



BSI Standards Publication

## Size designation of clothes

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Part 3: Methodology for the creation of body measurement tables and intervals

## National foreword

This British Standard is the UK implementation of [ISO 8559-3:2018](#).

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## Size designation of clothes —

Part 3:

### **Methodology for the creation of body measurement tables and intervals**

*Désignation des tailles des vêtements —*

*Partie 3: Méthodologie de création de barèmes de mensuration du  
corps et des intervalles*



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## Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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This document was prepared by Technical Committee ISO/TC 133, *Clothing sizing system — size designation, size measurement methods and digital fittings*.

A list of all parts in the [ISO 8559](http://www.iso.org/iso/8559) series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at [www.iso.org/members.html](http://www.iso.org/members.html).

## Introduction

In order to size mass-produced clothes, the body size of the intended wearer has to be defined and identified with the nearest size on a table of sizes. In this garment-related system, the body size is defined by scales of the appropriate primary dimensions. A good degree of standardization is achieved by the establishment of open-ended size scales with (fixed or not) intervals in at least the primary control dimension for each garment type. Where body shape is characterized by two primary girth dimensions, the first is placed on fixed scale, while the second (the dependent variable) is not.

The processing of body measurement data as described in this document results in the grouping of body sizes appropriate to the studied population concerned. Examples of garment size tables are readily compiled from this information.

The frequency distribution of body sizes is a useful means of determining which body sizes are applicable to the bulk of the population. Consequently, systems can be adjusted, particularly in the case of waist girth for women's wear for which body shape is defined by dimensions other than the waist girth.

Distribution of body dimensions can change due to changes over time. However, it might not be necessary to update a size table if the products can accommodate the population. As the results of the sizing surveys of the different countries vary, the tables in this document provide the required flexibility.

As an application of the methodology, measurement tables, in conjunction with body shapes, can be used to produce fit mannequins (known as "dummies").



# Size designation of clothes —

## Part 3:

# Methodology for the creation of body measurement tables and intervals

## 1 Scope

This document describes the principles of the establishment of tables for body measurements, defines the categories of tables (related to intervals), and lists the population groups (infants, girls, boys, children, women, men) and sub-groups to be used for developing ready-to-wear garments. The body measurement tables and intervals are mainly used by the clothing sector to make the development of well-fitting products easier and more accurate.

The described methodology is mainly based on the application of statistical analysis, using body dimension data. The statistical level has deliberately been kept to a low level in order for the content to be made readily comprehensible to the widest possible readership.

This methodology is applicable to various sets of body dimensions. It can be useful to determine intervals for the size designation as described in [ISO 8559-2](#). Values in the tables in this document are examples.

Garment dimensions are not included in this document.

It is necessary to use a general approach providing inbuilt flexibility, in order to keep the whole sizing system capable of adapting to changes (e.g. demographic criteria), because body shape and proportions for any one targeted population group differ significantly.

NOTE [ISO 15535](#) can be convenient for recording and organizing the population data.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

[ISO 8559-1](#), *Size designation of clothes — Part 1: Anthropometric definitions for body measurement*

[ISO 8559-2](#), *Size designation of clothes — Part 2: Primary and secondary dimension indicators*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in [ISO 8559-1](#) and [ISO 8559-2](#) and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

### 3.1

#### **explanatory variable**

input data that is used to calculate simple or multiple linear regression

### 3.2

#### **dependent variable**

input data that is used to calculate simple or multiple linear regression, with *explanatory variable(s)* ([3.1](#))

### 3.3

#### **interval**

difference between the two adjoining values in a body measurement table

### 3.4

#### **drop**

<men> half difference between chest girth and waist girth, expressed in centimetres, with a negative value when the chest is smaller than the waist

## **4 Principles related to the methodology of the creation of the body measurement tables**

### **4.1 General**

In order to get a garment fitting correctly on a body, it is essential to collect the body dimension measurements. These measurements are useful to design the 2-dimensional garment pattern, which are to be assembled in garment production. These measurements are useful also to design the 3-dimensional garment, such as seamless knitted garments.

Within the clothing industry, when faced with the need to mass produce clothing articles intended to fit a population of varying morphologies, a series of body measurement tables are internally determined in order to design the appropriate clothing articles. The creation of body measurement tables is based on a statistical approach of the body dimensions of the population.

The producer/retailer strategy, taking into account its market location, its targeted population, etc. leads to the creation of its own body measurement tables. Nonetheless, whatever the basis of the body measurement tables, their creation is based on the same principles as described in this document.

Any regression formula calculated for one group of population is specifically applicable to this group and should not automatically be applied to other groups.

[Annex A](#) gives an overview of the clothing industry needs regarding the anthropometric data.

[Annex B](#) shows an example of a body measurement table content.

[Annex D](#) gives an overview of key statistical tasks.

### **4.2 Selection of the explanatory variables and the dependent variable (statistical methodology)**

The explanatory variable refers to the selected variable input data in the measurement tables. They are mainly based on a dimension characterizing a body measurement (as defined in [ISO 8559-1](#)) or based on other body characteristics (e.g. body mass).

[Annex C](#) describes statistical models commonly used for the creation of body measurement tables.

The selection of the explanatory variable is based on various criteria:

- the two or more selected explanatory variables, representing body dimensions, shall be statistically independent and perpendicular: one representing the measurement on the vertical axis and the others that of width or girth (on the horizontal axis);
- a robust correlation does exist between the explanatory and dependent variables;
- based on the given ranges and/or intervals related to the development of clothing, the number of sizes is led by the combination of the chosen dimensions;

— the values of the measurements are easy to remember by the consumer.

The selection of the explanatory variables shall be carried out through various statistical studies, with the successive addition of dimensions to the statistical model. This allows the best combination of the dimensions for the explanatory variables and the dependent variable to be obtained.

It is important to take into consideration the following questions while selecting the explanatory and dependent variables in order to design and develop clothing that fits as many target consumers as possible.

- a) What are the standard deviations of the dimensions selected as the dependent variable in relation with the dimension(s) selected as the explanatory variables?
- b) What should be the relation between the standard deviations mentioned in a) and the tolerance of clothing fitting?

The selection of explanatory variable is usually from the few most important dimensions, such as height, chest girth, waist girth, hip girth.

