RESEARCH ON DEVELOPING A SIZE SYSTEM AND DESIGNING SHOE LASTS FOR MEN WITH DIABETES IN VIETNAM

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ABSTRACT. This paper presents the method and results of developing a shoe last sizing system on the basis of the foot parameter system, designing shoe lasts for men with diabetes in Vietnam. Diabetic patients often have foot complications and need to use extra depth shoes or custom shoes to protect their feet and prevent foot ulcers. The parameters of 5 shoe last sizes by length and 3 sizes by width according to the French sizing system have been developed. The results show that the shoe last parameters for men with diabetes are much larger than those for healthy men, especially the ball girth and width are larger by about 20 mm and 5 mm, respectively. Afterward, shoe lasts were designed and modified using 3D CAD tools for style, fit and comfort specifically suited for men with diabetes. Using shoe last design software, 3D printing technology to design and fabricate a shoe last, the proposed approach proved the viability of designing and manufacturing extra depth shoes for men with diabetes in Vietnam.

KEY WORDS: shoe lasts, sizing system, extra depth diabetic shoes

CERCETĂRI PRIVIND DEZVOLTAREA UNUI SISTEM DE MĂRIMI ȘI PROIECTAREA CALAPOADELOR DESTINATE ÎNCĂLȚĂMINTEI PENTRU BĂRBAȚII CU DIABET DIN VIETNAM

REZUMAT. Această lucrare prezintă metoda și rezultatele dezvoltării unui sistem de dimensionare a calapoadelor pe baza sistemului de parametri ai piciorului, proiectând calapoade de încălțăminte pentru bărbații cu diabet din Vietnam. Pacienții diabetici au adesea complicații ale piciorului și trebuie să folosească pantofi cu adâncime suplimentară sau pantofi personalizați pentru a-și proteja picioarele și pentru a preveni ulcerul piciorului. S-au stabilit parametrii a 5 mărimi de calapod pe lungime si 3 mărimi de calapod pe lățime, conform sistemului francez de dimensionare. Rezultatele arată că parametrii calapodului de încălțăminte pentru bărbații cu diabet sunt mult mai mari decât cei pentru bărbații sănătoși, în special circumferința în zona metatarsienelor și lățimea sunt mai mari cu aproximativ 20 mm, respectiv 5 mm. Ulterior, s-au proiectat și modificat calapoade folosind instrumente CAD 3D pentru stil, potrivire și confort, corespunzătoare bărbaților cu diabet. Folosind un software de proiectare a calapoadelor și tehnologia de imprimare 3D pentru a proiecta și fabrica un calapod, abordarea propusă a dovedit viabilitatea proiectării și fabricării pantofilor cu adâncime suplimentară pentru bărbații cu diabet din Vietnam.

CUVINTE CHEIE: calapoade, sistem de mărime, pantofi pentru diabetici cu adâncime suplimentară

RECHERCHE SUR LE DÉVELOPPEMENT D'UN SYSTÈME DE TAILLE ET LA CONCEPTION DE FORMES DE CHAUSSURES POUR LES HOMMES DIABÉTIQUES AU VIETNAM

RÉSUMÉ. Cet article présente la méthode et les résultats du développement d'un système de dimensionnement des formes de chaussures sur la base du système de paramètres du pied, en concevant des formes de chaussures pour les hommes atteints de diabète au Vietnam. Les patients diabétiques ont souvent des complications aux pieds et doivent utiliser des chaussures de profondeur supplémentaire ou des chaussures sur mesure pour protéger leurs pieds et prévenir les ulcères du pied. On a développé les paramètres de 5 tailles de formes de chaussures en longueur et 3 tailles en largeur selon le système de pointure français. Les résultats montrent que les paramètres de la forme de chaussures pour les hommes diabétiques sont beaucoup plus grands que ceux pour les hommes en bonne santé, en particulier la circonférence dans la zone des métatarsiens et la largeur et sont plus grandes d'environ 20 mm et 5 mm, respectivement. Par la suite, des formes de chaussures ont été conçues et modifiées à l'aide d'outils de CAO 3D pour un style, un ajustement et un confort spécifiquement adaptés aux hommes atteints de diabète. En utilisant un logiciel de conception de chaussures et une technologie d'impression 3D pour concevoir et fabriquer une forme de chaussure, l'approche proposée a prouvé la viabilité de la conception et de la fabrication de chaussures à profondeur supplémentaire pour les hommes diabétiques au Vietnam.

MOTS CLÉS : formes de chaussures, système de dimensionnement, chaussures à profondeur supplémentaire pour les diabétiques

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INTRODUCTION

Shoe lasts, 3D molds utilized to make footwear, play an important role in shoe production, affecting the shape, fitting, and size of shoes. Wooden or metal shoe lasts are tools for designing and manufacturing shoes, satisfying the biomechanical prerequisites of the inside, style, fit, and comfort. To achieve these requirements, shoe lasts are designed based on foot shapes, sizing systems, and parameters. The complication of the shoe last making process is to determine the necessary data for building a standardized last from various foot dimensions (Figure 1).

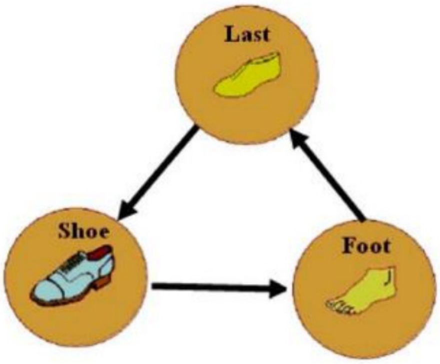

Figure 1. Correlation between foot, last, and shoe [1]

In the footwear industry, shoe last design is an arduous job. This is related to the requirements of shoe comfort, production technology and aesthetics [2]. Varied countries have developed a size system or a shoe last parameter system for numerous types of shoes (dress, casual, sport, hiking, work shoe, sandal, moccasin) [3]. The dimensions of a shoe last are not exactly equivalent to the homologous dimensions of the foot, though the foot is the model for it [2, 4]. Setting up the shoe last size system is the conversion of foot parameters into homologous last parameters. This represents the relationship between the foot and the last. And it depends on the age, gender of the shoe user, the type of shoes, the height heel of the last, and the purpose of the shoe or the requirements for the shoes.

