A new methodology for the development of sizing systems for the mass customization of garments

Maria L. Mpampa, Philip N. Azariadis and Nickolas S. Sapidis
Department of Product and Systems Design Engineering, University of the Aegean, Ermoupolis, Greece

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Abstract

Purpose – The purpose of this paper is to derive a new method for developing sizing systems for the mass customization of garments.

Design/methodology/approach – A range of recently published works has been studied. A new method is derived by following a basic statistical analysis on anthropometric data which are supported by an iterative mass customization model and introduced "satisfaction performance" indices. The derived method is applied successfully to an anthropometric data consisting of 12,810 Greek men.

Findings – With the proposed method, it is possible to control the degree of mass customization and the corresponding number of garment sizes. Under this way, a balance between the number of sizes (in other words: production cost) and the percentage satisfaction of consumers can be achieved. The proposed method consists of six subsequent tasks which are applied to the target population data for the development of mass customization models for male shirts, coats and trousers.

Research limitations/implications – Future work could be focused on the development of methods for the automatic garments grading with respect to the proposed mass customization models and practise.

Originality/value – The methodology presented in this paper can be applied to the development of mass customization models for other categories of garments and target population.

Keywords Garment industry, Human anatomy, Mass customization

Paper type Research paper

1. Introduction

Garments are manufactured massively using predefined size charts which allow for the reduction of production cost. It is, therefore, practically impossible to obtain a perfect fit between a piece of cloth and an individual buyer (Kotha, 1995; Pine, 1993). Owing to their low cost, *prêt-a-porter* garments are dominating the modern markets, while partial individualization is achieved using sizing systems with normalized dimensions. Under this way, absolute individualization is sacrificed to the benefit of production economy (Fralix, 2000; Walter, 2006).

The concept of mass customization is devised to serve the individualized needs of consumers and increase their satisfaction percentage (Anderson *et al.*, 1999). This term implies a strategy for producing customized garments with maximum differentiation through a low-cost production process (Davis, 1987). Nowadays, this manufacturing model is enabled by modern information technologies, computer-aided design and manufacture systems, three-dimensional (3D) body scanners, interactive web-based

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applications, etc. (Ashdown and Delong, 1995; Salusso-Deonier, 1989; Gazzuolo *et al.*, 1992). From the manufacturers' point of view, there is an apparent trend on producing individualized garments with the greatest possible differentiation without affecting the production cost (DeLong *et al.*, 1993).

However, the relation between the size charts and body dimensions is not constant because of the changes that occur in the human population. Recent body surveys in Germany proved that a garment sizing system for a certain body type does not cover more than the 25 per cent of the population in which it is addressed (Lanenegger and van Osch, 2002; Walter, 2002). Hence, body measurements should be updated regularly in order to provide current information on essential sizes and their geographical distribution in the population (Istook *et al.*, 2003).

Consequently, for a successful garment mass customization model, the development and maintenance of up-to-date anthropometric databases of the target market population is essential (Salusso-Deonier, 1982; LaBat and Delong, 1990; Workman, 1991; Goldsberry *et al.*, 1996; Ashdown, 1998). Such an approach necessitates the existence of a proper methodology for producing sizing systems (which are not proportionally graded) with respect to a target population and the corresponding garments type(s). These sizing systems should satisfy the majority of the target population and at the same time should imply a cost-effective and affordable production process by the garment manufacturer (Fralix, 2000; Walter, 2006).

In the present work, a new methodology for the development of effective sizing systems is proposed, aiming at the introduction of mass customization in the manufacturing process of a garment company. With the proposed methodology one is able to derive a sizing system appropriate for a particular group of people (i.e. children, elderly, solders, etc.). The effectiveness of the proposed methodology is illustrated by applying it to the development of size charts for a target population consisting of 12,180 Greek men between 20 and 30 years old. With the obtained charts, we were able to produce garments that satisfy up to 92.4 per cent of the population.

In the next section, we introduce the main methodology for producing sizing systems with respect to a specific target population and garment type, and with a variable degree of mass customization. Sections 3 and 4 present an application of the new methodology for producing certain garments for a Greek population consisting of 12,810 men. Finally, Section 5 concludes the paper giving also some remarks for future work.

2. The proposed methodology for the development of sizing systems

2.1 Review of existing works and main definitions

One early empirical sizing system, the CS 215-58 Standard, was developed in the USA in 1958 based on the manufacturers' experience. In 1970, another empirical sizing system, the PS 42-70 Standard of the USA, was developed using military anthropometrical data and a "trial-and-error" approach. Both sizing systems were based on out-of-date measurements taken at 1941 (Ashdown, 1998). Later, the development of new anthropometric databases demanded the classification of human bodies under various body types. This classification was achieved by Salusso-Deonier (1982) through a method called as "Principal component sizing system (PCSS)". Soon after, Tryfos (1986) proposed another method based on the "integer programming" approach in order to minimize the number of the different sizes in a size chart. This method attempts to optimise an objective function (or indicator) named as the "aggregate loss of fit" which measures the difference between real body dimensions and the produced size charts.

In 1994, the American Society for Testing and Materials (ASTM) developed the ASTM D5585-94 Standard of the USA utilizing the experience of garment designers and market information. This sizing system was validated using US army and navy anthropometrical data. Ashdown (1998) and McCulloch *et al.* (1998) focused on the development of sizing systems more satisfactory than the ASTM D5585-94 using the "aggregate loss of fit" indicator in combination with the PCSS method. Gupta and Gangadhar (2004) proposed a "statistical" method for the minimisation of the "aggregate loss of fit" indicator with respect to the population's body-type distribution. These models, however, were not developed with respect to the mass-customisation concept but to support the mass production of garments.