And then multiple regressions lead to calculate a residual standard deviation, which provides information not explained by the combination of explanatory variable on the prediction of dependent variable. Lower is the residual standard deviation; more satisfactory is the combination of the main dimensions regarding the prediction of the related dependent variable. The residual standard deviation is comparable with the clothing fitting tolerances. The point is that the residual standard deviation leads to calculate a difference allowing for a measured value data, i.e. 95 % of concerned people at this value are placed in this difference, to be compared with the tolerances.

The dependent variable refers to the selected variable input data in the measurement tables that can be used with the explanatory variable. They are mainly based on a dimension characterizing a body measurement (as defined in [ISO 8559-1](#)).

The concept of the residual standard deviation, as mentioned in this sub-clause, is suitable for the dependent variable.

## 5 Categories of body measurement tables

### 5.1 "Statistic" tables

The creation of the body measurement tables, according to the principles as described in [Clause 4](#) leads to obtaining tables which may be qualified as "statistic" tables.

The tabled dimensions, expressed in centimetres, are generally predicted data, which cannot be suitable for the clothing development. They are not adapted to the design process for ready to wear clothing industry (such as pattern creation, design software). In these tables, intervals are variable.

The content of a body measurement table is based on the explanatory variable, expressed as a body dimension (as defined in [ISO 8559-1](#)) and the series of the predicted dependent variable expressed as a body dimension (as defined in [ISO 8559-1](#)), see example in [Annex B](#).

### 5.2 "Linearly smoothed" tables

Only processed data in the form of tables are used for the clothing development.

The first level is to linearly smooth the data to be adapted, for example, to the design software [Computer Assisted Design (CAD)], based on the choice of the value of the step. It means that in these tables, the interval within a sub-group is even. This action leads to "smoothed" tables (see example in [Table 1](#)).

**Table 1 — Example of linear smoothing of data**

	Sub-group 1				Sub-group 2			Sub-group 3			
	inter- val	size #1	size #2	size #3	size #4	interval	size #5	size #6	size #7	interval	size #8
waist girth (cm)	<i>variable</i> 65,0	50,0	51,5	54,2	56,0	<i>variable</i>	58,5	60,5	62,0	<i>variable</i>	
			after linear smoothing								
waist girth (cm)	2,0 66,0	50,0	52,0	54,0	56,0	2,5	58,5	61,0	63,0	3,0	

## 6 Choice of the data

### 6.1 General

In general, as mentioned in 4.2, the choice of the two independent explanatory variables is based on:

- as the length data: height, and
- as the circumference data: chest/bust girth, or waist girth, or hip girth.

Nonetheless the choice of two independent explanatory variables can be different in relation to the type of garment.

For example, in the case of trousers for men, the choice of the two-independent data can be inside leg length (as length data) and waist girth (as circumference data).

### 6.2 Homogeneous population: improvement in relation to sub-groups of the population

#### 6.2.1 General

From measurement of a population, several groups can be defined so that each group is relatively homogeneous in morphology, in order to get more accurate and reliably predictable system and ensure a better match between the body measurement scales and the clothing fitting.

In order to get a more homogeneous population, additional statistical calculations are carried out to improve the value of  $R^2$ , i.e. closer and closer to the value 1.

NOTE 1 A value of  $R^2$  greater than 0,8 is found to be satisfactory.

These additional statistical calculations are based on the determination of sub-groups, which can be based, for example, on the gender, body shape characteristics (e.g. drop values), height, body mass and age.

NOTE 2 Body Mass Index (BMI), which combines the body mass and height (body mass divided by height squared), is sometimes used to determine a sub-group.

NOTE 3 For infants, children, girls and boys, a sub-group based on “age” leads to too large a variation and therefore such a sub-group is not sufficiently homogeneous.

Explanatory variables mentioned in the following subclauses are examples of those commonly used for the creation of body measurement tables. When two explanatory variables are mentioned, the first variable represents the measure on the vertical axis and the second represents the measure on the horizontal axis (girth or width).

### 6.2.2 “Infants” group

Explanatory variables are height and waist girth.

Sleep bag: Explanatory variables are height and head girth.

Sub-group: mass.

### 6.2.3 “Children” group (girls and boys)

Explanatory variables are height and hip girth.

Sub-group: based on morphology (e.g. waist girth, BMI).

### 6.2.4 “Girls” group

Explanatory variables are:

- height and hip girth;
- height and bust girth.

### 6.2.5 “Boys” group

Explanatory variables are:

- height and waist girth;
- height and chest girth.

### 6.2.6 “Women” group

To fit the upper body, explanatory variables are height and bust girth.

To fit the lower body, explanatory variables are height, hip girth or waist girth.

For bras, explanatory variables are:

- height and under-bust girth;
- height and bust girth.

Sub-group: based on morphology (e.g. ratio between bust girth, waist girth and hip girth).

### 6.2.7 “Men” group

To fit the upper body, the usual selected explanatory variables are "height" and "chest girth" (see example in [Annex B](#)).

Especially for shirts, the selected explanatory variables can be "arm length" and "neck girth".

To fit the lower body, the usual selected explanatory variables are "height" and "waist girth".

The “men” sub-groups can be based on body shapes, known as "drop". The following drop values are commonly used:

- a) Drop 16 to 10
- b) Drop 8 to 6
- c) Drop 4 to 2

- d) Drop 0
- e) Drop -2 to -4

## 7 Decisions on intervals and ranges

### 7.1 Intervals

In order to maintain maximum flexibility, it is left up to a company to choose the appropriate intervals.

### 7.2 Range

Range is calculated by using one half plus or half minus the interval from the explanatory variable.

EXAMPLE For a height (as explanatory variable) of 156 cm, the range of 154 to 158 cm leads to an interval of 4 cm (see [Table 2](#)).

**Table 2 — Example of height range**

<b>Height</b>	<b>156</b>
Range	154      158
Interval	4

### 7.3 Examples — Men

#### 7.3.1 Explanatory variable based on height

In order to accommodate variations in height by company, body measurement tables are commonly based on 4 cm (example in [Table 4](#)) or 8 cm (example in [Table 3](#)) intervals.