The length of the last is longer than the foot length. The last bottom length is its curved length and is equal to the bottom pattern length. This length is equal to the length of the foot minus the room around heel and plus the toe allowance [2-6]. The toe allowance includes the minimal addition to toe movement, the addition for child's foot growth for about 1 year, the addition according to aesthetics [2, 3].

The last width is closely related to the foot print and girth, which may influence the design of the last, the fit and the aesthetics of the footwear. According to AKA64-WMS system, the ball width of the last bottom, depending on the type of shoe, is equal to 37 to 40% of the ball girth of foot [4]. The width of the last bottom also depends on its heel lift. When the last heel lift is increased, its bottom width is narrowed [2, 4, 6]. The last width should be neither greater than the foot width, nor smaller than the footprint width, or the shoe will be too flat or too narrow in the metatarsophalangeal joint (MPJ) area [2-4, 6]. Therefore, the last width should be an intermediate value between the two widths, according to different situations. For example, the last bottom width with high heel lift will be closer to the foot print. Whereas the last with low heel lift will have a bottom width closer to the foot width [2, 3, 6].

Several foot girths may be utilised in shoe last design, such as ball girth, waist girth, instep girth, heel girth and ankle girth. The ball girth, which is the circumference length of the MPJ, is one of the most important dimensions in shoe last design. The ball girth of a last is also slightly longer or shorter than the ball girth of the foot. This depends on the type of shoe and its use conditions [2-6]. For example, a last for leather shoes for men or women may have girths shorter than the homologous girths of the foot. This means allowing the shoe to slightly compress the foot without causing discomfort [2, 3]. Meanwhile, the lasts of children's shoes, sports shoes, and safety shoes have girths longer than the homologous girths of the foot. The waist girth also changes according to different situations and is smaller in lasts for high-heeled shoes [2, 4]. To ensure comfortable wear, the instep girth of most lasts should be greater than that of the foot [4, 6]. The insole is inserted into the shoe after the shoe last is removed from it.

Therefore, it is necessary to take into account the thickness of the insole into the parameters of the shoe last girths, especially the closed girths [7].

Research shows that there is an angle of about 15 degrees between the toes and the bottom of the foot, when the foot hangs naturally [2, 4]. This is called the toe spring. Shoes with appropriate toe spring are able to support the toes and reduce the bending of the MPJ during walking or running. They will also deter excessive wrinkling of the upper, and wear and tear on the outsole, so extending serviceable life. The toe spring is also reduced with an increase in heel height [2-6].

The optimal last heel height reported in many studies is 25–45mm [2-4, 8]. However, high heels are designed mainly for fashion and aesthetics, and may be from 50mm to 80mm, and in extreme cases, over 100mm. Heel elevation also affects the design of shoe lasts, as the room around the heel of the foot or heel shift will become smaller [4, 6], or bigger [2, 3] thus altering the length of the last.

Currently, there are no standards or regulations on the shoe lasts and footwear for diabetic patients in Vietnam, thus general recommendations are given on designing extra depth diabetic shoes. Suggestions and recommendations from published reports could be used in shoe last design such as the heel height should be up to 20 mm [9], between 15 to 25 mm [10], from 20 to 30 mm [11, 12], not more than 50 mm [13]; an addition to the bottom length at the toe at least 10 mm [9]; shoe insole thickness from 5 to 10 mm [9]; shoe weight less than 700g/pair. Other issues such as a change in foot parameters, the presence of edema that leads to increased foot parameters, and the recommendation of choosing shoes in the afternoon, also need to be taken into consideration before designing the last and manufacturing extra depth shoes for the foot characteristics of diabetic patients.

The design of shoe lasts for diabetic patients is an urgent issue, particularly, for patients with foot problems or a high risk of ulcers. Footwear-related factors aggravate foot ulceration, leading to infection and in the worst case partial or full amputation. Modified shoe last has been studied to meet foot shape and biomechanical functions among individuals, therefore, reducing the risk of foot ulcers. However, a systematic procedure has not been established to customize shoes for these patients. Shoe lasts made by skilled craftspeople could be time-consuming, unreliable, heavily relied on techniques and experience. So far, there have been a number of studies on custom shoe last design based on 3D foot shape and parameters [1, 14-16]. These CAD systems can identify diabetic footwear to adjust sizing geometry for individuals thus minimizing pressure infliction while preserving the fashion style.