Loker *et al.* (2005) describe a variety of size-specific statistical and visual analysis methods than can be applied to market body scan data to improve the apparel fit of a sizing system. They apply their method to modify an existing sizing system of a garments company. Finally, Hsu and Wang (2005) use a decision tree-based data-mining approach to establish a sizing system for the manufacture of garments, which allows for a wider coverage of body shapes with a fewer number of sizes and generates regular sizing patterns and rules. Their method is specialised for men's pants.

In this paper, we adopt two definitions originated in Lanenegger and van Osch (2002) for the characterization of garment dimensions. These definitions will be referred later by using the terms constraints A and B:

- *Definition 1 (constraint A).* A dimension is called as primary when it plays an essential role in assessing when a garment is wearable by a consumer or not. In other worlds, a primary dimension tells when a piece of garment is able to cover the entire body of a consumer or not.
- *Definition 2 (constraint B).* A dimension is called as secondary when it plays an essential role in assessing a garment's fitting. In other words, a secondary dimension measures how a piece of garment (that fulfils constraint A) fits in a consumer's body.

Both constraints A and B are mentioned in the present paper as manufacturing constraints and vary with respect to the garment's type (i.e. upper/lower body clothing, etc.). The purpose of the introduced method is to provide a feasible mass customization model for a particular target group and a garment type, which will be also called as related garment.

The chest girth, waist girth and height are commonly used for the manufacture of the upper body garments. The neck girth and sleeve/arm length are commonly used for the manufacture of shirts. The waist girth and inside leg length are commonly used for the manufacture of lower body garments. In the methodology proposed in this paper, a set of body measurements (linear dimensions of height, inside leg length, sleeve/arm length, and girth dimensions of chest, neck and waist) of a target population is analyzed producing primary and secondary sizes that correspond to the primary and secondary dimensions of the related garment(s), respectively. The input body measurements should comply with the manufacturing constraints of the related garment(s). Then a sizing system is derived with the minimum number of different garment sizes according to a chosen mass customization model. Consumers' satisfaction is assessed with a new tool that is proposed in this paper.

2.2 The proposed mass customization methodology

The overall methodology consists of six subsequent stages, which are shown in Figure 1 and are detailed in the following paragraphs.

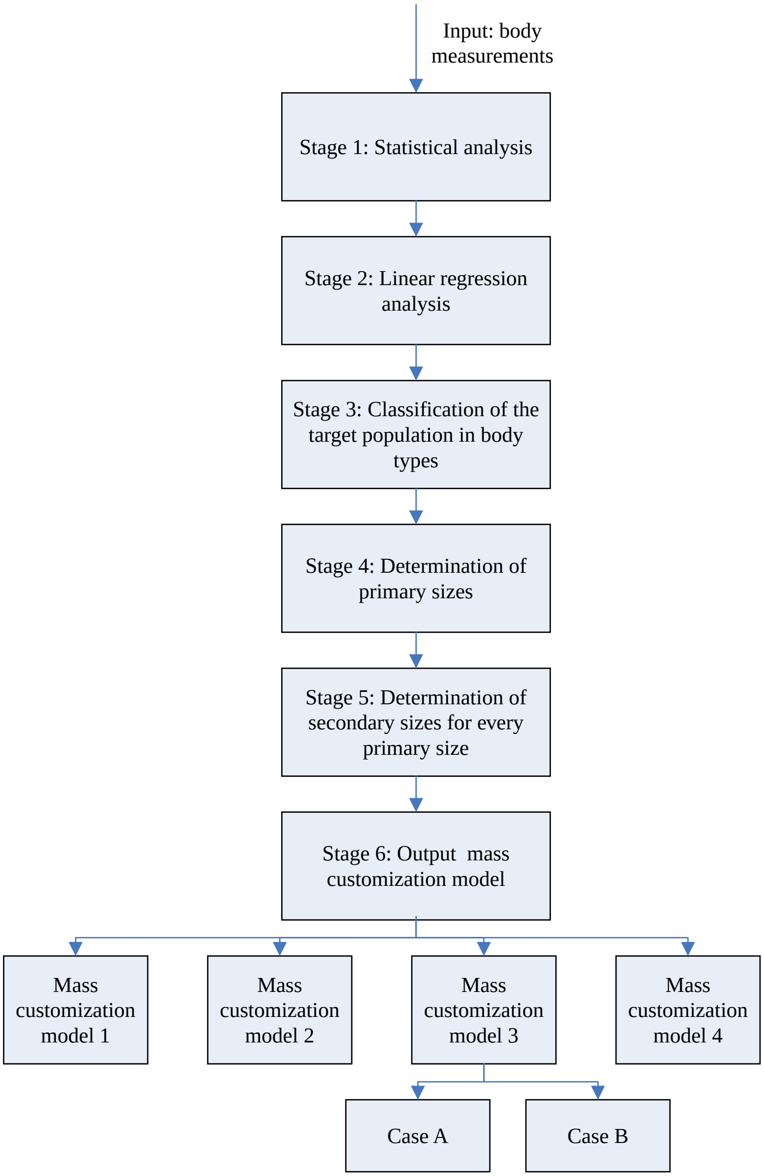

Figure 1. The flow chart of the proposed mass customization methodology

Stage 1: statistical analysis of body data. A statistical analysis of body measurements takes place in order to determine the range of the various body dimensions. This analysis includes the calculation of the minimum (Min), maximum (Max) and mean value (Mean) as well as the standard deviation (SD) for every distinct set of body measurements.