**Table 3 — Example for ranges for heights for men with 8 cm intervals with starting point of 156 cm**

	Dimensions in centimetres													
<b>Height</b>	<b>156</b>		<b>164</b>		<b>172</b>		<b>180</b>		<b>188</b>		<b>196</b>		<b>204</b>	
Range	152	160	160	168	168	176	176	184	184	192	192	200	200	208
<i>Intervals</i>	<i>8</i>		<i>8</i>		<i>8</i>		<i>8</i>		<i>8</i>		<i>8</i>		<i>8</i>	

**Table 4 — Example for ranges for heights for men with 4 cm intervals with starting point of 156 cm**

	Dimensions in centimetres													
<b>Height</b>	156	160	164	168	172	176	180	184	188	192	196	200	204	208
Range	152	156	160	164	168	172	176	180	184	188	192	196	200	204
<i>Inter-</i>	4	4	4	4	4	4	4	4	4	4	4	4	4	4
<i>vals</i>	4	4	4	4	4	4	4	4	4	4	4	4	4	4

#### 7.3.2 Explanatory variable based on chest girth

In order to accommodate variations in chest girth by company, body measurement tables are commonly based on constant interval value (such as 4 cm – as shown in [Table 5](#) – or 6 cm – as shown in [Table 6](#)) or are sometimes based on a combination of interval values (such as consecutive values of 6, 8, and 10 cm as shown in [Table 7](#)).

**Table 5 — Example for ranges for chest girth for men with 4 cm intervals with starting point of 76 cm**

Dimensions in centimetres

Mean value	76	80	84	88	92	96	100	104	108	112	116	120	124	128	132	136	
Range	77	78	82	85	89	92	96	100	104	108	112	116	120	124	128	132	136
	7	8	2	6	6	0	4	4	8	8	2	2	6	0	4	4	8
	4																

				1													
				1													
				2													
				2													
				2													

				3													
				3													
				3													
				3													
				3													
				8													
				2													
				2													
				6													

*Intervals* 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4

**Table 6 — Example for ranges for chest girth for men with 6 cm intervals with starting point of 76 cm**

Dimensions in centimetres

Mean value	76	82	88	94	100	106	112	118	124	130	136											
Range	73	79	79	85	85	91	91	97	97	103	103	109	109	115	115	121	121	127	127	133	133	139
<i>Intervals</i>	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6

**Table 7 — Example for ranges for chest girth for men with a combination of 6 cm, 8 cm and 10 cm intervals with starting point of 78 cm**

Dimensions in centimetres

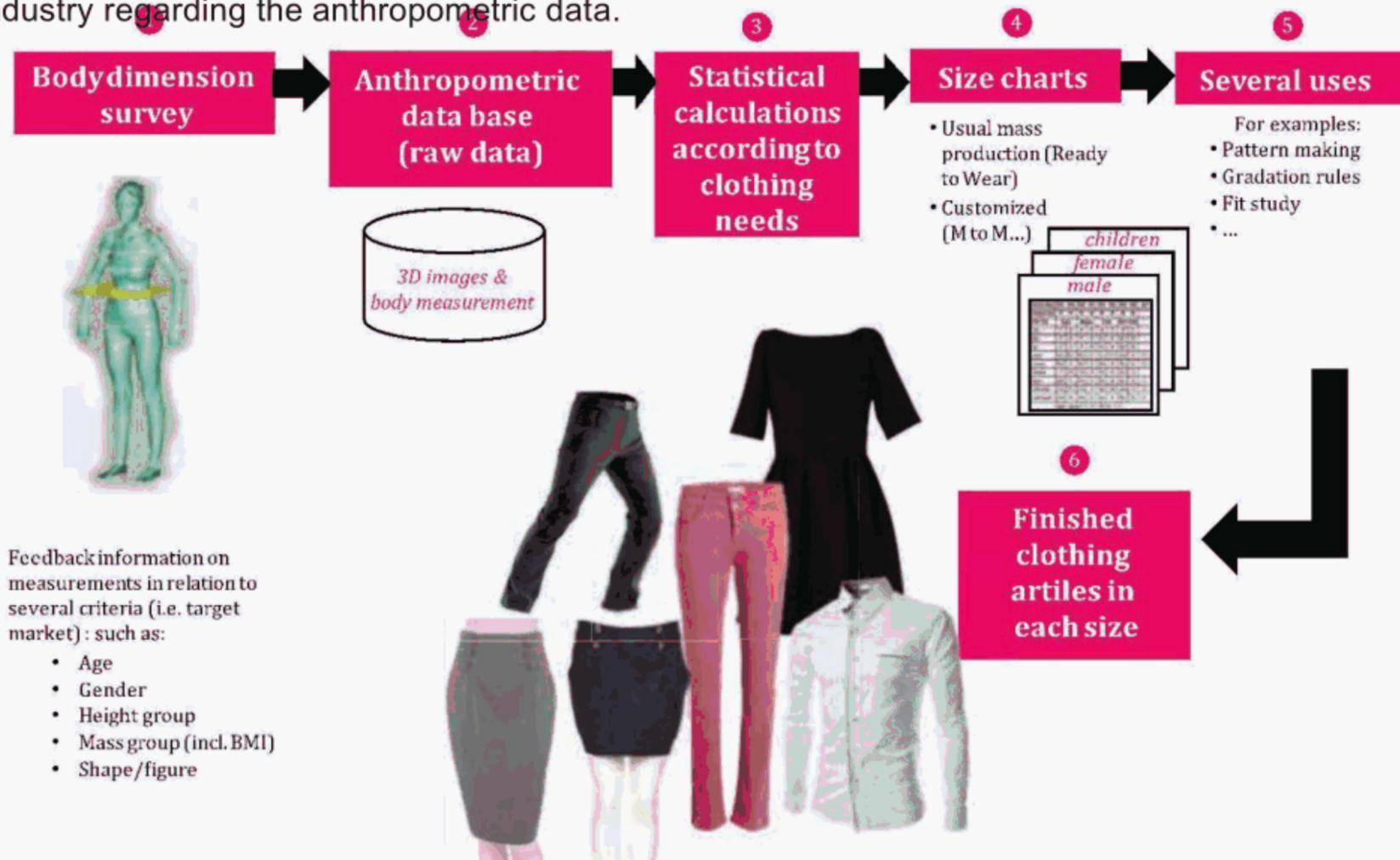
<b>Mean value</b>	78	84	90	96	102	110	120							
Range	75	81	81	87	87	93	93	99	99	105	106	114	115	125
<i>Intervals</i>	6	6	6	6	6	8	10							



## Annex A (informative)

### Clothing industry needs related to anthropometric data

The following flowchart, [Figure A.1](#) is intended for summarizing the needs of the clothing industry regarding the anthropometric data.



