UNIVERSITY OF BELGRADE

FACULTY OF MECHANICAL ENGINEERING

AHMED ALI OMAR ESSDAI

MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESIGN

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МУЛТИВАРИЈАНТНИ МОДЕЛ ЗА АНТРОПОМЕТРИЈСКО ПРОЈЕКТОВАЊЕ УНУТРАШЊЕГ ПРОСТОРА ВОЗИЛА И МАШИНА

Докторска дисертација

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Dedicated

To whom I respect more than myself, my mother, my wife, my children (Hanan, Ali, and Hesham), and my brothers, also in memory of my sister Aisha, and my father Ali Essdai, all with love and appreciation. To my supervisor Prof. Vesna Spasojević Brkić, with sincere appreciation and thankfulness

Mentor of Doctoral Dissertation

Prof. Dr Vesna Spasojević Brkić

University of Belgrade, Faculty of Mechanical Engineering

Members of the Committee

Prof. Dr Bojan Babić

University of Belgrade Faculty of Mechanical Engineering

Prof. Dr Vladimir Popović

University of Belgrade Faculty of Mechanical Engineering

Prof. Dr Zorica Veljković

University of Belgrade Faculty of Mechanical Engineering

Prof. Dr Ivan Mihajlović

University of Belgrade Technical faculty Bor

Date of Defense:

Ментор докторске дисертације

Проф. Др Весна Спасојевић Бркић

Универзитет у Београду Машински факултет

Чланови комисије

Проф. Др Бојан Бабић

Универзитет у Београду Машински факултет

Проф. Др Владимир Поповић

Универзитет у Београду Машински факултет

Проф. Др Зорица Вељковић

Универзитет у Београду Машински факултет

Проф. Др Иван Михајловић

Универзитет у Београду Технички факултет у Бору

Датм одбране:

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MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESIGN

ABSTRACT

Although it is known that the study of human-machine interaction in a system, in terms of its improvement and adjustments is a way to improve the efficiency of functioning, reduce fatigue, preserve human health and ensure optimum working environment conditions, it is still a challenge for many engineers - machine and vehicle constructors and experts who deal with this problem. Thus, the compatibility of the anthropometric characteristics of the driver/operator of the vehicle and machinery with cab dimensions, as well as the dimensions and position of the equipment in the cabin, directly affects the user from the aspect of comfort, health and working ability, and consequently influence the performance, productivity and financial losses as well as safety of the work environment, in a very broad scope. By reviewing the existing literature, it can be concluded that there is very little research dealing with the problem that is the subject of this dissertation.

Bearing in mind other numerous development problems of the regions of Serbia and Libya, it is expected that the establishment and verification of the original model for the anthropometric design of the interior space of vehicles and machines on samples of Serbian and Libyan drivers and operators for transport machines will be a useful tool for decision-makers in subjected industries that will enable better functional management on a global scale. In accordance with this, the initial hypotheses were then defined, processed and confirmed in the dissertation using collected anthropometric measurements by static anthropometry, on the specific populations, involving samples of 1,514 drivers and 133 crane operators to confirm the present demographic differences.

By applying correlation and regression analysis, as well as by testing the hypothesis, the first was confirmed. There are significant differences in the anthropometric measurements of the Serbian and Libyan populations, according to gender, nationality and occupation (drivers and operators), which indicates the need for the design for a specific population of users or requires the inclusion of all specific user populations as opposed to the previous design practices for the general population.

The the original model for the anthropometric design of the interior space of vehicles and machines was next proposed and verified. It has been shown that when dealing with design problems involving more dimensions, a new model based on multivariate statistical modeling should be used instead of the commonly used univariate percentile method. Through the proposed integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model. Thus, the goal is to determine a limited, as small as possible and the most adapted three-dimensional space for a person, with the new original methodology that takes, as an anthropometric constraint, combinations of extreme pairs of dimensions and uses the theory of mechanisms and biomechanics for user accommodation. By checking the model, it was shown that the model is accurate and precise, since it covers 95% of the population of interest and, in that manner, all posted hypotheses have been confirmed.

On the basis of the multivariate model for anthropometric adaptation, the dimensions of the minimum space required for the comfortable and safe accommodation are set to 1327 × 1123 × 1926 mm for Serbian and 1203 × 1090 × 1838 mm for Libyan crane operators and 1500 × 561 × 1230mm for Serbian and 1400 × 591 × 1155mm for Libyan passenger car drivers. Those results are in line with previously shown demographic differences between these populations.

A generalization of the model defined in this dissertation establishes a platform for wider application of the proposed and confirmed model in other contexts, as well as the possibility of its further development and improvement, which is a proposal for further research in the subject area.

Keywords: Multivariate modeling, Crane cabin, Vehicle interior space, Anthropometric measurements.

Scientific field: Mechanical Engineering

Narrow scientific field: Industrial Engineering **(**Ergonomics)

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МУЛТИВАРИЈАНТНИ МОДЕЛ ЗА АНТРОПОМЕТРИЈСКО ПРОЈЕКТОВАЊЕ УНУТРАШЊЕГ ПРОСТОРА ВОЗИЛА И МАШИНА

Сажетак

Иако је познато да истраживање интеракције човека и машине у систему, са аспекта његовог унапређења, односно прилагођавања у циљу побољшања ефикасности функционисања, смањења замора и очувања здравља човека и обезбеђивања оптималних услова радне средине, представља изазов бројним инжењерима конструкторима машина и возила, као и многим другим стручњацима који се баве овом проблематиком, прегледом постојеће литературе долази се до закључка да постоји веома мали број истраживања која се баве проблемом који је предмет ове дисертације, како у свету, тако и код нас. Тако, усклађеност антропометријских карактеристика возача/руковаоца возила и машина са димензијама кабине, као и са димензијама и положајем опреме у кабини, директно утиче на на самог корисника са аспеката комфора, здравља и радне способности, а последично на радни учинак, продуктивност и финансијске губитке компаније као и на безбедност радног окружења, шире посматрано.

