footwear industry to adopt our result than the original KATS systems, while investing minimum amount of resources for customized production.

Detailed results for each cluster of size groups are summarized in the TABLE III and IV. For women's case, the difference α and β of ball girth is somewhat similar between size groups as with the value of 14-15mm. But for men's case, it shows even wider size variations between groups. Foot breadth also shows similar patterns. For women's case, foot breadth variations are mostly within 5mm range between clusters, but for men's case, it shows larger variations than the value of 5mm in 6 size groups. The variation of Instep circumference is like-wisely similar as with 11-16mm for women, and 13-18mm for men. The other measures show no significant variations between size groups. Lateral malleolus height that is additionally added to this study shows somewhat significant variations between size groups only for men's case. The production rate column of TABLE III and IV are the instance ratios between the clusters against all size groups. This is given as for a suggestion to produce shoes for each size groups' clusters.

TABLE III
RESULT OF WOMEN

Shoe size	Segmentation	Ball girth	Foot breadth	Instep height	Lateral malleolus height	Instep circumference	Pternion to Metatarsophala-ngeal I length	Pternion to Metatarsophala-ngeal V length	Production rate
220	α(alpha)	217	85	51	62	213	161	140	4.84%
	β(beta)	231	90	55	65	228	161	140	4.71%
225	α(alpha)	219	86	52	62	215	164	143	7.33%
	β(beta)	233	91	54	64	230	164	142	7.78%
230	α(alpha)	222	88	52	62	219	168	147	14.00%
	β(beta)	237	93	54	65	233	168	145	8.76%
235	α(alpha)	226	90	53	64	222	171	150	14.45%
	β(beta)	241	95	56	66	236	171	147	7.72%
240	α(alpha)	232	92	54	66	226	175	153	13.54%
	β(beta)	246	97	56	68	241	174	148	4.05%
245	α(alpha)	228	91	52	64	224	179	155	3.07%
	β(beta)	242	96	57	68	235	179	156	6.15%
250	α(alpha)	226	91	52	63	224	186	163	1.18%
	β(beta)	244	99	59	68	240	183	156	2.42%

Units are in mm.

TABLE IV
RESULT OF MEN

Shoe size	Segmentation	Ball girth	Foot breadth	Instep height	Lateral malleolus height	Instep circumference	Pternion to Metatarsophala-ngeal I length	Pternion to Metatarsophala-ngeal V length	Production rate
245	α(alpha)	241	94	59	68	241	177	156	8.12%
	β(beta)	255	101	66	71	256	179	153	7.99%
250	α(alpha)	243	96	61	70	244	183	160	10.07%
	β(beta)	259	102	65	72	259	182	156	10.27%
255	α(alpha)	243	97	60	68	244	186	163	6.51%
	β(beta)	250	102	69	75	257	188	167	5.44%
	γ(gamma)	264	102	63	70	260	186	155	6.11%
260	α(alpha)	248	99	61	70	249	188	165	9.80%
	β(beta)	260	105	68	73	263	190	165	8.46%
265	α(alpha)	249	100	63	71	252	193	169	5.84%
	β(beta)	265	106	65	73	266	193	166	7.25%
270	α(alpha)	252	102	63	73	255	196	172	4.30%
	β(beta)	267	109	68	76	268	198	168	3.29%
275	α(alpha)	251	103	65	74	256	201	176	2.42%
	β(beta)	270	109	63	73	269	199	169	2.48%
280	α(alpha)	253	103	62	71	254	205	174	0.67%
	β(beta)	272	112	68	77	272	206	178	1.01%

Units are in mm.

V. Conclusion

For all size groups, more than 2 clusters of shoe lasts are found with the distance ratio between 1.29-1.85. Judging from the standard deviations of each size dimension, it seems that ball girth, instep circumference, and foot breadth mostly determine the classification of clusters. For women's case, the differences of ball girth and foot breadth have similar value ranges between clusters within the value of 14-15mm and 5mm, respectively. But those patterns do not show up for men's case.

One size does not fit all at least for footwear industry. With our clustered result, authors hope that more practical guide lines to produce shoes can be developed afterward. People will be more satisfied with multiple size options, and producers can economically manage small number of clusters. While interpreting the result of this research, dataset inherent bias such as physical builds of Korean, ages of subject should be carefully considered by the user. It should also be reevaluated according to the updates of original KATS dataset.

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