**Figure A.1 — Needs of the clothing industry regarding the anthropometric data**

## Annex B (informative)

### Example of a body measurement table content

Selected explanatory variables: height and chest girth (intended for a targeted "men" group, upper body garments).

The following body measurement table, [Table B.1](#), is based on the following explanatory variables: height ( $X_1$ ) and chest girth ( $X_2$ ). The body measurement table contains data only based on one value of height. Consequently, different tables have to be determined for each selected height. All values of the body dimensions are usually given in centimetres[13].

NOTE The letters in [Table B.1](#) could refer to body landmarks and might be given with the body drawing (see example [Figure B.1](#)). Not all body measurements listed in [Table B.1](#) or body measurement positions indicated on [Figure B.1](#) are from [ISO 8559-1](#).



Table B.1 — Example of body measurement table of “men” groups

Height at 181 cm	Sub-group 1 (Drop = 4)						Sub-group 2 (Drop = 3)						Sub-group 3 (Drop = 2)						
	Interval evolu- tion	range #1	range #2	range #3	range #4	range #5	range #6	Interval evolu- tion	range #7	range #8	range #9	range #10	range #11	range #12	Interval evolu- tion	range #13	range #14	range #15	range #16
A Chest girth	4	76	80	84	88	92	96	4	100	104	108	112	116	120	4	124	128	132	136
B Waist girth	4,4	60,4	64,8	69,2	73,6	78	82,4	4,4	86,8	91,2	95,6	100	104,4	108,8	4,9	113,7	118,6	123,5	128,4
C Hip girth	3,4	70,9	74,3	77,7	81,1	84,5	87,9	3,1	91	94,1	97,2	100,3	103,4	106,5	3,1	109,6	112,7	115,8	118,9
D Seat girth	3	82,1	85,1	88,1	91,1	94,1	97,1	2	99,1	101,1	103,1	105,1	107,1	109,1	1,6	110,7	112,3	113,9	115,5
E Thigh girth	1,7	45,3	47	48,7	50,4	52,1	53,8	1,1	54,9	56	57,1	58,2	59,3	60,4	0,8	61,2	62	62,8	63,6
F Knee girth	1	31,9	32,9	33,9	34,9	35,9	36,9	0,7	37,6	38,3	39	39,7	40,4	41,1	0,7	41,8	42,5	43,2	43,9
G Calf girth	1,2	30	31,2	32,4	33,6	34,8	36	0,6	36,6	37,2	37,8	38,4	39	39,6	0,6	40,2	40,8	41,4	42
H Ankle girth	0,6	22,4	23	23,6	24,2	24,8	25,4	0,4	25,8	26,2	26,6	27	27,4	27,8	0,3	28,1	28,4	28,7	29
I Front breast width	1	31	32	33	34	35	36	1	37	38	39	40	41	42	0,9	42,9	43,8	44,7	45,6
J Back width	1	34	35	36	37	38	39	1	40	41	42	43	44	45	0,9	45,9	46,8	47,7	48,6
K Head girth	0,4	55,3	55,7	56,1	56,5	56,9	57,3	0,2	57,5	57,7	57,9	58,1	58,3	58,5	0,1	58,6	58,7	58,8	58,9
L Neck girth	1,1	32,1	33,2	34,3	35,4	36,5	37,6	1,1	38,7	39,8	40,9	42	43,1	44,2	1	45,2	46,2	47,2	48,2
M Neck-base girth	1,1	38,8	39,9	41	42,1	43,2	44,3	0,9	45,2	46,1	47	47,9	48,8	49,7	0,8	50,5	51,3	52,1	52,9
N Up-per-arm girth	1,1	23,1	24,2	25,3	26,4	27,5	28,6	0,7	29,3	30	30,7	31,4	32,1	32,8	0,5	33,3	33,8	34,3	34,8

Table B.1 (continued)

Height at 181 cm	Sub-group 1 (Drop = 4)					Sub-group 2 (Drop = 3)					Sub-group 3 (Drop = 2)								
	Interval evolu- tion	range #1	range #2	range #3	range #4	range #5	range #6	Interval evolu- tion	range #7	range #8	range #9	range #10	range #11	range #12	Interval evolu- tion	range #13	range #14	range #15	range #16
O Wrist girth	0,5	14,6	15,1	15,6	16,1	16,6	17,1	0,3	17,4	17,7	18	18,3	18,6	18,9	0,2	19,1	19,3	19,5	19,7
P Shoul- der length	0,1	13,8	13,9	14	14,1	14,2	14,3	0,03	14,33	14,36	14,39	14,42	14,45	14,48	0,03	14,51	14,54	14,57	14,6
Q Scye depth	0,2	22,5	22,7	22,9	23,1	23,3	23,5	0,2	23,7	23,9	24,1	24,3	24,5	24,7	0,2	24,9	25,1	25,3	25,5
R Crotch- waist height	0,4	27,8	28,2	28,6	29	29,4	29,8	0,3	30,1	30,4	30,7	31	31,3	31,6	0,2	31,8	32	32,2	32,4
S Back waist length	0,1	45,5	45,6	45,7	45,8	45,9	46	0,1	46,1	46,2	46,3	46,4	46,5	46,6	0,1	46,7	46,8	46,9	47
T Shoul- der slope	0	22	22	22	22	22	22	0	22	22	22	22	22	22	0	22	22	22	22
U Waist height	0	110	110	110	110	110	110	0	110	110	110	110	110	110	0	110	110	110	110
V Out- side leg length	(+1)	111	111	111	111	111	111	(+1,2)	111,2	111,2	111,2	111,2	111,2	111,2	(+1,5)	111,5	111,5	111,5	111,5
W Cervical height	0	157	157	157	157	157	157	0	157	157	157	157	157	157	0	157	157	157	157
X Crotch height	-0,4	82,2	81,8	81,4	81	80,6	80,2	-0,3	79,9	79,6	79,3	79	78,7	78,4	-0,2	78,2	78	77,8	77,6
Y Waist- knee height	0	61,6	61,6	61,6	61,6	61,6	61,6	0	61,6	61,6	61,6	61,6	61,6	61,6	0	61,6	61,6	61,6	61,6
Z Knee height	0	48,4	48,4	48,4	48,4	48,4	48,4	0	48,4	48,4	48,4	48,4	48,4	48,4	0	48,4	48,4	48,4	48,4
LB Arm length	0	62,7	62,7	62,7	62,7	62,7	62,7	0	62,7	62,7	62,7	62,7	62,7	62,7	0	62,7	62,7	62,7	62,7