Имајући у виду и друге бројне развојне проблеме региона Србије и Либије, очекује се да ће успостављање и провера оригиналног модела за антропометријско пројектовање унутрашњег простора возила и машина на узорцима српских и либијских возача и руковаоца транспортним машинама представљати и користан алат који ће доносиоцима одлука у предметним индустријама омогућити много ефикасније функционално управљање на глобалном нивоу. У складу са тим дефинисане су иницијалне хипотезе, које су у дисертацији обрађене и потврђене, а затим је успостављена база антропомера предметних популација на основама начела статичке антропометрије, која укључује 1514 возача и 133 руковаоца дизалицом, а са циљем потврде присутних демографских разлика.

Најпре је применом корелационе и регресионе анализе, као и тестирањем хипотеза доказано да постоје значајне разлике у антропометријским мерама разматраних

српских и либијских популација, а зависно од пола, националности и занимања (возача и руковаоца), што указује на потребу пројектовања за специфичну популацију корисника, односно налаже укључивање свих специфичних популација корисника за разлику од досадашње праксе пројектовања за општу популацију.

Затим је предложен и проверен оригинални модел за антропометријско пројектовање унутрашњег простора возила и машина. Показано је да при решавању проблема пројектовања који укључују више димензија треба трагати за новим моделом који не треба да користи униваријантни перцентилни метод, већ мултиваријантно моделирање. Путем предложеног интегралног модела за антропометријску адаптацију заснованом на методама мултиваријантне статистике могуће је вишедимензионални проблем свести на тродимензионалн, просторни модел. Тако је испуњен циљ да се ограничени, што мањи, а човеку што боље прилагођен простор ограничен висином, дужином и ширином унутрашњег простора одреди новом оригиналном методологијом, тако што као антропометријско ограничење узимамо комбинације екстремних величина парова и низова антропомера којима треба прилагодити кабину, уз примену теорије механизама и биомеханике. Провером модела показано је да је модел довољно тачан и прецизан, са обухватом 95% популације од интереса, те су на тај начин потврђене постављене хипотезе овог истраживања.

На основама мултиваријантног модела за антропометријску адаптацију одређене су димензије минималног потребног простора за комфоран и безбедан смештај руковаоца и возача и оне износе 1327×1123×1926 mm за српске и 1203×1090×1838 mm за либијске руковаоце дизалицом, односно 1500×561×1230mm за српске и 1400×591×1155mm за либијске возаче путничког аутомобила. Дати резултати су у складу са претходно потврђеним демографским разликама између разматраних популација.

Генерализацијом модела дефинисаног у овој дисертацији успоставља се платформа за ширу примену предложеног и потврђеног модела истраживања у другим контекстима, као и могућност даљег развоја и унапређења модела, што је и предлог даљих истраживања у предметној области.

Кључне речи: Мултиваријантно моделирање, кабина крана, унутрашњи простор путничког аутомобила, антропометријска мерења.

Научна област: Машинство

Ужа научна област: Индустријско инжењерство

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NOMENCLATURE

Abbreviation	Definition	unit
WEI	Weight	kg
STH	standing height	mm
SIH	sitting height	mm
LLL	lower leg length	mm
ULL	upper leg length	mm
SHW	shoulder width	mm
HIB	hip breadth	mm
ARL	arm length	mm
SMD	Serbian male drivers	
LMD	Libyan male drivers	
SCO	Serbian crane operators	
LCO	Libyan crane operators	
SM	Serbian males	
LM	Libyan males	
SFD	Serbian female drivers	
LFD	Libyan female drivers	
SR	Serbians (all participants)	
LI	Libyans (all participants)	
N	sample size	
Med.	Median	
Min.	minimal value	
Max.	maximal value	
R	Rank	
SD	standard deviation	
c_v(%)	coefficient of variation	
D	Kolmogorov statistics	
p	p-value	
SIG.	Significance	
n.s.	not significant	
VT	variable type	
r	coefficient of correlation	
r^2(%)	coefficient of determination	
z	z test for difference of means	
p	significance level	
P05	5th percentile	
P50	50th percentile	
P95	95th percentile	
P99	99th percentile	
PC	Principal component	

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1. INTRODUCTION

Ergonomics has great potential to contribute to the design of all kinds of systems with people (work systems, product/service systems) and an understanding of human variation facilitates the idea to fulfill the user's requirements (Dul et al., 2012). To develop appropriate product designs, we need to understand the diversity in user needs (Khalid, 2006). More specifically, the aim of ergonomics is to adapt the devices, machines and workplaces to the worker, i.e. design work equipment, procedures and the environment to facilitate work and to achieve the greatest performance effects with the least effort during the work process. Also, the aim of this scientific discipline is to eliminate or reduce fatigue, exhaustion and pain, as well as to increase workplace safety and work efficiency, among other things, in the way that devices and machines are designed in accordance with the principles of anthropometry. Anthropometry (Pheasant, 2014), as a science that defines physical measures, is used by interior designers with the aim to make the users feel comfortable in their interior environment through optimal working posture usage, prevent injuries and improve safety and facilitate task execution in a more productive way.

In addition to the great attention paid to the problem of the ergonomic modeling of technical systems, the method of anthropometric adjustment of the vehicle and machine cabins to suit drivers and operators has not been systematized and methodologically completed, although it is known that human error causes 85.2% of vehicle accidents and 60% of the accidents in lifting operations (Hesse et al., 2011; Milazzo et al., 2016). In the academic literature, there are research studies on the analysis of anthropometric measurements, most often using univariate modelling methods, such as percentiles, but they rarely orient themselves towards further modelling of the interior space, although the minimization of space can lead to significant effects in the economic, ecological and security areas (Bedinger et al., 2016; Diakaki et al., 2015).

Also, although the process of modeling complex technical systems is very much present in the relevant literature, it still cannot be argued that all aspects of the development of mathematical models, as well as the modeling procedures themselves, are fully known, accurate enough, correct and adequate.