Novel CAD tools have been employed to design shoe last for diabetic patients with the technologies of risk reduction for foot ulceration and preserving shoe styles. The footwear and original aesthetic parameters necessary to measure geometrical models and design features were identified based on the foot model and geometric algorithms for shoe last processing. The last design for diabetic patients was based on biomechanical variables regarding diabetic feet having high pressure at the joint of the metatarsal and hallux. Ball, instep, and heel circumference are demonstrated to cope with the space required for the foot and the custom insole. Limited changes in the foot shape were guaranteed during walking to avoid friction with the upper and shear loading. The ball girth was clarified to have enough room to fit the foot comfortably; otherwise, a shoe too tight leads to ulcers in the medial area of the first metatarsal head and in the lateral area of the fifth metatarsal head. A shoe, having a high and rounded toe box, provides the best fit for the toes allowing toes to move comfortably inside the shoe [17]. Computer-aided reverse engineering system (CARESystem) are used to develop the design process and fabrication of ankle foot orthotics (AFO) for patients with diabetes [18]. The study results showed that the shape of the shoe fit the standard AFO and the first patient experienced comfort for the 4-week long testing period. The use of this technology reduced the time for both the design and fabrication of the AFOs by 64%

[18]. The reverse engineering (RE) combined with an artificial neural network, a termed self-organizing map (SOM) was used to select a shoe last for footwear design to help relieve the pain associated with diabetic neuropathy and foot ulcers [19]. With this technology, the most suitable shoe last for each patient with a mild diabetic foot can be determined by calculating the relative fitness function for each patient [19].

In Vietnam, Bui *et al*. conducted a study on anthropometric characteristics of 412 female feet with diabetes and investigated the patient's requirements for shoes. The authors identified the types of foot lesions and built a system of patient foot parameters [20, 21]. This data, combined with the results of a patient survey about the requirements for extra depth shoes have been the basis for building a shoe last size system, favorable for designing shoe lasts for women with diabetes in Vietnam [7, 22]. The shoe last quality is assessed by wearing tests and pressure measurements on patients' feet using a pressure sensor system [23]. The results show that the shoe last met the requirements for up-scale manufacturing [24]. The results of the study on foot shape and parameters of men with diabetes in Vietnam show that there is a difference in foot width and circumference of men with diabetes compared with the feet of healthy men [25]. In addition, extra depth shoes for diabetic patients need to meet specific requirements such as using insoles with a minimum thickness of 5 mm, shoes with a high and wide toe, heel height not exceeding 3 cm, and so on [9-12]. Therefore, developing a sizing system and designing lasts to fabricate extra depth diabetic shoes for men with diabetes in Vietnam are necessary and novel. Therefore, in this study, we used the established foot parameter system [25], and based on the shoe requirements, to build a shoe last size system, design the last of extra depth shoes for men with diabetes in Vietnam.

EXPERIMENTAL

Methods

The process of designing a shoe last of extra depth shoes for men with diabetes is alike compared to that for women with diabetes [7], as shown in the flowchart in Figure 2.

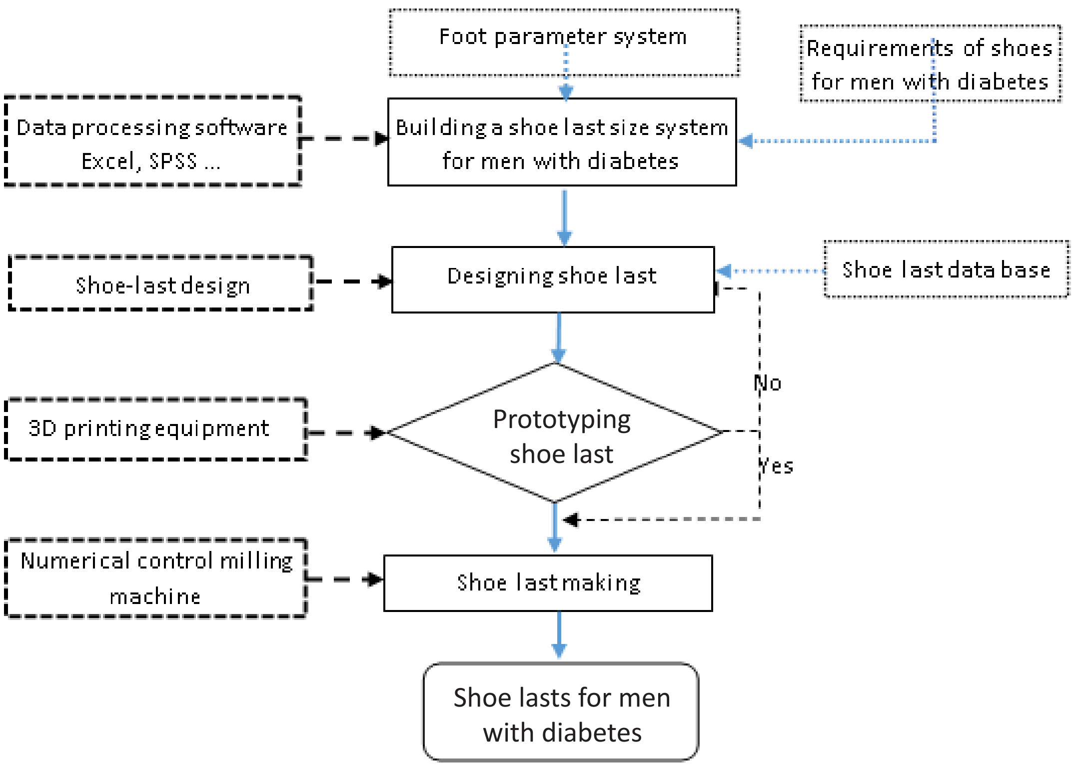

Figure 2. Flowchart for developing a sizing system and designing a shoe lasts of extra depth shoes for men with diabetes

To design the lasts, it is necessary to have data on the shape and parameters of the foot. From here, a system of foot parameters is built including foot parameters and their increments of adjacent sizes. From the main data, the foot parameters, combined with the requirements of shoes for men with diabetes such as high and wide toe shoes, 15 mm toe allowance, shoes that do not constrict the foot, insole thickness at least 5 mm, heel height not more than 25 mm and so on will be calculated or converted into the corresponding foot parameters of the shoe last. Building a shoe last size system is fundamental before further steps utilizing a 3D shoe last design software, 3D printing equipment, a CNC milling machine to design and manufacture the lasts.