Table B.1 (continued)

Height at 181 cm	Sub-group 1 (Drop = 4)							Sub-group 2 (Drop = 3)							Sub-group 3 (Drop = 2)				
	Interval evolu- tion	range #1	range #2	range #3	range #4	range #5	range #6	Interval evolu- tion	range #7	range #8	range #9	range #10	range #11	range #12	Interval evolu- tion	range #13	range #14	range #15	range #16
HT Head height	0	24	24	24	24	24	24	0	24	24	24	24	24	24	0	24	24	24	24
ED Front crotch length	0,9	30,7	31,6	32,5	33,4	34,3	35,2	0,6	35,8	36,4	37	37,6	38,2	38,8	0,5	39,3	39,8	40,3	40,8
EF Back crotch length	1,1	37,5	38,6	39,7	40,8	41,9	43	0,8	43,8	44,6	45,4	46,2	47	47,8	0,5	48,3	48,8	49,3	49,8

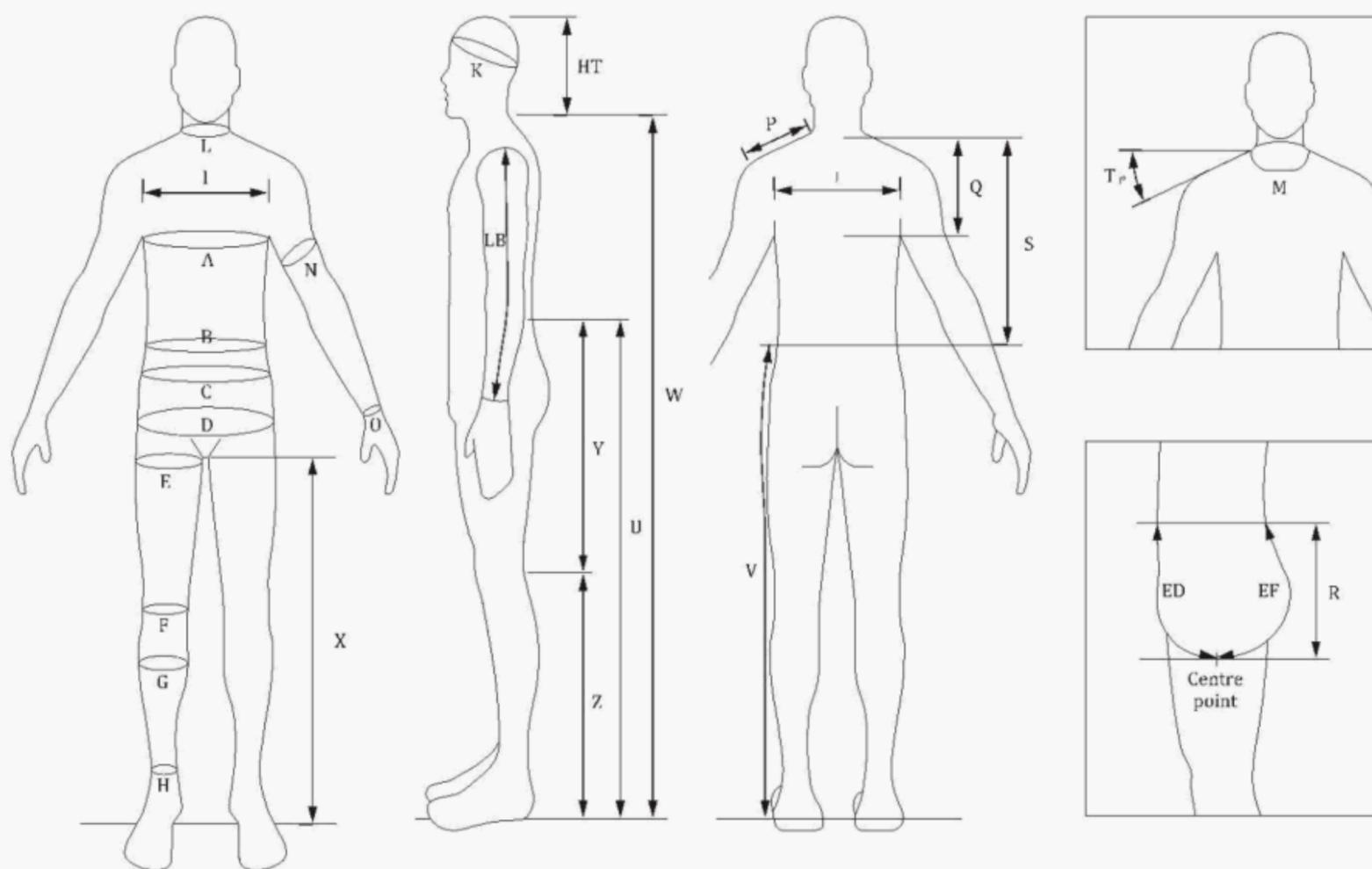


Figure B.1 — Body measurements in relation to [Table B.1](#)

## Annex C (informative)

### Statistical models commonly used for the creation of body measurement tables

#### C.1 General

Body measurement tables are created based on a commonly used method in statistics: mainly simple or multiple linear regressions.

To achieve precise results, the multiple linear regression model with two explanatory variables is mainly carried out and this model is described in [C.2](#). According to the needs (e.g. lower precision in comparison to the "two explanatory variables" model, the single linear regression model with one explanatory variable can be used and this model is described in [C.3](#). Additional models are mentioned in [C.4](#).