These facts leave enough room for further research in the field of the anthropometric modeling of technical systems.

1.1 The subject and scientific goal of this doctoral dissertation

The subject of this doctoral dissertation's research is the development of a multivariate model for the ergonomic/anthropometric adaptation of the interior space of the cabins of vehicles and machines, with the aim to enable operators to work comfortably and safely, managers to achieve high-level performance, and societies to have cleaner technologies.

The following facts are particularly important: 1. Modern cabins have been designed on the basis of anthropometric measures from decades ago, and today's drivers/operators are about 15 kg heavier, 2. previous research rarely focused on ergonomic factors, although drivers and operators of transport machines have the highest number of median days on sick leave and 6-7 times the risk of fatal outcome compared to other workers, 3. anthropometric measurements of drivers and operators of transport machines are drastically different from those of 30 years ago (Guan et al., 2012), yet those measurements are used today for designing cabins (in the US, the first such research was carried out last year and there is still no such thing in Europe), 4. The rulebook on the safety of machines adopted in the Official Journal of the RS 13/2010 (European Directive 2006/42/EU) requires taking into account the ergonomic principles in the design of machines, and, accordingly, it is necessary to pay more attention to ergonomic design, and 5. the production of cabins and their components can significantly contribute to the increase in industrial production according to a post-crisis model of economic growth, targeting middle and high-tech areas, the production of machines, devices and transport vehicles both in Serbia and elsewhere (Hesse et al., 2011; Brodie, 2010; Strahan et al., 2008; Sieber et al., 2014; Annie and Lucile, 2014; Buntak et al., 2013; Spasojevic Brkic et al., 2015; Brkić-Spasojević et al., 2016).

It is known that the study of the interactions of a person and a machine in a system, in terms of its improvement, that is, adjustments in order to improve the efficiency of functioning, reduce fatigue and preserve human health and ensure optimum working environment conditions, is a challenge for many engineers and machine and vehicle constructors, as well as other experts who deal with this problem. However, in reviewing the existing literature, we conclude that there is very little research dealing with the problem that is the subject of this dissertation, both in the world and in our country. The importance of studying the subject of this dissertation largely exceeds the number of published papers. Thus, it should be noted that a review of the available literature and those results indicate insufficient research and attention to the topic, and the methodology based on multivariate methods is a good basis for solving the problem of anthropometric optimization, which can have a further impact on the community (in line with the European Commission documents, Global Europe 2050, Europe 2020 strategy, Road Safety Programme 2011-2020, eSafety Vision, Vision Zero, directives 2005/27/EC, 2006/42/EC, 2009/104/EC, 2010/40/EC, etc.). Previous research has undoubtedly indicated that the compatibility of the anthropometric characteristics of the drivers/operators of the transport machines with cabin dimensions, as well as the dimensions and position of the equipment in the cabin, affect several very important factors. The first category includes factors related to the effects that an anthropometric mismatch of the cabin (with the equipment in it) has on the user from the aspect of comfort, health and working ability. This is relevant because working positions that are not in accordance with ergonomic and biomechanical recommendations and principles over time lead to the occurrence of occupational diseases and the reduction of working ability. The second category includes factors related to the effects that the anthropometric mismatch of the cabin consequently has on the performance, productivity, and financial losses of the company. The third category includes factors related to the effects that the anthropometric mismatch of the cabin has on safety.

The scientific goal within this doctoral dissertation is to set up and verify the original model for the anthropometric design of the interior space of vehicles and machines, which will arise after the systematization of existing knowledge in the field of ergonomics, risk, safety and health at work in different contextual frameworks with the newly established methodology on methods of multivariate statistics. The newly established methodology will be applied to characteristic examples of the importance in machine engineering - the passenger car drivers' population in order to model the interior space of the cabin required for the comfortable and safe accommodation of drivers and crane operators for the purpose of their comfortable and safe accommodation without distraction in the crane cabin with iterative sampling, both in

Serbia and Libya (the population of Serbia is on average taller with a lower body mass index compared to Libya, while data for specific strata are not available in the literature either in earlier or more recent time periods).

It is also evident that research in the wide field of ergonomics is very scarce in the Libyan context. One of the rare surveys regarding safety issues in Libya (Hammad et al., 2011) concludes that workers on construction sites often do not utilize fall or hearing protection devices, and there is no training performed in hazard identification and elimination. It is also known (Al-Ghaweel et al., 2009) that road traffic accidents are the number one killer in Libya. Accordingly, it would be interesting to offer the very first study of anthropometric data on drivers and crane operators and its modelling in interior space.

In accordance with the subject and the general scientific goal, the following aims at a lower level within this doctoral dissertation can be defined:

- Defining the concept of the subject research;
- Analysis of available research in the field;
- Collection of data on anthropometric measures from the populations concerned;
- Experimental confirmation of anthropometric measures growth and their different demographic distribution;
- Development of an integral multivariate model for anthropometric adaptation with minimal dimensions of the cabin space in which the driver/operator will be ergonomically accommodated;
- Designing the minimum space required for the driver/operator’s accommodation; and
- Validation of the proposed integral multivariate model for the anthropometric adaptation of the interior space of the vehicle cabins and machines by comparison with the results of the univariate methods.

1.2 Starting hypotheses and research methods

The starting hypotheses, which define the subject of the research, are derived from a literature analysis and a real-life situation characterized by the interaction of a person with a vehicle/machine in the modern environment. Namely, numerous problems that result in a large share of human errors indicate the presence of a complex problem that can be largely solved through an adequate anthropometric adjustment in accordance with the actual measures of specific populations. Bearing in mind other numerous development problems in the regions of Serbia and Libya, it is expected that the establishment of an original model for the anthropometric design of the interior space of vehicles and machines will be a useful tool that will enable decision makers in the industries concerned to be more efficient with functional management at the global level. In accordance with this, initial hypotheses have been defined, which should be processed and proved in this dissertation.