Stage 2: linear regression analysis. Using the least squares linear regression analysis technique, the correlation between different body dimensions is determined. In this way, one is able to distinguish the primary from the secondary dimensions of the sizing system; essential information for the manufacture of garment patterns (Robertson and Minter, 1996; Jarosz, 1999; Barroso *et al.*, 2005).

Generally, in this method, the selection of the primary and secondary dimensions is performed with respect to Constraints A and B in order to ensure that the produced sizing system will comply with the manufacturing constraints of the related garment and with the specific body measurements of the target population. This selection is facilitated using the correlation coefficient R. According to the BS 7231 Standard (BS 7231, 1990) two dimensions are related according to the following rules: if the correlation coefficient $R < 0.5$, then no relationship exists; if $0.5 < R < 0.75$, then there is a mild relationship; if $R > 0.76$, then a strong relationship exists. Using R, it is possible to reduce the number of independent measurements by removing those which exhibit a strong correlation along the primary and secondary dimensions.

Stage 3: classification of the target population in body types. The purpose of this stage is to classify the target population in body shapes according to the body measurements of each subject. The classification is performed utilizing:

- the height dimension; and
- the "drop value" DV = [(Chest girth) − (Waist girth)] (Cooklin, 1999; Gupta and Gangadhar, 2004).

The "drop value" parameter is used to classify the different body shapes of the target population by determining distinct relationships between key dimensions (Cooklin, 1999; prEN 13402-3, 2004). Based on drop values, the population is classified into categories which correspond to generally perceived body shapes.

In this stage, we separate the target population in six body types according to their height (Table I) and in seven body types with respect to their drop value (Table II). This partition will allow of a sizing system covering a large range of different body shapes.

Stage 4: determination of primary sizes. The determination of the primary dimension depends on the garment type and Constraint A. Therefore, using the results

Body type	Height (cm)
Very short < Mean − 2SD	< 164
Mean − 2SD < Short < Mean − SD	164-171
Mean − SD < Normal < Mean	171-178
Mean < Tall < Mean + SD	178-185
Mean + SD < Very tall < Mean + 2SD	185-192
Too much tall > Mean + 2SD	192 >

Table I.
Classification of the population vs height

of stage 2 analysis, we are able to associate a body dimension with the primary dimension that is used for the manufacture of the related garment. In this way, the target population is classified in primary sizes derived along the selected primary dimension.

In Gupta and Gangadhar (2004), the primary size ranges between [(Mean − SD), (Mean + SD)]. In this paper, we chose a larger range between [(Mean − 2SD), (Mean + 2SD)], in order to take into account a greater part of the population (>95 per cent). This choice, however, does not necessarily affect the final number of the produced garment sizes, since in the proposed method one is able to select the degree of mass customization.

A threshold δ is determined afterwards in order to define the difference between two successive primary sizes x_k, x_{k+1}. In this way, the obtained sizing system satisfies Constraint A as long as the corresponding part of the population lies within the interval [Mean − 2SD, Mean + 2SD]. The resulted number of primary sizes is:

$$n = \frac{(\text{Mean} + 2\text{SD}) - (\text{Mean} - 2\text{SD})}{\delta} = \frac{4\text{SD}}{\delta} \quad (1)$$

Although the development of a sizing system can be based either on a constant or a variable δ (McCulloch *et al.*, 1998), in the proposed method, a constant δ is selected for compatibility with the prEN 13402-3 (2004) standard. The effectiveness of this particular selection is verified by the application of the proposed method in recent anthropometric data.

Stage 5: determination of secondary sizes for every primary size. For every primary size, a set of secondary sizes is developed according to the type of garment and Constraint B. Similarly to the primary dimension, the secondary dimension lies also within [Mean − 2SD, Mean + 2SD] and the number of obtained secondary sizes n is calculated through equation (1). All secondary sizes are grouped together into two-dimensional tables with respect to the selected primary dimension and are utilized for the development of the required sizing system.

Stage 6: selection of a mass customization model. Each mass customization model defines a sizing system that starts with the "medium body shape" (according to Stage 3) and proceeds to covering "neighboring body shapes" according to this model. Each model depends on the desired mass customization degree which is iteratively improved in sequential steps. For each obtained mass customization model, a sizing system is developed according to the following scheme:

(1) *Step 0: mass production.* Development of medium sizes (primary sizes) only, which are traditionally used for the mass production of *prêt-a-porter* garments.

Table II.
Classification of population according to the "drop value"

Body type	Difference of chest – waist girth (cm)
Very small	>18
Small	14-18
Medium	10-14
Full	6-10
Large	2-6
Extra large	−2 to 2
Very extra large	< −2

(2) *Step 1: mass customization model 1.* Development of two secondary sizes for every primary size according to the first secondary dimension.

(3) *Step 2: mass customization model 2.* Development of eight secondary sizes for each primary size according to the first and second secondary dimensions. This model is valid for garments with two secondary dimensions.

(4) *Step 3: mass customization model 3*:

- *Case A (only one secondary dimension exists).* Development of four secondary sizes for every primary size according to the secondary dimension.
- *Case B (at least two secondary dimensions exist).* Development of up to 25 sizes along the two secondary dimensions for every primary size. These sizes are produced for the two body categories which are "before" and "after" the medium body shape.