This technique allows to model the linear relationship between one or more explanatory variables (denoted  $X_i$ ) and a dependent variable (denoted  $Y$ ).

An explanatory variable can be based on a specific body dimension (or, even, a calculated value from a specific body dimension; e.g. logarithm of specific body dimension data).

The purpose of this method is twofold: to fit models that will help explain the dependent variable as a function of the explanatory variable and predict the values of measurements according to any value of the explanatory variable.

#### C.2 Multiple linear regression models with two explanatory variables

In the framework of multiple regressions,  $n$  observations (total number of individuals in the study population) are available to perform the following three calculations: the secondary surveying (or dependent variable to predict, called  $Y$ ) and those two main measurements, denoted  $X_1$  and  $X_2$ , characterized by continuous variables (the explanatory variables). The goal is to estimate  $Y$  by a linear combination of two explanatory variables  $X_1$  and  $X_2$ .

The multiple linear regression models are as follows:

$$Y = \lambda + \alpha \times X_1 + \beta \times X_2 + \varepsilon$$

where

$\lambda$ ,  $\alpha$  and  $\beta$  are constants (model parameters: coefficients and regression constant);  
 $\varepsilon$  is the residuals.

This relation includes statistical "noise", which is characterized by the residuals. These residuals represent the difference between reality and representation (prediction) by the model.

The coefficients  $\lambda$ ,  $\alpha$  and  $\beta$  are determined by the weighted least squares method intended to minimizing the residuals.

However, the model is valid only if the adjustment and hypothesis of regression tests are checked.

The most important hypothesis to check is as follows: "errors (or residuals) are centred normally distributed (mean value equal to 0), have the same variance (homoscedasticity) and are not correlated between them."



Example: Based on the French survey carried out in 2006, a formula of "waist girth" (in cm), as the dependent variable  $Y$ , was calculated from "height" (in cm), as the first explanatory variable  $X_1$  and "mass" (in kg) as the second explanatory variable  $X_2$ . The numerical formula was:

$$G_w = 131,835\ 3 - 0,662\ 4 \times h + 0,951\ 4 \times m.$$

where

$G_w$  is waist girth, in centimetres;

$h$  is height, in centimetres;  $m$

is mass, in kilogrammes.

Based on this numerical formula, the application for a person (175 cm and 80 kg) gives the following result: 92,027 3 rounded at (theoretically, i.e. predicted) 92 cm.

NOTE Another set of data (from specific groups of population, another national survey, etc.) will lead to other numerical coefficients.

### C.3 Simple linear regression model (with one explanatory variable)

In the framework of single regressions,  $n$  observations (total number of individuals in the study population) are available to perform the following two calculations: the secondary surveying (or dependent variable to predict, called  $Y$ ) and this main measurement, denoted  $X_1$ , characterized by continuous variable (the explanatory variable). The goal is to estimate  $Y$  by a linear combination of the explanatory variable  $X_1$ .

The single linear regression models are as follows:

$$Y = \lambda + \alpha \times X_1 + \varepsilon$$

where

$\lambda$  and  $\alpha$  are constants (model parameters: coefficients and regression constant);

$\varepsilon$  is the residuals.

As explained in [C.2](#), this relation includes statistical "noise", which is characterized by the residuals. These residuals represent the difference between reality and representation (prediction) by the model. The coefficients  $\lambda$  and  $\alpha$  are determined by the weighted least squares method intended to minimize the residuals. The model is valid only if the adjustment and hypothesis of regression tests are checked. The most important hypothesis to check is as follows: "errors (or residuals) are centred normally distributed (mean value equal to 0), have the same variance (homoscedasticity) and are not correlated between them."

### C.4 Alternative models

Multiple linear regression models with three explanatory variables have been found suitable for some surveys.

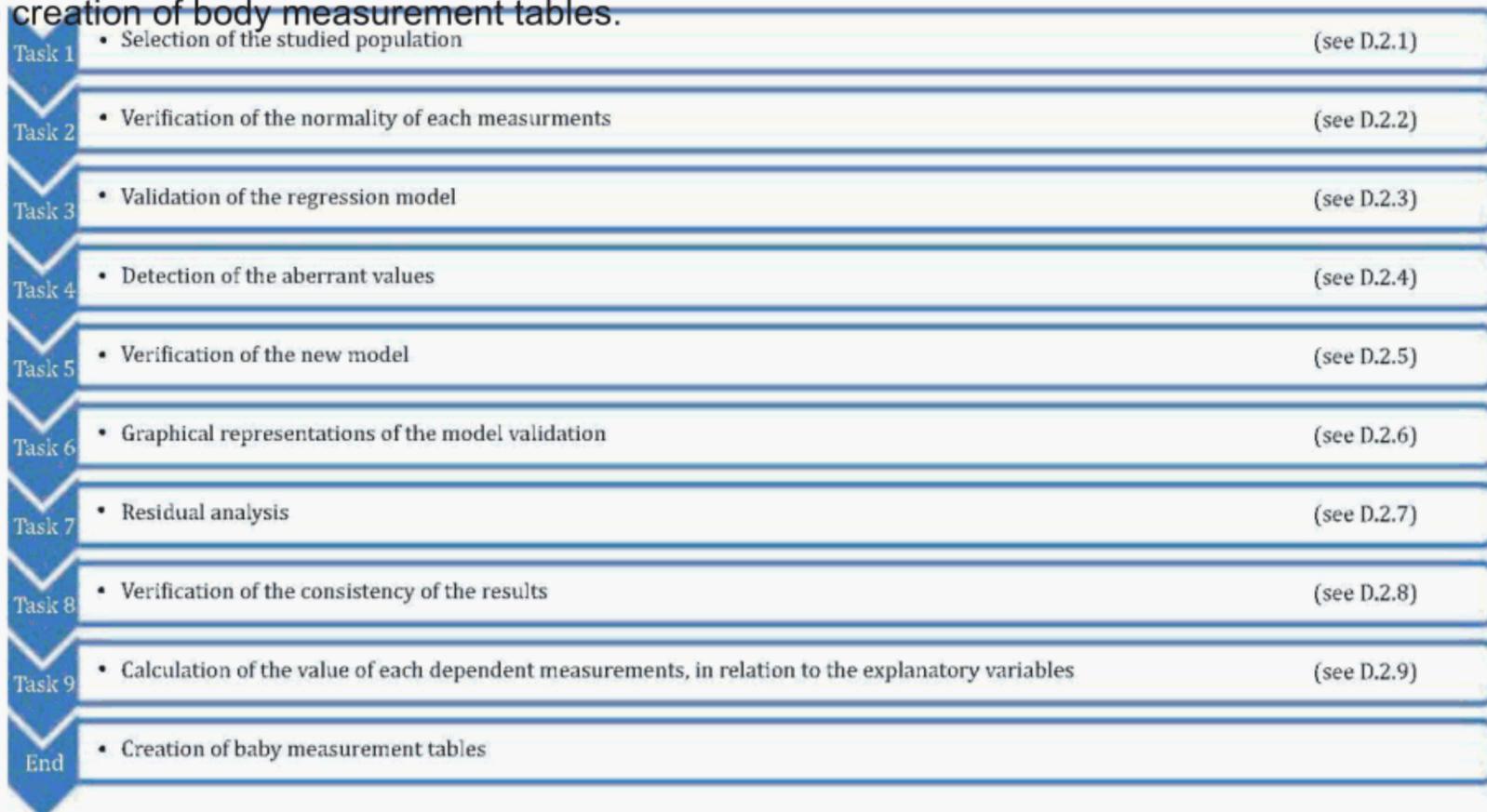
## Annex D (informative)