The basic hypotheses that can be made on the basis of previous results in the literature can be defined as follows:

H_{01} – The anthropometric measurements of Serbian and Libyan drivers as well as crane operators show significant differences depending on gender, occupation and nationality.

H_{02} – By using multivariate statistics on the data of Serbian and Libyan drivers, as well as crane operators, it is possible to establish a sufficiently precise, original model for the anthropometric design of the interior space of vehicles and machines (namely passenger cars and crane cabins).

Previous research commonly used a univariate percentile method to ensure that a particular product corresponds to a population between the 5th and 95th percentiles, which would be appropriate for 90% of the population of interest. However, when it comes to product design problems involving more than one dimension, this method shows significant drawbacks (Zehner et al, 1993; Lee & Bro, 2008; and Epifanio et al., 2013). The first disadvantage is that in reality there are no people who have all of the dimensions between the 5th and the 95th percentile; it is evident that, for example, a 5-percentile person does not have to have the 5th percentile dimension of all particular body parts. Furthermore, when more than one dimension is involved in the problem of design, the use of percentiles actually involves a significantly lower percentage of the population than the desired 90%. Thirdly, the percentile method as a boundary model, in terms of dimensions, involves only the overall large and overall small models, without taking into account body configurations involving extreme measures of different dimensions. The above leads to the conclusion that when solving the problem of designing which involves more dimensions one should look for a new model that should not use a univariate percentile method (Guan et al., 2012), but a multivariate model should be used. Also, the goal is to limit size, creating the smallest possible space in the adapted interior that will suit a person. Space must be limited by the height, length and width that are determined by the new original methodology, by taking as an anthropometric constraint the combination of extreme pairs and the anthropometric measures series.

On this basis, the following specific hypotheses can be formulated, which will be checked using the anthropometric measurement samples of Serbian and Libyan drivers, as well as crane operators:

H1 - Using an integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy.

H2 - Anthropometric measurements have mechanical and mathematical functions that determine all three dimensions of the space, taking into account over 90% of the population.

H3 - On the basis of a multivariate model for anthropometric adaptation, it is possible to give recommendations for dimensioning the interior of the crane cabin in such a way that comfortable and safe accommodation of the users is ensured.

H4 - On the basis of a multivariate model for anthropometric adaptation, it is possible to determine the dimensions of the minimum required space for a driver in a passenger vehicle in such manner that the driver has comfortable and safe accommodation.

For the successful realization of the research goals and confirmation of the hypotheses of this doctoral dissertation, the basic and specific methods of logical reasoning and scientific knowledge will be used. Methods of analysis, modeling and statistical methods will be used following the basic methods of scientific research. In addition to the basic methods of research, the following special methods will be used:

1. Inductive and deductive methods of conclusion,
2. Analytical and synthetic methods,
3. Causal method,
4. Specific methods of abstraction, generalization and specialization, as well as
5. Comparative method.

In order to successfully fulfill the aims of this research, special scientific methods will be applied, such as descriptive statistics, hypothesis testing and statistical reasoning, as well as multivariate statistical analysis methods together with the principles of biomechanics.

During the research within the framework of this topic of the doctoral dissertation, the following scientific contributions can be expected:

- Establishing databases of the anthropometric measurements of certain populations based on the principles of static anthropometry and proof of the present demographic differences (between Serbian and Libyan drivers and crane operators).
- Defining an original integral research approach based on extreme sizes of pairs/arrays of anthropometric measurements to form an integral model of anthropometric optimization of space and development of an integral multivariate model for the anthropometric adaptation of the driver/operator in the cabin of the vehicle/machine of adequate coverage and accuracy.
- The procedure for designing the minimum space required for the driver/operator.
- By generalizing a defined model for strategy prioritization, a platform will be created for a wider application of research models in other contexts, as well as the possibility of further development and improvement of the model.

2 LITERATURE REVIEW

2.1 Approaches in Anthropometric Design

Anthropometric data are widely used when designing for humans. Namely, establishing accurate recommendations based on anthropometric data is the key to appropriate design. Anthropometric measurements are often taken to check how a relevant population performs various functions and movements in an interior space e.g. anthropometric data are widely used to eliminate or to minimize the mismatch between workers and their working environments. Designers make certain assumptions when using anthropometric data and, based on these assumptions, they develop design recommendations. It is well known that anthropometric measurements depend on gender, race, age, occupation (Spasojević-Brkić et al., 2014a), nationality, and nutrition (Fatollahzadeh, 2006).

A large number of previous studies showed the importance of anthropometric data usage when designing for drivers or operators.

In a study about truck drivers (Guan et al., 2012), a large sample was collected in 15 states across the continental part of the United States. The sample consisted of 1,950 persons (1,779 men and 171 women); data were collected in the period from January 2006 to March 2009, taking into account age, gender, race category, and body weight. The anthropometric measurements were taken from participants wearing street clothes, by means of anthropometric instruments (i.e. beam caliper, sliding caliper, and steel tape). There were two types of anthropometric dimensions taken: static and dynamic (Fatollahzadeh, 2006). Static dimensions refer to the actual size of a human body, while dynamic dimensions (functional measures) refer to the ability of a body to achieve certain tasks in a certain determined space, type of travel and enclosure, and include the description of measurement of human mobility, agility, or flexibility (Fatollahzadeh, 2006).

Designing for a fixed percentile (e.g., 5^{th}, 50^{th}, or 95^{th}) is the most frequent method. It simply implies that an individual with a given percentile stature would also be in the same percentile as far as the other body dimensions are concerned, and that is not realistic. For instance, when designing for the 50th percentile, even if a tolerance of 15% is given above and below each dimension, no single complete set of body dimensions can be included (Roebuck et al., 1975). Porter et al. (1993) confirms that people vary considerably in their body proportions and that very few people can be expected to be consistently around a certain percentile (usually 95th, 50th or 5th) for more than a few measurements and provides persuasive data about percentile values for a number of body dimensions recorded by a small sample of British automotive engineers of the Vehicle Ergonomics Group at Loughborough University (Figure 2.1**).** Also, if a person's stature is broken down into few vertical dimensions then the total stature differs significantly from the sum (Hertzberg, 1960). Accordingly, the percentile approach is applicable only in the case of a small number of dimensions and at least one unique nationality (Guan et al., 2012).