(5) *Step 4: mass customization model 4.* Development of all possible sizes for every primary and secondary dimension. This model corresponds to a sizing system with the maximum population satisfaction and the larger number of different garment sizes. This is the best possible degree of mass customization for a particular target population. Our experiments show that the resulted garments fit to the 99.9 per cent of the target population.

The selection of a mass customization model is facilitated using a new assessment tool called as "Total satisfaction percentage." The new index is based on the value of "satisfaction percentage" according to the following definitions.

Definition 3 ("satisfaction percentage"). For each size k of the sizing system of a given mass customization model j, and for each garment type i, the satisfaction percentage a_{ijk} of the target population is equal to the percentage of the target population that its three characteristic (one primary and two secondary) body dimensions (x_i, y_i, z_i) fall within the corresponding garment sizes (x_{ik}, y_{ik}, z_{ik}) up to a maximum tolerance value ($\Delta x_{i,\max}$, $\Delta y_{i,\max}$, $\Delta z_{i,\max}$), i.e. $|x_i - x_{ik}| \leq \Delta x_{i,\max}$, $|y_i - y_{ik}| \leq \Delta y_{i,\max}$, $|z_i - z_{ik}| \leq \Delta z_{i,\max}$. Here:

$$(\Delta x_{i,\max}, \Delta y_{i,\max}, \Delta z_{i,\max}) = \frac{1}{2}(\delta_p, \delta_{s1}, \delta_{s2}),$$

where δ_p, δ_{s1}, δ_{s2} correspond to the constant difference between two successive values of the primary dimension, and the first and second secondary dimensions, respectively.

Definition 4 ("total satisfaction percentage"). The "Total satisfaction percentage" a_{ij} of a target population with respect to a given garment type i and a mass customization model j is calculated by:

$$\acute{a}_{ij} = \sum_{k=1}^{n} \alpha_{ijk} \tag{2}$$

Contrarily to existing approaches (see, e.g. the "aggregate loss" of fit (Tryfos, 1986; McCulloch *et al.*, 1998; Gupta and Gangadhar, 2004)) the proposed indicator is able to measure the degree (or percentage) to which a certain sizing system "satisfies" the target population. On the other hand, the "aggregate loss" index simply expresses the average Euclidean distance between the dimensions of individuals and their allocated garment size. Therefore, the proposed index is able to assist a garment manufacturer to select the mass customization model that is most appropriate for its production process and market pursues.

3. Application of the proposed methodology for the development of mass customization models for a Greek-men population

The proposed methodology is applied to anthropometric data that correspond to 12,180 Greek men from the entire country aging between 20 and 30 years old. Six basic body dimensions were measured the time period between 2003 and 2004 by the traditional technique. These include the linear dimensions height, inside leg length, sleeve/arm length and the girth dimensions of chest, neck and waist.

The purpose of this application is to derive mass customization models for the production of men:

- shirts;
- garments of the upper body (excluding shirts and underwear); and
- garments for the lower body.

In order to avoid redundant analysis, this section presents the first five stages of the application of the proposed method, while Section 4 summarizes the different mass customization models according to stage 6.

3.1 Stage 1: statistical analysis of body data

The results of the statistical analysis of the six body dimensions of the 12,180 individuals are listed in Table III. The mean values (Mean) express the body dimensions of the "average" 20-30 years old Greek man.

3.2 Stage 2: linear regression analysis

For each pair of body dimensions, the linear regression correlation coefficient R is calculated in order to determine the body dimensions that will be utilized for satisfying constraints A and B with respect to the related garment type. Table IV summarizes the results of this analysis.

According to Table IV, there is a strong relationship ($R = 0.9948$) between the chest and waist girth as it is also shown in Figure 2. For clarity reasons, the diagram points (rhombs) depict the mean value of the waist girths that correspond to a certain chest-girth value.

Similarly, the chest girth vs the neck girth has very strong relationship, while there is a mild relationship between the chest girth and the height. There is no strong relationship between the waist girth and linear dimensions. The height has strong relationship with the linear dimensions sleeve and inside leg length.

Table III. The results of the statistical analysis of the six body dimensions of the target population

Dimension	Mean	SD	Min	Max	Mean − SD	Mean + SD	Mean − 2SD	Mean + 2SD
Height	178	7	154	208	171	185	164	192
Chest girth	96.7	8.7	82	137	88	106	80	114
Waist girth	88.3	10.8	70	135	77	99	67	110
Neck girth	38.8	2.5	34	51	36	41	34	44
Inside leg length	80	5	65	117	75	85	69	90
Sleeve length	61.3	3	54	71	58	64	56	67

Summarizing, there is a strong linear correlation within length and girth dimensions, but there is no linear correlation between length and girth dimensions. This is an important observation since most empirical size diagrams are based on a linear increment of the sizing systems. In other words, it is mistakenly supposed that when the girth body size is increased, the height size is increased, respectively. Because of this issue, existing sizing systems result to clothes which are suitable to a limited percentage of the target population (Ashdown, 1998; Lanenegger and van Osch, 2002).

Based on the above, the chest girth is selected as the primary dimension for upper body garments, while the neck girth is chosen as the primary dimension for the case of shirts. Also, the waist girth is considered as the primary dimension for the development of lower body garments. The rest of the dimensions like the height, sleeve or leg length will be selected as secondary dimensions with respect to one of the related garment types.