### Tasks in statistics

#### D.1 General

This annex is drafted to give an overview of the key statistical tasks. It is intended for any readers having a basic knowledge in statistics. Further detailed information about statistic tools might be found with the help of skilled statisticians.

The flowchart in [Figure D.1](#) summarizes the subsequent statistical tasks to be carried out leading to the creation of body measurement tables.



**Figure D.1 — Flowchart of the statistical tasks leading to the creation of body measurement tables**

#### D.2 Statistical tasks

##### D.2.1 Task 1 — Selection of the studied population

Within the framework of the creation of body measurement tables, it is necessary first to select the targeted population to be studied.

The consequence is that the statistical models are different according to the selected populations.

The body measurements are based on the body dimension definitions as given in [ISO 8559-1](#).

The ranges of measurements are constructed in a particular division of populations to make them as homogeneous as possible regarding the morphology.

## D.2.2 Task 2 — Verification of the normality of each measurement

This approach requires checking the hypothesis of the normality of the distribution of each measurement taken into account in a model.

Statistical tests are performed for each of the regression models to check the hypotheses, such as Kolmogorov-Smirnov test or Henry's line jointly with a histogram.

NOTE Further information about normality can be found in ISO 5479.

## D.2.3 Task 3 — Validation of the regression model

### D.2.3.1 General

The different phases of a study of a regression model can be summarized by these following successive steps.

- 1) Creation of the model: it is assumed that the variable  $Y$  is explained linearly by explanatory variables via a regression model (see [Annex C](#)).
- 2) Estimation: the parameters are estimated using the collected in the studied population data (see Task 1).
- 3) Validation of the model, through the validation of the hypothesis of the normality of residuals (see Task 2).

Various problems can occur during this task, such as, among others, the poor correlation of certain individual values in comparison with the studied model. Several statistical tools enable the detection and removal of these individuals from the model in order to improve it.

By usually using the least square method, a calculation is undertaken to obtain estimates of regression coefficients.

NOTE Further information about regression can be found in [ISO 3534-4](#).

For complete results of the student's  $t$  test, the significance of each of the estimated parameters is checked using confidence intervals (at 95 %): if the value 0 is not included in these intervals, the estimated parameters are significant and therefore allow explain some of the variation in the dependent variable.

### D.2.3.2 Analysis of variance (known as ANOVA)

Within the framework of the analysis of variance, the Fisher-Snedecor test (test of the hypothesis of non-regression test or Fisher overall) indicates whether at least one of the variables contributing significantly to the model, testing the following hypotheses: "coefficients (such as  $\lambda$ ,  $\alpha$ ,  $\beta$ ) are equal to zero" versus "at least one of the coefficients is not zero".

If the critical probability of the test is less than 0,05, then the hypothesis "coefficients are equal to zero" is rejected with a risk lower than  $p = 5\%$  (significance level selected). It means then that at least one of the coefficients is not null and that the relation (or part of the relation) between the dependent variable and the explanatory variables is significant.

NOTE Further information about  $F$  distribution can be found in [ISO 3534-1](#), [ISO/TR 12845](#), [ISO/TR 13195](#), [ISO/TS 17503](#) and [ISO/TR 29901](#).

From the previous test that measures the overall significance of the model, the individual significance of each parameter in the model set has then to be studied.

Two additional statistical criteria are used to validate and confirm (or not) the prediction model: Student's  $t$  test ([D.2.3.3](#)) and the coefficient of determination, called  $R^2$  ([D.2.3.4](#)).

### D.2.3.3 Student's t test

This test is related to the nullity of a regression coefficient: significance test of a coefficient: hypothesis "the regression coefficient is equal to zero" versus "the regression coefficient is nonzero".

This test is performed for each model coefficient (e.g.  $\lambda$ ,  $\alpha$ ,  $\beta$ ) and to measure the value of an explanatory variable in the model with the  $t$ -value (corresponding to the Student's  $t$  statistic for the null hypothesis). If the  $t$ -value is less than 0,05, the hypothesis "the regression coefficient is equal to zero" is rejected. The tested variable is then significant for the model.

However, this test is considered as partial as the estimator of each coefficient depends on all the other parameters of the regression.

NOTE Further information about  $t$  distribution can be found in [ISO 3534-1](#).

### D.2.3.4 The coefficient of determination, $R^2$

This coefficient measures the goodness of fit of the regression model. It represents the proportion of variation in the dependent variable provided by the model compared the total variation of the same variable. The qualified model is considered satisfactory when the true values of the measurement to explain estimates.

NOTE 1 Further information about correlation coefficient can be found in [ISO 3534-1](#).

The model is even better than this coefficient is close to 1.