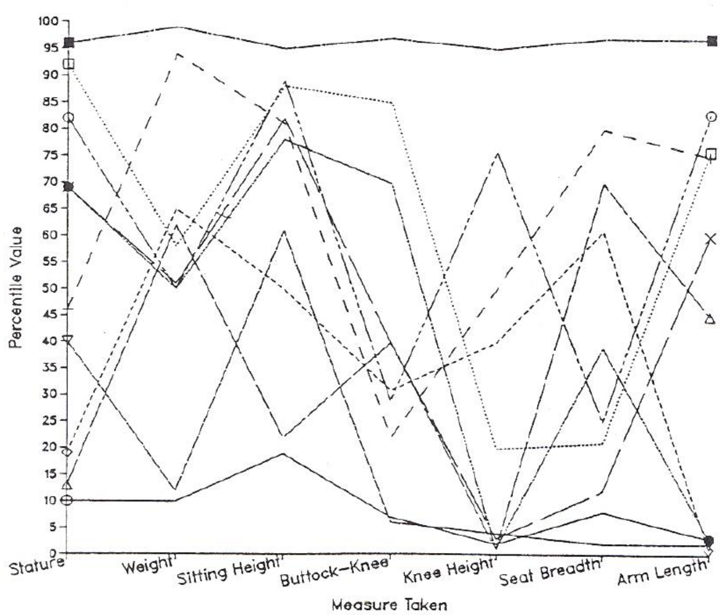

Figure 2.1 Percentile values for a variety of dimensions from a sample of British automotive engineers (*n*=10) (Porter et al., 1993)

An interior space designer has to search for other techniques to ensure that the models are statistically correct. One method is to measure a group of men or women who are in the 5th or 95th percentile in both stature and weight and to calculate the median values of all other dimensions among the group (Haslegrave, 1986). These median values are additive, allowing the model to be statistically ‘correct'. But the problem with this approach is that, unless the total sample is very large, the number of people who fall into the two extreme categories is likely to be quite small.

Whatever method is chosen to define a variety of statistically 'correct' models, there is still the problem of estimating the percentage of people accommodated by a particular design. A common mistake made by many automotive manufacturers is to use the 5th percentile female stature and 95th percentile male stature manikins to assess a driving package, because in that case a large percentage of persons is not covered, on average 30%, depending on the number of included dimensions (Porter et al., 1993).

The Principal Components Analysis (PCA) with the Varimax rotation method and the Kaiser Normalization might be applied to anthropometric data to evaluate the design and comfort of vehicle seats according to several papers (Brkic et al., 2015, Chung et al, 2004; Fatollahzadeh, 2006; Guan et al., 2012; and Spasojević-Brkić et al., 2015). There were four factors extracted in the survey (Fatollahzadeh, 2006), namely: 1) variables of length segments, 2) variables of the weight and volume characteristics of drivers, 3) variables of the height of segments and 4) variables of hand length and foot breadth. Guan et al. (2012) applied the Multivariate Accommodation Model (MAM) for 35 anthropometric dimensions and found that MAM is an effective approach in design. Guan et al. (2012) again claim that the 5th - 95th percentile approach can be criticized for a decrease in accommodation when there is more than one dimension involved in the design. In the same study, the authors used SAS software and found that 12 sets of dimensions were reduced. Nadadur, and Parkinson (2012) proposed the Anthropometric Range Metric (ARM) approach for assessing the variation of 24 body measures for the populations of nine different nationalities. Kolich et al. (2004) used multivariate modelling techniques - stepwise, linear regression and the artificial neural network on data collected on seat-interface pressure measures, anthropometric characteristics, demographic information, and perceptions of seat appearance, while Park et al. (2000) found a difference in preferred driving posture between two different ethnicities - Koreans and Caucasians.

Such studies lead to the conclusion that workplace design depends on the approach applied in data modeling, in the anthropometric characteristics of users, and that national background can have a significant effect on workplace design and modelling due to the differences in anthropometric characteristics (Park et al., 2000).

A survey by Klarin et al. (2011) adopts methodology based on the fact that in a range of anthropometric measurements of equal total lengths, each measurement has segments of different lengths because people with the same leg length often have different upper and lower leg lengths. According to that fact, the passenger car interior space design should accommodate extreme measurements in a manner that anthropometric measurements behave as mechanical mechanisms (Klarin et al., 2011). In the same context for Serbian drivers, authors have found that the hip width in a sitting position has a significant effect on seat width, while the shoulder width affects hand control and car width, as well as that shoulder width, had a high variation among the same population, which gives an indication that male drivers' shoulder width is greater than the shoulder width of female drivers for this population (Klarin et al. 2011). Moreover, the use of modern anthropometry data for interior modelling is recommended, since there are significant differences in seat dimensions compared to the International Standards Organization (ISO 8566-5, 1992) standard (Brkić et al., 2015). Klarin et al. (2009) have also pointed out that there is a difference in the angle of foot controls (towards the space reach of driver toe and heel) from 70º to 62.5º. Such differences justify the need for continual evaluation of interior vehicle space design and modelling, with different approaches used in order to quantify and determine the parameters related to interior vehicle space modelling (Essdai et al., 2017). On the other hand, the use of the univariate, percentile approach indicates that certain construction constraints of the components in the crane cabins are the main reasons for reduced visibility and improper working postures of operators (Zunjic et al., 2015). Kushwaha and Kane (2016), Brkić et al. (2015) and Gustafson-Söderman (1987) conducted, surveys that also use the percentile approach. One of the rare surveys to use the factor analysis for crane operators is Spasojević-Brkić, (2014b), and it indicates the significance of the main crane operators' anthropometric measures and provides an initial framework for the design of the workplace.