3.3 Stage 3: classification of the population in body types

3.3.1 Population vs height. The resulted classification of the target population is depicted in Table V. The population is divided into six categories with respect to the height dimension.

Dimension	Height	Chest girth	Waist girth	Neck girth
Height	*1.0000*	*0.7875*	0.7024	0.7543
Chest girth	0.6354	*1.0000*	*0.9928*	*0.9634*
Waist girth	0.6740	*0.9948*	*1.0000*	*0.9700*
Neck girth	0.3886	*0.9866*	*0.9712*	*1.0000*
Inside leg length	*0.9802*	0.0387	0.2131	0.4704
Sleeve length	*0.9927*	*0.8531*	0.7664	0.7671

Table IV. Correlation coefficient *R* of the body dimensions

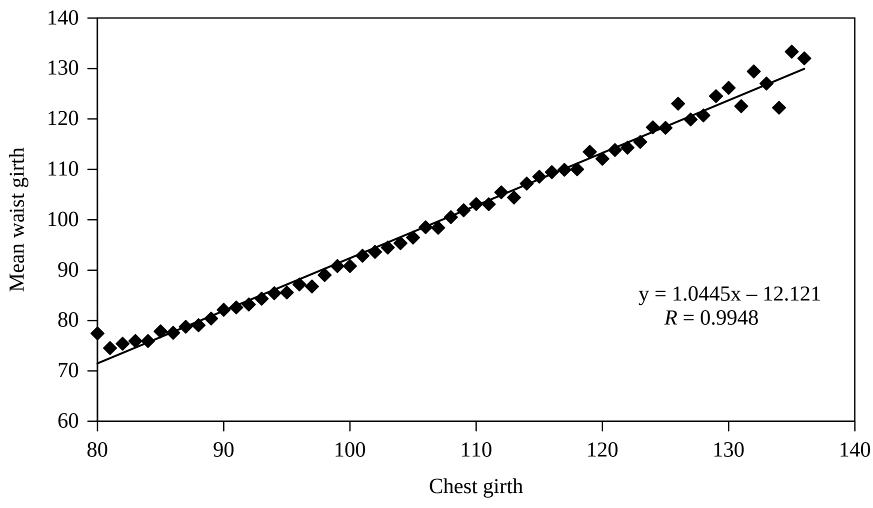

Figure 2. Correlation of chest girth vs mean waist girth

3.3.2 Population vs "drop value". The resulted classification of the target population according to the drop value is listed in Table VI. Based on this analysis, it results that a large part of Greek male population has greater waist girth compared to the "medium" body type and it is categorized under the "full" body type. Thus, the difference between chest and waist girth for the major percentage of the population equals to 8 cm.

3.4 Stage 4: determination of primary sizes

In this stage, the target population is classified in sizes according to the chosen primary dimension. More specifically:

- the chest girth is selected for the manufacture of the upper body garments;
- the neck girth is selected for the manufacture of shirts; and
- the waist girth is selected for the manufacture of lower body garments.

The chest girth dimension is subdivided setting by $\delta = 4$ cm between two successive sizes according to the EN Standard (prEN 13402-3, 2004). This results to eight discrete sizes ($n = 8$) in the range between 82 and 114 cm. Similarly, the neck girth dimension is subdivided according to $\delta = 1$ cm resulting to ten discrete sizes ($n = 10$) in the range between 34 and 44 cm. Finally, the waist girth is divided into sizes according to $\delta = 4$ cm, which results to ten discrete sizes ($n = 10$) in the range between 70 and 110 cm.

3.5 Stage 5: determination of secondary sizes for every primary size

3.5.1 Upper body garments (excluding shirts and underwear). For upper body garments (excluding shirts and underwear), the primary dimension is the chest girth and the secondary dimensions are the waist girth and the height. Both secondary dimensions lie within Mean − 2SD and Mean + 2SD. For example, for chest girth size 90-94, five waist girth sizes are developed ($\delta = 4$) which correspond to individuals belonging to

Table V. Classification of the population vs height

Body type	Height	Population	Percentage
Very short < Mean − 2SD	< 164	240	2.0
Mean − 2SD < Short < Mean − SD	164-171	2,040	16.7
Mean − SD < Normal < Mean	171-178	4,568	37.5
Mean < Tall < Mean + SD	178-185	3,978	32.7
Mean + SD < Very tall < Mean + 2SD	185-192	1,143	9.4
Too much tall > Mean + 2SD	192 >	211	1.7

Table VI. Classification of the target population according to the drop value

Body type	Difference of chest − waist girth (cm)	Population	%
Very small	> 18	550	5
Small	14-18	1,302	11
Medium	10-14	2,707	22
Full	6-10	3,243	27
Large	2-6	2,313	19
Extra large	− 2 to 2	1,333	11
Very extra large	< − 2	732	6

the Medium body type. This distribution is depicted with the 3D graph shown in Figure 3.

Introducing the height as the second secondary dimension four more sizes are developed for every primary and first secondary size as it is shown in Table VII for chest girth size between 90 and 94 cm. These four height sizes correspond to the short, normal, tall and very tall body types.

3.5.2 Male shirts. The primary dimension for male shirts is neck girth and the secondary dimension is sleeve length. The secondary dimension lies within Mean − 2SD and Mean + 2SD. For example, for neck size 38, six sleeve length sizes are developed ($\delta = 2$) which correspond to individuals belonging to the Medium body type. This distribution is depicted with the 3D graph shown in Figure 4.