However, commonly, the "adjusted  $R^2$ " is used but it does not increase automatically (unlike  $R^2$ ) when adding a new parameter in the model. It will grow only if the added variable contributes significantly to explaining the dependent variable. When the number of individuals is important,  $R^2$  and "adjusted  $R^2$ " are very close.

NOTE 2 When  $R^2$  is close to 1, the model is very satisfactory, whereas for  $R^2$  equal or close to 0, the model is inadequate.

### D.2.4 Task 4 — Detection of aberrant individuals

The validation phase carried out following the collection of data of the studied population can discard most aberrant values from the statistical analysis by correcting these values. However, some can remain and are due to the fact that an individual can be atypical in its original population and not necessarily the total population.

The presence of some atypical individuals ("outliers") can strongly influence the results and questioning, contributing to the determination of the regression line and the modification of the characteristics of the specified model. The criterion of least squares used is very sensitive to these outliers, hence the need to examine more closely. There are several statistical criteria to detect these influential individuals (such as "Cook's distance", "leverage effect", "Standard Influence on Predicted Value").

NOTE Further information about outlier coefficient can be found in [ISO 5725-1](#), [ISO 5725-2](#), and [ISO 16269-4](#).

### D.2.5 Task 5 — Verification of the new model

Once these aberrant individuals are removed, a new statistical model is performed and accompanied tests Student, Fisher-Snedecor, as well as checking the goodness of fit of the updated model with the adjusted coefficient of determination (adjusted  $R^2$ ). The previous tasks are carried out again.

This validation task is mainly based on the residual analysis using graphical tools ([D.2.6](#)). They allow checking the model, as well as the validity of the hypothesis of linearity, homoscedasticity (equal variances) and normality of residuals.

### D.2.6 Task 6 — Graphical representations of the model validation

The following three graphics are used to check and validate the predictive system issued by the model.

- 1) The predicted values of  $Y$  in accordance with its actual values

This point cloud crosses the observed values of the dependent variable with the predicted values. It illustrates the coefficient of determination  $R$  (equivalent to the simple correlation between the predicted value of  $Y$  and the actual value of  $Y$ ).

If this point cloud is aligned with the line  $y = x$ , this means that the regression gives good results.

- 2) The predicted values and actual values of  $Y$  based predictors.

This graph represents both the predictions of the variable  $y$  and actual values as a function of explanatory variables. It allows assessing the outcome of the prediction variables contributing to the model.

- 3) The confidence interval for the prediction and estimation

The confidence interval of an estimate defines the limits within which is probably an individual value read from the regression line. This interval shows that, for a given variable  $X_i$  of values  $X$ , the true value of the variable  $Y$  should be within the confidence interval.

The prediction interval of an estimate defines the limits within which likely fall a new observation  $Y$  if it is part of the same statistical population as the sample.

### D.2.7 Task 7 — Residual analysis

Examination of the residuals is important; it ensures the normality of residuals. Graphics also help to meet this need for model validation hypothesis.

- 1) Residuals centred reduced depending on the variable  $Y$

This point cloud crosses "studentized" residuals with the actual values of  $Y$ . Points should be uniformly distributed between  $-2$  and  $+2$  limits without presenting specific shapes (e.g. crescent shape).

The percentage of individuals outside the range  $-2$  to  $2$  should be less than 5 % of the studied population. Standardized residuals located outside of this range allow suspect outliers. Then it might be useful to check and even to recalculate the regression after removing these points.

- 2) Histogram of residuals

The histogram of the residuals and the coefficients of Kurtosis and Skewness inform the normality of residuals. The Kolmogorov-Smirnov test, which compares the empirical distribution function to a theoretical distribution function (here, the normal distribution), can also reveal if the normality of the residuals is significant.

- 3) Quantile-Quantile Normal and Normal Probability Plot - Probability Plot

Other graphical tools exist. PP plot (probability - probability representation) and QQ plot (quantile - quantile representation) allow visual comparison of the match of the observed cumulative distribution function to a theoretical cumulative distribution function (normal distribution).

The normality hypothesis is analysed using a QQ plot graph comparing the amounts of estimated residuals to the expected value of the same quantities under the hypothesis of normality. If the theoretical distribution fits the data well, the points on the graph are aligned properly along the Henry's line.

4)  $Y$  residuals based on estimated values of  $Y$

When the points are concentrated around the line  $y = 0$ , which means that the prediction error values observed are very small.

It is important to check that the graphs of the residuals of the variable  $Y$  as a function of the values of explanatory variable(s)  $X_1$  and/or  $X_2$  do not show any trend.

5)  $Y$  residuals according to the variable  $X_1$  or  $X_2$

For each value of the explanatory variable, when the error made on the prediction of  $Y$  is low (concentrated around 0), then it is possible to show that the prediction does not give satisfactory results for certain individuals since the residuals are important too. Therefore, there is homoscedasticity of the values because the errors have the same variance.

**NOTE** In some cases, heteroscedasticity can appear. This can be due to the fact that persons with atypical measurements are taken into account in the statistical analysis. In this case, the variability of residuals decreases as the values of the explanatory variables increase: morphological differences thus appear.

### D.2.8 Task 8 — Verification of the consistency of the results

To ensure consistency of results, it is simply possible to analyse the differences between the actual sample values and the values predicted through calculations of means and quantities. Thus, it is possible to know the relative error committed for 90 % of the studied population. For example, if 90 % of the population has a relative error between -4,50 % and 5,60 %, while the estimate can be considered very satisfactory.

**NOTE** The relative error is given by the ratio between the residual (difference between the predicted value and the actual value) and the actual value. An overestimation of the prediction resulted in a positive relative error, and vice versa.

### D.2.9 Task 9 — Calculation of the value of each dependent measurement, in relation to the explanatory variables

After validation of the hypothesis of normality, the coefficients (e.g.  $\lambda$ ,  $\alpha$ ,  $\beta$ ) can be replaced in the regression model estimates that have found them.

Thus, it is possible to have a prediction of the  $Y$  variable considered for any value of the explanatory variables.

**NOTE** In cases where some variables are poorly explained by the regression model, (the coefficient of determination  $R^2$  is too low), the calculation of an average of the measurement is considered in the scale of measurements for the studied population. A regression is performed under the condition of having at least 50 individuals in the studied population.

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