In previous research studies, authors have applied not only different approaches but devices for measurement, too. For instance, a survey conducted by Klarin et al. (2009) used a 3D scanner to determine the joint angles. Such a device provided a more effective approach that saved time and made angle measurement very easy. Nadadur (2012) has used a 3D scanner to collect anthropometric dimensions from the North American and European population, but there were limited data since the 3D scanner is not a portable device. In the case of large-scale anthropometry studies, the conventional anthropometric measurement tools are found to be more practical (Heuberger et al., 2008; Del Prado, 2007; Omić et al., 2017; and Barroso et al., 2005).

2.2 The vehicle interior space modelling

Previous studies show that there is a need to optimize the interior vehicle space and to enhance the safety and comfort of multi-users. Klarin et al. (2011) have shared an opinion that the passenger car is still not adapted enough to a human being and proposed a solution for optimal workspace for foot controls accommodation so that foot controls would be positioned horizontally along the *x*-axis from the “0” point forwards at 320mm, and vertically along the *z*-axis at 230mm, while space height along the z-axis amounts to 465mm, determined in terms of four segments by the anthropometric measurements of the foot of the 95th percentile man and the 5th percentile woman, according to the Serbian population of drivers. The angle for knee movement in the x-y plane when the lower leg and sitting height form a 90º angle, from the hip forward is 33º for the 5th percentile man, 53º on average, and 73º for the 95th man. The values of flexibility inwards are 11º, 31º, 51º, as shown in Figure 2.2, Klarin et al. (2011). Moreover, a survey by Klarin et al. (2009) introduced an algorithm in terms of mechanical rules with respect to the anthropometric mechanisms, by applying coordinates, the “0” point located at the contact point between the shoe heel and floor line of the vehicle, to quantify the design of a driver-passenger car system. The findings have shown the following values for controls accommodation: horizontally, the *x*-axis is 320mm, vertically, along the z-axis is 230mm, and the space height along the *z*-axis amounts to 460mm while for foot controls location and use, the foot control angle is 62.5º towards the space reach of the driver’s toe and heel, although the technical literature suggested 70º.

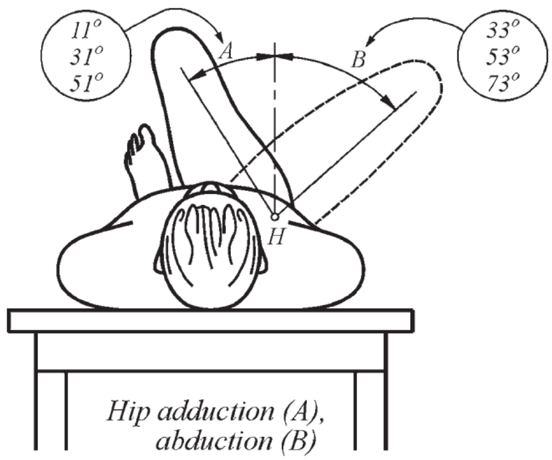

Figure 2.2 Upper leg range (Klarin et al., 2011)

Andreoni et al. (2002) states that the ergonomic details and approach used in determining and evaluating the interface between the driver and the car are vital in order to ensure high visibility with easy reach of all controls and displays, and, upon that, it is evident that real progress could be achieved in interior vehicle modelling.

Kolich (2003) points out that there are two very important kinds of ergonomic criteria: physiological and anthropometric.

Most of the previous seat design studies have focused on physiological factors such as vertebral discs, muscles, joints, and skin. These could be quantified through the electromyography device (Bush et al., 1995; Lee and Ferraiuolo, 1993; Sheridan et al., 1991), disc pressure measurement (Andersson et al., 1974), vibration transmissibility (Ebe and Griffin, 2000), and pressure distribution at the occupant–seat interface (Kamijo et al., 1982; Hertzberg, 1972). It is evident that such studies do not take into consideration human anthropometric characteristics (Reed el at. 1991). Hence, the preferable driver posture could not be achieved without considering the anthropometric criteria. Guan et al. (2012) conclude that there were anthropometric changes in width and girth between truck drivers across a quarter of a century.

According to various previous research results it can be concluded that when aiming to model the optimal workplace, enhance work efficiency, improve safety and comfort concepts (Fatollahzadeh, 2006 and Klarin et al., 2009), further research is needed since the interior space of a passenger car is not adapted enough for a human being.

There is also the significantly dynamic nature of anthropometric measures which leads to the conclusion that the updating of anthropometric data is a vital task for ergonomic design. In this context, Klarin et al. (2011) have also mentioned a fact that anthropometric measurements change over time. Heights have increased, whereas other dimensions, i.e. foot length, shoulder width, and hip width have varied too, and therefore the anthropometric measurements should be continuously monitored. The recent accomplishment of empirical/prediction models (i.e. multiple linear regression, artificial neural network) in improving vehicle seat comfort are more effective in cost and time than the trial and error approach, which is time-consuming, expensive, and prone to measurement errors related to reliability and validity.

The RAMSIS tool has been established to verify interior vehicle layout, i.e. joint angles. RAMSIS stands for Rechnergestütztes Anthropometrisches Menschmodell zur Insassen Simulation (Computer-Based, Anthropometric Human Model for Passenger Simulation). It was used by Vogt et al. (2005) to create a dependable and theoretically justified approach to design interior vehicle layout. Along with RAMSIS, several authors and standards (Bubb 1992, Dupuis 1983, Rebiff 1996, and DIN 33408, 1981) recommend the ideal joint angles for sitting in a passenger car, as defined in Figure 2.3, and their values illustrated in Table 2.1.