3.5.3 Lower body male garments. For lower body male garments like the trousers, the primary dimension is the waist girth and the secondary dimension is the inside leg length. The secondary dimension lies within Mean − 2SD and Mean + 2SD. For example, for waist girth size 74-78, six inside leg length sizes are developed ($\delta = 3$) which correspond to individuals belonging to the Medium body type. This distribution is depicted with the 3D graph shown in Figure 5.

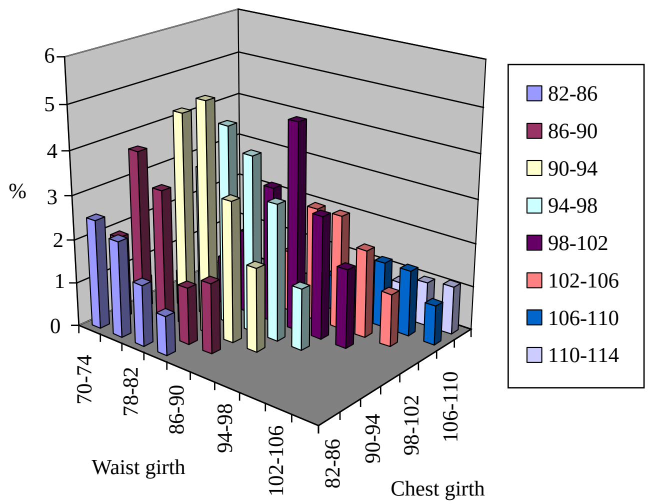

Figure 3.
3D representation of the sizes produced according to the chest (primary dimension) and the waist girth (secondary dimension)

Table VII.
Sizes for upper body men garments (excluding shirts and underwear) and corresponding population percentages for chest girth size between 90 and 94 cm

		Height (per cent)				
Chest girth	Waist girth	164-171	171-178	178-185	185-192	Total
90-94	74-78	0.60	1.20	0.70	0.10	2.60
	78-82	0.90	2.00	1.50	0.30	4.70
	82-86	1.00	2.20	1.50	0.40	5.10
	86-90	0.50	1.30	1.00	0.30	3.10
	90-94	0.40	0.70	0.70	0.10	1.90
Total		3.40	7.40	5.40	1.20	17.40

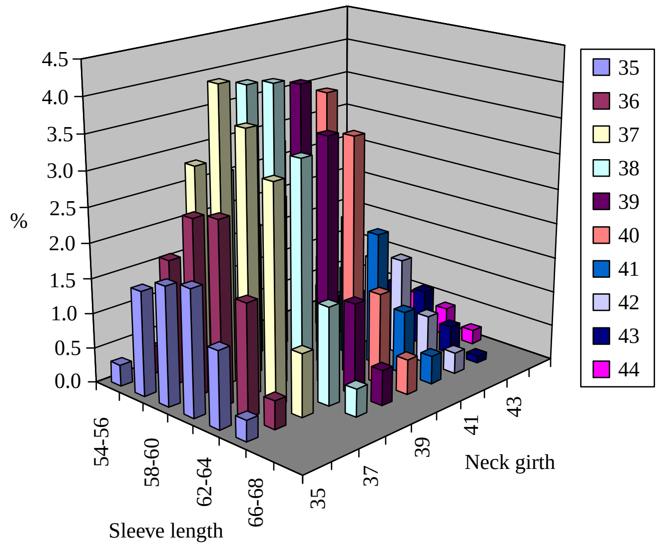

Figure 4.
3D representation of the sizes derived according to the neck (primary dimension) and sleeve length (secondary dimension)

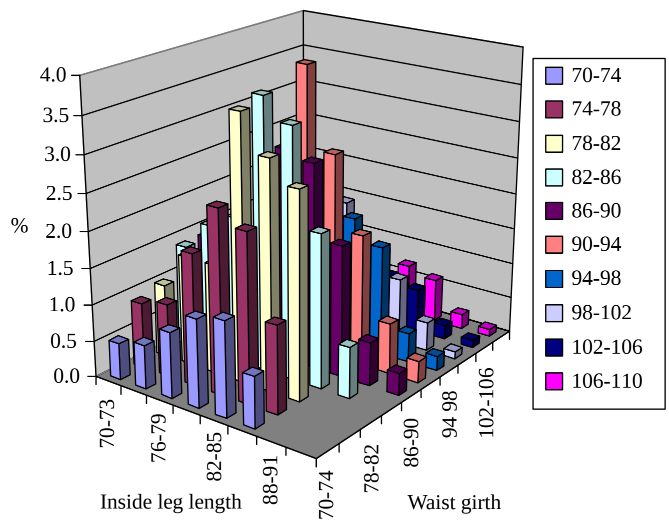

Figure 5.
3D representation of the sizes derived according to the waist girth (primary dimension) and the inside leg length (secondary dimension)

4. Mass customization models for the Greek men population: application of stage 6 of the new methodology

The mass customization models presented in section 2 are applied to the following categories of male garments:

- shirts;
- coats; and
- trousers.

Mass production for *prêt-à-porter* garments correspond to conventional sizing systems. The rest sizing systems presented below correspond to the mass customization models 1-4.