Method for Determining Shoe Last Parameters in the Size System

The shoe last parameters for men with diabetes were determined on the basis of foot measurements in the established system of foot parameters [25] and shoe requirements for diabetics. In the study [25], we built a system of foot parameters according to the French size system including 5 sizes by length (231.5, 238, 244.5, 251, 257.5 mm) with increments between sizes is 6.5 mm. Each size by length has 3 sizes by width with 10 mm increments. The foot length determines shoe last sizes according to the length of its bottom surface. The ball girth determines shoe last sizes by width. Parameters of average foot size 244.5 mm by length with 3 sizes by width are shown in Table 1.

Table 1: Parameters of average foot size 244.5 mm by length with 3 sizes by width of Vietnamese men with diabetes [25]

№	Foot parameters	Values by width, mm		
		A	B	C
1	Foot length **Lf**	244.5	244.5	244.5
2	Length to medial ball **Lmb**	180.0	180.0	180.0
3	Length to lateral ball **Llb**	159.4	159.4	159.4
4	Length to the end of 5th toe **L5toe**	202.4	202.4	202.4
5	Length to instep point **Lins**	78.5	78.5	78.5
6	Length to center of lateral ankle **Lla**	55.7	55.7	55.7
7	Width of medial ball **Rmb**	95.4	99.5	103.7
8	Width of lateral ball **Rlb**	92.2	96.2	100.1
9	Width of ball **Rb**	98.6	102.9	107.2
10	Width of heel **Rh**	62.6	65.3	68.0
11	Height at 1st toe **C1toe**	19.2	20.0	20.8
12	Medial ball height **Cmb**	31.4	32.8	34.1
13	Instep height **Cins**	51.1	53.3	55.5
14	Height at lateral ankle center **Cla**	57.1	59.5	62.0
15	Medial ball girth **Vmb**	221.1	230.6	240.2
16	Lateral ball girth **Vlb**	225.2	235.0	244.7
17	Ball girth **Vb**	231.0	241.0	251.0
18	Waist girth **Vw**	225.5	235.2	245.0
19	Instep girth **Vins**	235.0	245.1	255.2
20	Heel (cross) girth **Vh**	301.7	314.7	327.8
21	Ankle girth **Va**	196.4	204.9	213.4

Determining the Lengths of the Shoe Last Bottom

The length of the bottom surface of the shoe last (bottom length Lsl) is determined by the formula [2]:

$$Lsl = Lf - Sh + P1 + P2 + P3 \quad (1)$$

where Lf is the foot length; P1 is the minimal addition to toe movement. Because shoes for diabetic patients have high and wide toes, so P1 = 15 mm [2, 4]; P2 is the addition for foot growth for about 1 year. In the study [7], 30 female diabetic feet were re-measured after 1 year. The results showed that the patient's foot length was almost unchanged. Therefore, in this study, inherit the research results [7] and take P2 = 0 mm for the shoe-last for men with diabetes; P3 is the addition according to aesthetics. Shoes for diabetics have wide and high toes, so P3 = 0 mm; Sh is the room around heel or heel shift [2, 3]:

$$Sh = 0.02Lf + 0.05Hh \quad (2)$$

where Hh is the heel lift, mm. The maximum Hh for shoes for diabetics is 30 mm [9-12]. According to the results of the patient survey, the majority of patients required this height to be 10 mm, similar to shoe last for sport shoes. This height ensures both comfort and aesthetics for the shoe. Therefore, in this study, Hh = 10 mm was used.

The remaining parameters according to the length of shoe last bottom surface Lsln are determined according to the corresponding parameters of the foot Lfn by the formula [2, 4]:

$$Lsln = Lfn - Sh \quad (3)$$

Determining the Girths of the Shoe Last

The value of the ball girth and the girths in the closed vertical cross sections of the shoe last Vslg are determined according to the respective parameters of the foot Vfg using the formula [7]:

$$Vslg = Vfg.K + 2Tis \quad (4)$$

where Tis is the insole thickness; K is the coefficient, determined by the formula [2]:

$$K = 1 + (\Delta O1 + \Delta O2 - q)/Vb \quad (5)$$

where Vb is the ball girth of the foot, mm; ΔO1 is the average change in ball girth of the foot at the end of the day and with walking, ΔO1 is about 5 mm [2, 3]; ΔO2 is the mean change of patient's ball girth after 1 year. The results of the study for the feet of diabetic women showed that after 1 year, the foot size increased by 2.8 mm, or ΔO2 = 3 mm. Therefore, in this study, inheriting the research results [7] and using ΔO2 = 3 mm to design a shoe last for men with diabetes; q is the allowable reduction in foot circumference when compressing. Studies on the feet of diabetic patients [26-28] have concluded that there is poor blood circulation in the patient's feet, the skin of the feet is vulnerable to impact, compression, etc. Therefore, shoe uppers should not be pressed against the skin surface of diabetic patients' feet. This is similar to shoes for children's feet. That is, q = 0 mm should be used.

Thus, the value K = 1 + 8/Vb. With an average foot length of 244.5 mm, Vb = 241.0 mm, K = 1 + 8/241 = 1.033.

The heel cross girth of the shoe last or back length V4 may not take into account the thickness of the insole, calculated by the formula [2]:

$$V4 = Vh.K \quad (6)$$

where Vh is the heel cross girth of the foot.