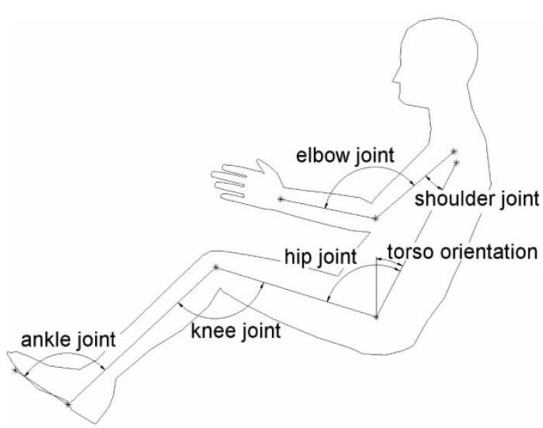

Figure 2.3 Posture joints definition (Vogt et al., 2005)

Table 2.1 Recommended joints angles for sitting in a passenger car (Vogt et al., 2005)

Recommended Joint	RAMSIS	Bubb (1992)	DIN 33408 (1981)	Dupuis (1983)	HdE (1998)	Rebiffe (1996)
Torso orientation	27º	-	-	-	-	-
Shoulder joint	22º	9º - 69º	38º	-	-	0º - 25º
Elbow joint	127º	134º - 158º	120º	-	-	80º-20º
Hip joint	99º	101º - 113º	95º	105º-115º	110º	95º-20º
Knee joint	119º	142º - 152º	125º	110º 120º	145º	95º-35º

Vogt et al. (2005) define a concept for an interior layout process in terms of the ergonomic posture of the human body and comfort angles for the human skeleton (Figure 2.3), with four theoretical seating concepts that cover eye point, hand point, or heel point, as illustrated in the flowchart shown in Figure 2.4. By setting either eye point, hip point, heel point, or hand point, as fixed points for all anthropometric types (as defined by the RAMSIS typology in Table 2.2) the adjustment fields in each case of four theoretical concepts could be obtained as shown in Figures 2.5, 2.6, 2.7, and 2.8 by Vogt et al. (2005) (all dimensions in mm).

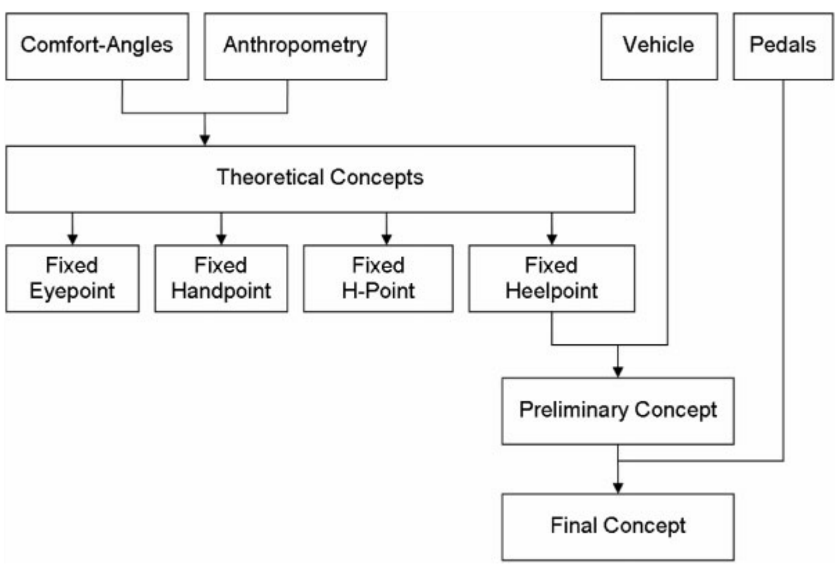

Figure 2.4 Interior vehicle layout concept (Vogt et al., 2005)

Table 2.2 RAMSIS Typology (Vogt et al., 2005)

Gender	Male – Female
Body height	Very short – Short – Medium -Tall – Very tall
Torso length	Short torso – Medium torso – Long torso

Vogt et al. (2005) conclude that the final seating concept could be described as illustrated in Figure 2.9 (All the dimensions in mm) with the recommendation that the concept generated by RAMSIS needs more verification for real use to uncover the weakness of the adjustment fields.