4.1 Sizing systems for male shirts

Ten medium sizes are proposed according to the mass production model of *prêt-a-porter* shirts. The medium sizes correspond to sleeve length 60-62 cm (Table VIII):

- According to mass customization model 1, 30 sizes are developed based on the sleeve length: ten for sleeve length 58-60 cm and ten for sleeve length 62-64 cm.
- Mass customization model 2 is not applicable in this case because there is not a need to use a second secondary dimension.
- Mass customization model 3 implies the development of 50 sizes: four more sizes based on the secondary dimension are developed for each medium size. Hence, ten more sizes are produced for sleeve length 56-58 cm, and ten for sleeve length 64-66 cm.
- Mass customization model 4 implies the development of 59 sizes, which provides a comprehensive degree of mass customization for male shirts.

4.2 Sizing systems for male coats

Utilizing the chest and waist girth as well as height data of the target population, three mass customization models are developed for male coats. However, the obtained sizing systems can be regarded as general sizing systems for producing male upper garments excluding shirts and underwear. All results are summarized in Table IX, where for spacing reasons, we have omitted the sizes which correspond to chest girths between 94 and 110 cm:

- According to mass production model, eight medium sizes based on the chest girth are produced. These regular sizes correspond to the waist girth and height of body type B (Medium).
- According to mass customization model 1, 23 sizes are developed using the waist girth as secondary dimension. Seven sizes for body type A (small), eight for body type B (medium) and eight for body type C (full).

			Neck girth									
			0	1	2	3	4	5	6	7	8	9
Sleeve length			35	36	37	38	39	40	41	42	43	44
A	55	54-56	0A	1A	2A							
B	57	56-58	0B	1B	2B	3B	4B	5B	6B	7B	8B	9B
C	59	58-60	0C	1C	2C	3C	4C	5C	6C	7C	8C	9C
D	61	60-62	0D	1D	2D	3D	4D	5D	6D	7D	8D	9D
E	63	62-64	0E	1E	2E	3E	4E	5E	6E	7E	8E	9E
F	65	64-66	0F	1F	2F	3F	4F	5F	6F	7F	8F	9F
G	67	66-68				3G	4G	5G	6G	7G	8G	
H	69	68-70										

Table VIII. Sizing system for male shirts

Chest girth	Body type	Waist girth	Height 1 (Short) 164-171	2 (Medium) 171-178	3 (Tall) 178-185	4 (Very tall) 185-192
1 (82-86)	A-Small					
	B-Medium	70-74	1B1	1B2	1B3	1B4
	C-Full	74-78	1C1	1C2	1C3	1C4
	D-Large	78-82	1D1	1D2	1D3	1D4
	E-Extra large	82-86	1E1	1E2	1E3	1E4
2 (86-90)	A-Small	70-74	2A1	2A2	2A3	2A4
	B-Medium	74-78	2B1	2B2	2B3	2B4
	C-Full	78-82	2C1	2C2	2C3	2C4
	D-Large	82-86	2D1	2D2	2D3	2D4
	E-Extra large	86-90	2E1	2E2	2E3	2E4
3 (90-94)	A-Small	74-78	3A1	3A2	3A3	3A4
	B-Medium	78-82	3B1	3B2	3B3	3B4
	C-Full	82-86	3C1	3C2	3C3	3C4
	D-Large	86-90	3D1	3D2	3D3	3D4
	E-Extra large	90-94	3E1	3E2	3E3	3E4
⋮						
8 (110-114)	A-Small	94-98	8A1	8A2	8A3	8A4
	B-Medium	98-102	8B1	8B2	8B3	8B4
	C-Full	102-106	8C1	8C2	8C3	8C4
	D-Large	106-110	8D1	8D2	8D3	8D4
	E-Extra large					

Table IX.
Sizing system for upper body men garments excluding shirts and underwear

- According to mass customization model 2, 69 sizes are developed using the waist girth and height as secondary dimensions. Eight more sizes are produced for every primary size compared to the mass production model.
- According to mass customization models 3 and 4, 152 sizes are developed using the waist girth and height as secondary dimensions. About 24 more sizes are produced for every primary size compared with the mass production model. In this case, mass customization model 4 results to the same sizing system with the third one.

4.3 Sizing systems for male trousers

Utilizing the waist girth and inside leg length, four mass customization models are developed for male trousers. All results are summarized in Table X:

- According to mass production model, ten medium sizes based on the waist girth are produced. These medium sizes correspond to the inside leg length 79-82 cm.
- According to mass customization model 1, 30 sizes are developed using the inside leg length as secondary dimension. About 20 more sizes than the mass production model are developed: ten for inside leg length 76-79 cm and ten for inside leg length 82-85 cm.
- Mass customization model 2 is not applicable in this case since there is not a need to use a second secondary dimension.
- According to mass customization model 3, 50 sizes are developed using the inside leg length. About 20 more sizes are developed compared to mass

Inside leg length			Waist girth									
			0	1	2	3	4	5	6	7	8	9
			72	76	80	84	88	92	96	100	104	108
			70-74	74-78	78-82	82-86	86-90	90-94	94-98	98-102	102-106	106-110
A	72	70-73	0A	1A	2A	3A	4A	5A	6A	7A	8A	9A
B	75	73-76	0B	1B	2B	3B	4B	5B	6B	7B	8B	9B
C	78	76-79	0C	1C	2C	3C	4C	5C	6C	7C	8C	9C
D	81	79-82	0D	1D	2D	3D	4D	5D	6D	7D	8D	9D
E	83	82-85	0E	1E	2E	3E	4E	5E	6E	7E	8E	9E
F	86	85-88	0F	1F	2F	3F	4F	5F	6F	7F	8F	9F
G	89	88-91				3G	4G	5G	6G	7G	8G	9G
H	92	91-93					4H	5H	6H	7H	8H	9H

Table X.
Sizing system for lower body men garments

customization model 2: ten for inside leg length 73-76 cm, and ten for inside leg length 85-88 cm.