Determining the Bottom Widths of the Shoe Last

Diabetic men's shoes are designed with a low heel, high and wide toe to ensure no compression on the foot similar to children's shoes. Therefore, the calculation of the bottom width parameters of the child's shoe last (for sizes 18-35) according to the AKA64-WMS system can be used for the shoe last of men with diabetes [4]. The ball width of last bottom R1 is 38% of the ball girth Vb. In which, the width of the medial side is 15% and the width of the lateral side is 23% from the longitudinal axis of the shoe last bottom surface. The heel width of last bottom R2 = 2/3*R1 + 2mm (7) and its waist width R3 = 0.80*R1 (8).

Determining the Thickness of the Shoe Last

The thickness of the shoe last is usually greater than the height or thickness of the foot. Minimum forepart height Csln of the last are determined by forefoot height Cfn and insole thickness. That is, Csln ≥ Cfn + Tis (9).

Toe Spring

For diabetic shoes use the last with a higher toe spring than that of the last for casual shoes. This creates favorable conditions for the foot when walking. The shoe has a big toe spring, increasing the rolling effect of the foot, reducing the bend in the ball joint area. The high toe spring will also help reduce pressure on the ball joint [29, 30]. So, in this study, the toe spring of the last for diabetic men was 20 mm, which is 5 mm higher than the typical shoe for healthy men [31].

Determining the Increments of the Parameters in the Shoe Last Size System

The increments of adjacent size parameters in the shoe last size system are similar to those for the foot parameter system (see Table 2). The increments of the shoe last parameters are rounded to 0.5 mm.

Table 2: Increments of diabetic men's foot parameters of adjacent sizes by length and by width rounded to 0.5 mm

Nº	Foot parameters	Regression [25]	Increments, mm by length*	Increments, mm by width**
1	Lmb	Lmb = 0.736Lf	5	0
2	Llb	Llb = 0.652Lf	4	0
3	L5toe	L5toe = 0.828Lf	5.5	0
4	Rb	Rb = 0.427Vb	2	4
5	Rh	Rh = 0.271Vb	1.5	3
6	C1toe	C1toe = 0.083Vb	0.5	1
7	Cmb	Cmb = 0.136Vb	1	1.5
8	Cw	Cw = 0.976Vb	5	10
9	Vins	Vins = 1.018Vb	5	10
10	Vh	Vh = 1.306Vb	6.5	13

** The increment between adjacent sizes by length according to the French shoe sizing system is 6.67 mm (rounded to 6.5 mm)*
*** The increment between adjacent sizes by width (ball girth) in this study is 10 mm.*

Method of Designing Shoe Last for Men with Diabetes

The design data is a shoe last size system for men with diabetes, using the parameters of the average size by length and width. After designing the medium-sized last, the full range of sizes by length and width will be graded.

The shoe last for men with diabetes was designed by modifying the basic standard shoe last of casual shoes for Vietnamese men, that had heel height 10 mm, addition P1 = 15 mm, P2 = 0, and P3 = 0 [31]. The parameters to be controlled in the shoe last size system are shown in Figure 3 and Table 3. A shoe last design software [3] was used to design and grade the lasts.

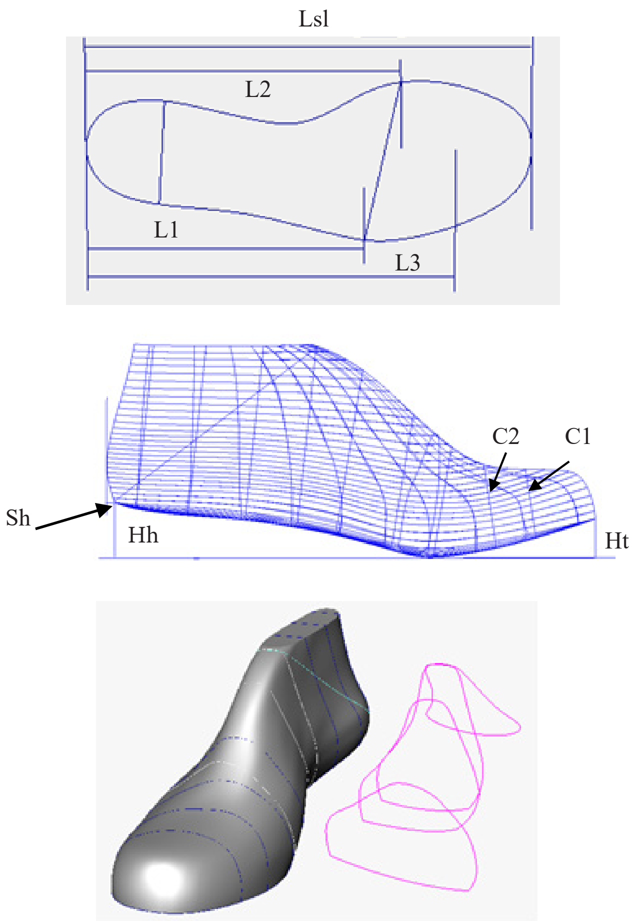

Figure 3. Shoe last parameters are controlled when designing the lasts of extra depth shoes for diabetic men using shoe last design software

The last 3D surface designed with shoe last design software [3] is transferred to the 3D multifunction printer ProJet MJP3600 Series for prototyping. The 3D printed last is the basis for correcting and perfecting its design.

RESULTS AND DISCUSSIONS

The Result of Building the Shoe Last Size System

Using formulas to convert foot data to shoe last parameters, taking into account the shoe requirements for diabetic patients, shoe last parameters for men with diabetes were determined. The results of the comparison of the last parameters for men with diabetes with that of the last for healthy men [31] are shown in Table 3.