- According to mass customization model 4, 73 sizes are developed. The produced sizing system satisfies 99.9 per cent of the target population.

4.4 Assessment of the developed sizing systems

Table XI shows the results of applying the proposed satisfaction percentage index for the assessment of the developed mass customization models for the three aforementioned garment types. In the case of mass production (model 0), the total satisfaction percentage values are unacceptably low, particularly when the garment manufacturing constrains involve three distinct dimensions (e.g. coats). The satisfaction percentage is considerably increased with mass customization model 1, which expresses a first step towards mass customization for the case of shirts and trousers. Mass customization 2 is required for cloths like coats where three dimensions are utilized by the corresponding manufacturing constraints. This model provides a significant improvement to the cloths fitting compared to the previous one.

Mass customization models 3 and 4 provide a considerable level of mass customization. The total satisfaction percentages of both models in the target population are very high, with the cost of producing a relatively large number of garment sizes. All results are shown in the graph of Figure 6.

5. Implementation

Mass production strategies have driven apparel production for decades with a negative impact in design and fit of clothing. These strategies have categorized whole populations by a relatively small number of sizing systems and made it virtually impossible to meet the needs of those individuals who have special fitting requirements (Istook, 2002). The proposed methodology for the development of sizing systems combined with computer-aided and information technologies can enable the creation of garments, customized for fit, in a very quick and accurate manner. These customized garments can be inserted into normal production lines as an additional "size" and produced like every other garment of the same style. This means that successful companies with huge libraries of garment styles would be able to implement the proposed mass customization strategy with relatively little effort. Potential increase in production cost that would occur due to cutting a few garments at a time, rather than hundreds, could be offset with increases in sales and customer loyalty.

The proposed method for mass customization can be implemented by using either manual measurements or automatic scanning as well as. In this paper, we applied the proposed method in sizing data taken by conventional manual methods which are usually subject to noise and inaccuracies. These shortcomings are not expected to appear in automatic scanning data which are high-accurate and filtered for noise removal. Finally, implementing a field research for the collection of anthropometric data are usually an expensive and time-consuming task which prerequisites the accomplishment of several criteria (Ujevic *et al.*, 2006). Discussing on this task is, however, out of the scope of the present research.

6. Conclusions

A new methodology for the mass customization of garments has been proposed in this paper. With the proposed method, it is possible to control the mass customization

	Upper body garments						Lower body garments	
	Shirts			Coats			Trousers	
Model	Number of sizes n	Total satisfaction (%)	Model	Number of sizes n	Satisfaction (%)	Model	Number of sizes n	Total satisfaction (%)
0	10	24.9	0	8	9.6	0	10	23.4
1	30	67.4	1	23	24.0	1	30	55.9
2	–	–	2	69	53.2	2	–	–
3	50	90.2	3	152	83.3	3	50	80.3
4	59	92.4	4	152	83.3	4	73	93.9

Table XI.
The total satisfaction percentage of the target population according to developed mass customization models

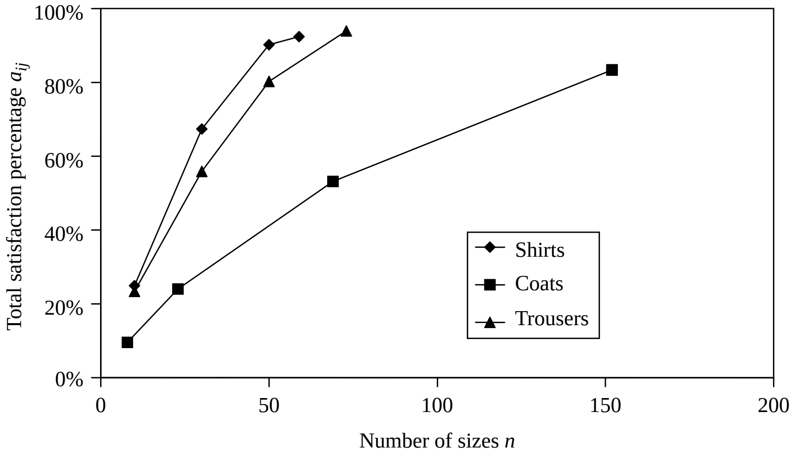

Figure 6.
The total satisfaction percentage of the target population with respect to the number of different garment sizes

degree according to four different models, which affect the corresponding sizing system of a specific garment type. In this way, a garments producer can choose the mass customization model that is closer to his manufacturing line and marketing pursues. This selection is facilitated through an assessment tool called "Total satisfaction percentage." This statistical tool is in place to examine how much a sizing system "satisfies" the target population and it is harmonized with the European Standards of sizing systems development, which are going to be applied in the near future.

The proposed methodology has been successfully applied for the development of mass customization models for male shirts, coats and trousers with respect to Greek men between 20 and 30 years old. This application indicates the limitations of conventional sizing systems and the advantages of using a "scalable" mass customization model.

The methodology presented herein, can be applied to the development of mass customization models for other categories of garments and target population. Our future work includes the development of methods for the automatic garments grading with respect to the aforementioned mass customization models and practise.

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Corresponding author
Philip N. Azariadis can be contacted at: azar@aegean.gr