Table 3: Comparison of shoe last parameters for men with diabetes with that of shoe last for healthy men (size 38)

№	Shoe-last parameters	Value		
		Men with diabetes, mm	Healthy men, mm	Difference, mm
1	Bottom length **Lsl***	254	≥ 253.5	-
2	Bottom length to medial ball $\mathbf{L_1}$	174.5	171	3.5
3	Bottom length to lateral ball $\mathbf{L_2}$	154	152	2
4	Bottom length to the end of 5th toe $\mathbf{L_3}$	197	190	7
5	Bottom ball width $\mathbf{R_1}$	92	87	5
6	Bottom heel width $\mathbf{R_2}$	63	60	3
7	Bottom waist width $\mathbf{R_3}$	74	70	4
8	Ball girth $\mathbf{V_1}$	259	239	20
9	Waist girth $\mathbf{V_2}$	253	237	16
10	Instep girth $\mathbf{V_3}$	263	246	17
11	Back length $\mathbf{V_4}$	337	310	27
12	Toe thick $\mathbf{C_1}$	≥ 25	24	≥ 1
13	Medial ball thick $\mathbf{C_2}$	≥ 38	38	-
14	Toe spring **Ht**	20	15	5
15	Heel height **Hh**	10	20	-10
16	Heel shift **Sh**	5.5	6	-0.5
17	Sock thick **Tis**	≥ 5	3	≥ 2

* The foot length of a diabetic man is 244.5 mm, and that of a healthy man's foot is 245 mm.

The results in Table 3 show that, except for the bottom length, the remaining parameters of shoe last for men with diabetes are larger than those of the shoe last for healthy men. Especially the ball girth and ball width differ by up to 20 mm and 5 mm, respectively. This confirms the need to develop a sizing system and design the lasts of extra depth shoes for men with diabetes. The causes of the difference in parameters are: 1) the foot circumference and width of diabetic men are larger than that of healthy men's feet; 2) shoes for diabetics using insoles of greater thickness; and 3) shoes should not compress the patient's foot.

Using the increments of the parameters for adjacent sizes by length and width (see Table 2), a shoe last size system with 5 sizes has been developed according to the bottom surface length from 241 mm to 267 mm, respectively sizes from 36-40 by the French system. Each size by length has 3 sizes by width (A1-A3), with 10 mm increments. With the same sizes by length, the length parameters of the shoe last (Lsl, L1, L2, L3) and Ht, Hh, Sh, Tis of the 3 sizes by width are unchanged, only its girth and width parameters are changed (Table 4).

Table 4: Values of the last parameters of extra depth shoes for men with diabetes in 3 sizes by width

Nº	Shoe-last parameters	Shoe-last size 36			37			38			39			40		
		A1	**A2**	A3	A1	**A2**	A3	A1	**A2**	A3	A1	**A2**	A3	A1	**A2**	A3
1	Bottom length **Lsl**	241	241	241	247.5	247.5	247.5	254	254	254	260.5	260.5	260.5	267	267	267
2	Bottom length to medial ball $\mathbf{L_1}$	164.5	164.5	164.5	169.5	169.5	169.5	174.5	174.5	174.5	179.5	179.5	179.5	184.5	184.5	184.5
3	Bottom length to lateral ball $\mathbf{L_2}$	146	146	146	150	150	150	154	154	154	158	158	158	162	162	162
4	Bottom length to the end of 5th toe $\mathbf{L_3}$	186	186	186	191.5	191.5	191.5	197	197	197	202.5	202.5	202.5	208	208	208
5	Bottom ball width $\mathbf{R_1}$	84	88	92	86	90	94	88	92	96	90	94	98	92	96	100
6	Bottom heel width $\mathbf{R_2}$	57	60	63	58.5	61.5	64.5	60	63	66	61.5	64.5	67.5	63	66	69
7	Bottom waist width $\mathbf{R_3}$	67.5	71	74.5	69	72.5	76	70.5	74	77.5	72	75.5	79	73.5	77	80.5
8	Ball girth $\mathbf{V_1}$	239	249	259	244	254	264	249	259	269	254	264	274	259	269	279
9	Waist girth $\mathbf{V_2}$	233	243	253	238	248	258	243	253	263	248	258	268	253	263	273
10	Instep girth $\mathbf{V_3}$	243	253	263	248	258	268	253	263	273	258	268	278	263	273	283
11	Back length $\mathbf{V_4}$	311	324	337	317.5	330.5	343.5	324	337	350	330.5	343.5	356.5	337	350	363
12	Toe thick $\mathbf{C_1}$	23	24	25	23.5	24.5	25.5	24	25	26	24.5	25.5	26.5	25	26	27
13	Medial ball thick $\mathbf{C_2}$	34.5	36	37.5	35.5	37	38.5	36.5	38	39.5	37.5	39	40.5	38.5	40	41.5
14	Toe spring **Ht**	18	18	18	19	19	19	20	20	20	21	21	21	22	22	22
15	Heel height **Hh**	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
16	Heel shift **Sh**	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
17	Sock thick **Tis**	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5

Results of Shoe Design for Men with Diabetes

The 3D shoe last surface of the medium size (size 38) designed on shoe last design software [3] (Figure 4) has the dimensions that meet the last size system built in Table 4, and ensures its aesthetic.

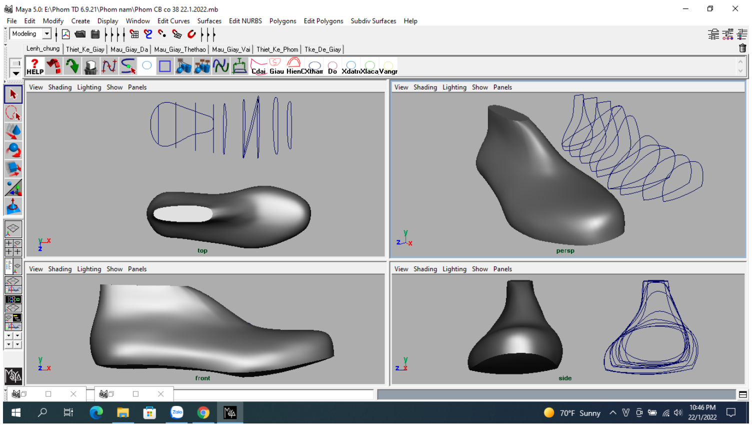

Figure 4. The designed 3D last surface of extra depth shoes for men with diabetes

The results of manufacturing the shoe last prototype on the 3D printer (Figure 5), using thermoplastic ABS, show that the designed last meets the requirements for shape and parameters as well as aesthetics. Its surface is smooth, transitions evenly between its regions.

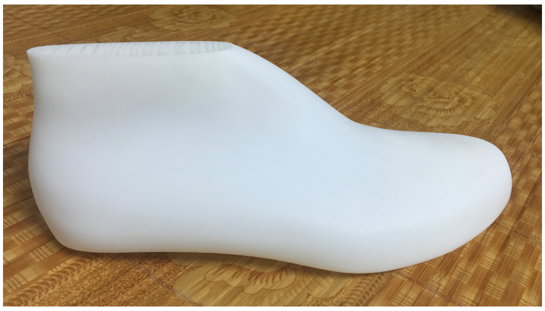

Figure 5. 3D printed shoe last prototype

Shoe last grading is performed with increments of 6.5 mm by length, 1.5 mm by ball width and 5 mm by ball girth. As a result, the 3D last surface data are obtained for the size range by length (Figure 6). It is possible to grade the shoe last by width sizes to get a full range of sizes for the design and production of extra depth shoes for men with diabetes.

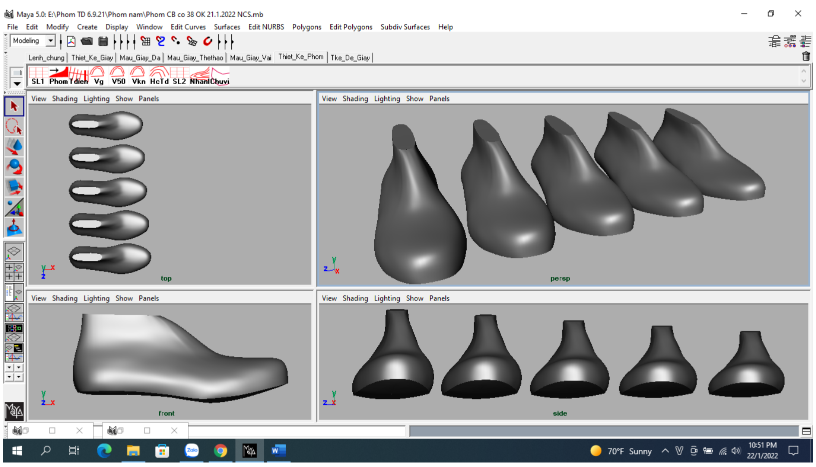

Figure 6. The size range by length of shoe last

CONCLUSIONS

This study has contributed to the establishment of procedures and methods for developing a sizing system and designing the lasts of extra depth shoes for diabetic patients. On the basis of the foot parameter system and the requirements of extra depth shoes for men with diabetes, the last size system has been built with 5 sizes by length (from size 36 to size 40 according to the French size system). Each size by length has 3 sizes by width with 10 mm increments. The shoe last parameters for men with diabetes are much larger than those for healthy men, especially its girth and width. The shoe last designed and fabricated in this study meets the requirements for shape and size, as well as aesthetics. This is the base for manufacturing shoe lasts and extra depth shoes that are suitable for the feet and requirements of men with diabetes in Vietnam.

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REFERENCES

1. Xiong, S., Zhao, J., Jiang, Z., Dong, M., A computer-aided design system for foot-feature-based shoe last customization, *Int J Adv Manuf Technol*, **2010**, 46, 11-19, https://doi.org/10.1007/s00170-009-2087-7.

2. Fukin, V.A., Huan, B.V., Development of the theory and methods of shoe-last design (in Russian), MGUDT Moscow, **2006**.

3. Huan, B.V., Establishing a method of receiving foot measurements and designing shoe-last using digital technology and informatics, PhD Thesis, MGUDT Moscow, **2006**.

4. Ma, X., Luximon, A., Part III Shoe lasts and other aspects of footwear manufacture (Design and manufacture of shoe lasts), in: Handbook of Footwear Design and Manufacture, Woodhead Publishing Limited, **2013**, 175-215.

5. Adrian, K.C., American Last Making: Procedures, Scale Comparisons, Sizing and Grading Information, Basic Shell Layout, Bottom Equipment Standards. Shoe Trades Publishing Co., **1991**.

6. Pivečka, J., Laure, S., The Shoe Last: Practical Handbook for Shoe Designers, International School of Modern Shoemaking, **1995**.

7. Cao, C.T.K., Bui, V.H., Research on establishing size system and designing shoe lasts for female diabetics in Vietnam, *JST: Engineering and Technology for Sustainable Development*, **2021**, 31, 1, 98-103, https://doi.org/10.51316/jst.148.etsd.2021.31.1.19.

8. Kochetkova, T.C., Kliuchnicova, B.M., Foot anthropometric and biomechanical bases for leather product design (in Russian), M. Light industry, **1991**, 190.

9. Bergin, S.M., Nube, V.L., Alford, J.B., Allard, B.P., Gurr, J.M., Holland, E.L., Horsley, M.W., Kamp, M.C., Lazzarini, P.A., Sinha, A.K., Warnock, J.T., Wraight, P.R., Australian Diabetes foot network: practical guideline on the provision of footwear for people with diabetes, *J Foot Ankle Res*, **2013**, 6, 6, 1-6, https://doi.org/10.1186/1757-1146-6-6.

10. Son, D.V., Research on the process of designing and manufacturing footwear for diabetics (in Vietnamese), Report on scientific research project of the Ministry of Industry and Trade of Vietnam, **2011**.

11. Meadows, M., Taking Care of your Feet, *FDA Consum*, **2006**, 40, 2, 16-24.

12. McInnes, A., Jeffcoate, W., Vileikyte, L., Game, F., Lucas, K., Higson, N., Stuart, L., Church, A., Scanlan, J., Anders, J., Foot care education in patients with diabetes at low risk of complications: a consensus statement, *Diabet Med*, **2011**, 28, 2, 162–167, https://doi.org/10.1111/j.1464-5491.2010.03206.x.

13. Nather, A., Signh, G., Diabetic Footwear: Current Status and Future Directions, *Diabetic Foot Problems*, **2008**, 527-539, https://doi.org/10.1142/9789812791535_0036.

14. Leng, J., A New Approach to Shoe Last Customization, The Chinese University of Hong Kong, A Master Thesis of Philosophy, **2006**, 94.

15. Wang, C.S., Chang, T.R., Lin, M.C., A Systematic Approach in Shoe Last Design for Human Feet, IEEE International Conference on Industrial Engineering and Engineering Management, **2008**, https://doi.org/10.1109/IEEM.2008.4738061.

16. Zhang, Y., Luximon, A., Pattanayak, A.K., Zhang, M., Shoe-last design exploration and customization, *J Textile Inst,* **2012**, 103, 5, 541–548, https://doi.org/10.1080/00405000.2011.589576.

17. Bernabéu, J.A., Germani, M., Mandolini, M., Mengoni, M., Nester, C., Preece, S., Raffaeli, R., CAD tools for designing shoe lasts for people with diabetes, *Comput Aided Des*, **2013**, 45, 6, 977-990, https://doi.org/10.1016/j.cad.2012.12.005.

18. Anggoro, P., Tauviqirrahman, M., Jamari, J., Bayuseno, A., Wibowo, J., Saputro, Y., Optimal Design and Fabrication of Shoe Lasts for Ankle Foot Orthotics for Patients with Diabetes, *Int J Manuf Mater Mech Eng*, **2019**, 9, 2, 62-80, https://doi.org/10.4018/IJMMME.2019040104.

19. Wang, C.-C., Yang, C.-H., Wang, C.-S., Xu, D., Huang, B.-S., Artificial neural networks in the selection of shoe lasts for people with mild diabetes, *Med Eng Phys*, **2019**, 64, 37-45, https://doi.org/10.1016/j.medengphy.2018.12.014.

20. Cao, C.T.K., Bui, V.H., Research on anthropometric characteristics of diabetic female feet in Hung Yen Vietnam (in Vietnamese), *Journal of Military Medicine and Pharmacy*, **2020**, 4, 32-37.

21. Cao, C.T.K., Bui, V.H., Research on building a size system for female diabetic feet in Vietnam (in Vietnamese), *Journal of Science and Technology of Technical Universities*, **2016**, 114, 88-94.

22. Cao, C.T.K., Bui, V.H., Research on examining the requirements for shoes for female diabetic in Vietnam, *Journal of Science and Technology of Hung Yen University of Technology and Education*, **2016**, 11, 96-101.

23. Cao, C.T.K., Bui, V.H., Research on making foot pressure measuring system and determining comfort pressure of shoe upper made from knitted fabric on the forefoot of the woman's foot, *Int J Psychosoc Rehabil*, **2020**, 24, 9, 3411-3423, https://doi.org/10.37200/IJPR/V24I9/PR290364.

24. Cao, C.T.K., Research on the use of textile materials in the design and manufacture of shoes for female diabetics in Vietnam, PhD Thesis, Hanoi University of Science and Technology, **2021**.

25. Bui, V.H., Cao, T.K.C., Nguyen, H.T., Phan, D.N., Le, T.X., Research on foot anthropometry of men with diabetes in Vietnam, *Leather and Footwear Journal*, **2022**, 22, 1, https://doi.org/10.24264/lfj.22.1.4.

26. Formosa, C., Gatt, A., Chockalingam, N., The importance of clinical biomechanical assessment of foot deformity and joint mobility in people living with type-2 diabetes within a primary care setting, *Prim Care Diabetes*, **2013**, 7, 45-50, https://doi.org/10.1016/j.pcd.2012.12.003.

27. Dalla Paola, L., Carone, A., Vasilache, L., Pattavina, M., Overview on diabetic foot: a dangerous, but still orphan, disease, *Eur Heart J Suppl,* **2015**, 17 (suppl A), 64-68, https://doi.org/10.1093/eurheartj/suv023.

28. Andrew, J.M., Boulton, M.D., The Pathway to Foot Ulceration in Diabetes, *Med Clin North Am*, **2013**, 97, 5, 775-790, https://doi.org/10.1016/j.mcna.2013.03.007.

29. Zamosky, I., Shoe Modifications in lower-extremity orthotics, *Bulletin of Prosthetics Research-Fall*, **1964**, 95.

30. Janisse, D.J., Janisse, E., Shoe Modification and the Use of Orthoses in the Treatment of Foot and Ankle Pathology, *J Am Acad Orthop Surg*, **2008**, 16, 3, 152-258, https://doi.org/10.5435/00124635-200803000-00006.

31. Bui, V.H., Hong, H.T., Research on building sizing systems and designing shoe-lasts for Vietnamese men based on foot measurements, Proceedings of the 2nd National Scientific Conference on Textiles and Leather (NSCTEX2020), **2020**, 43-52.