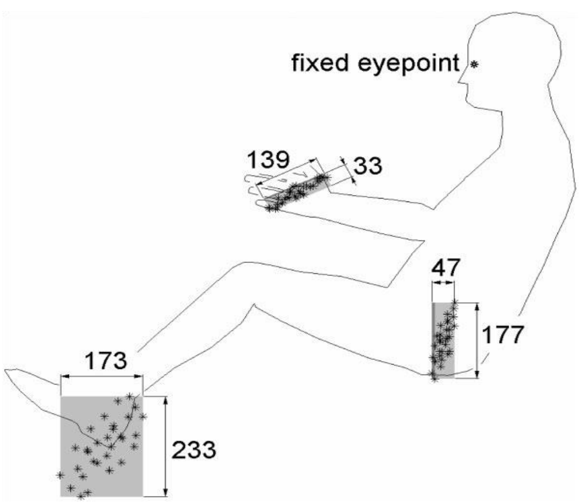

Figure 2.5 Fixed eye

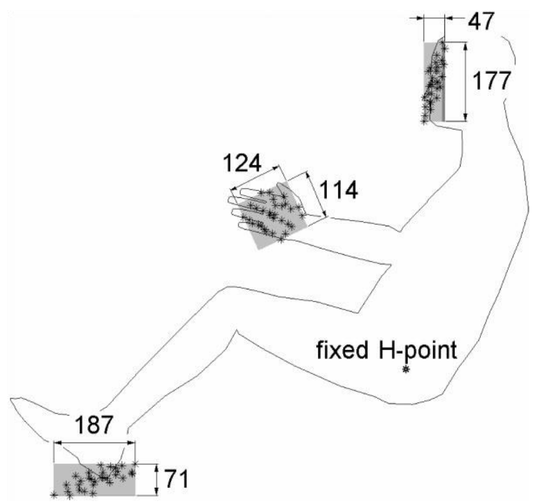

Figure 2.6 Fixed hip point

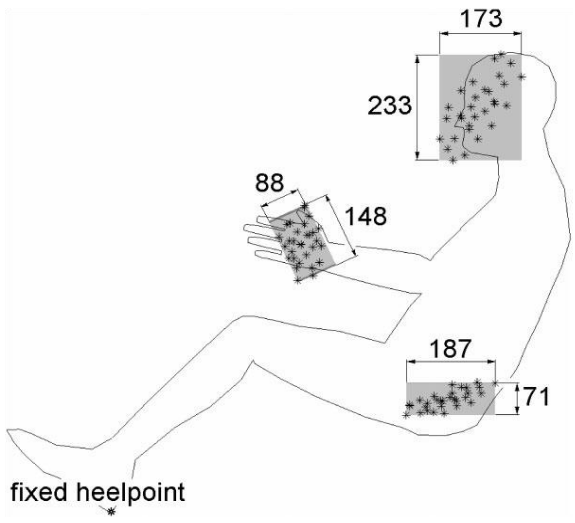

Figure 2.7 Fixed heel point

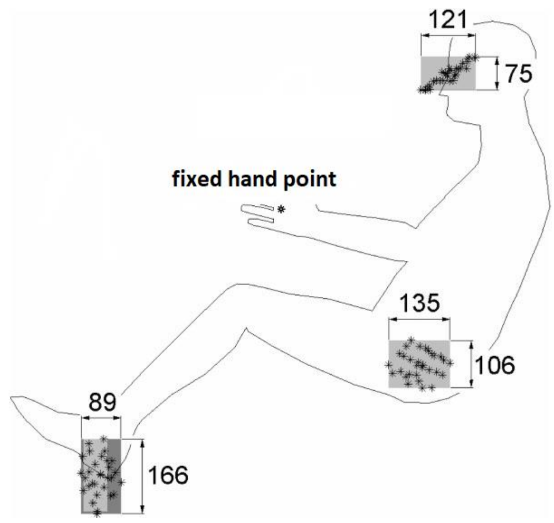

Figure 2.8 Fixed hand point

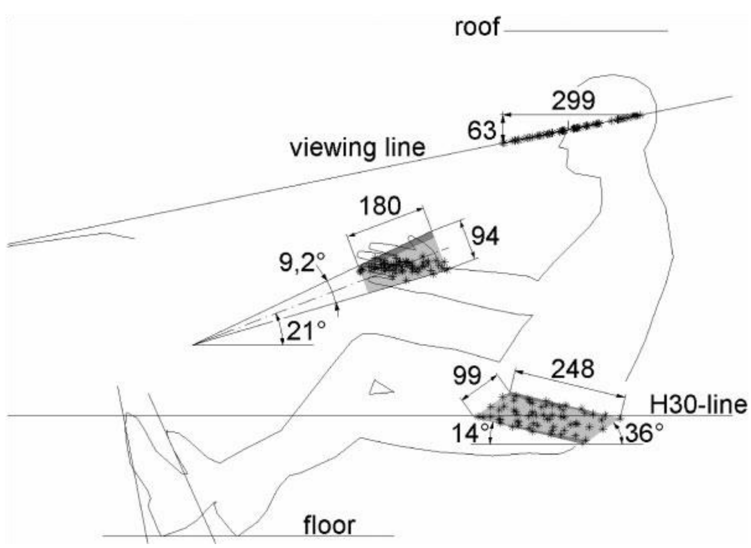

Figure 2.9 Final concept (Vogt et al., 2005)

Parkinson et al. (2005) and (Parkinson and Reed, 2006) have introduced a new approach to the optimization of interior vehicle modelling, and Figure 2.10 shows their methodology.

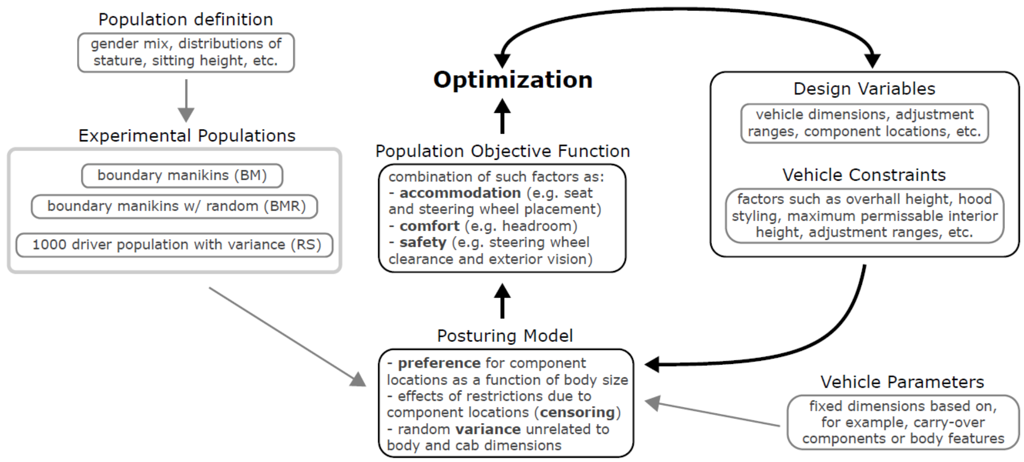

Figure 2.10 Flowchart of the optimization process (Parkinson and Reed, 2006)

Most previous studies reflect the fact that the changes and variations that take place over time in human anthropometrical characteristics are due to related factors i.e. gender, age, race, occupation, nationality, and nutrition (Spasojević et al., 2014a; Fatollahzadeh, 2006; and Guan et al., 2012). In addition, changes take place over time (Klarin et al., 2011) and lead to the fact that the updating of anthropometric data is a vital element in comfort design, particularly in vehicle interior design (Parkinson and Reed, 2006). Klarin et al. (2011) pointed to the need for continual evaluation of interior vehicle space design and modeling, with different approaches such as the algorithm model, that could be used to quantify and determine the parameters related to the interior vehicle space modelling, while Kolich et al. (2004) have shared the opinion that the use of empirical/prediction models (i.e. stepwise multiple linear regression) would be more effective and should be more widely used.

Vehicle interior space modelling includes aspects of seat comfort, human interactions, visual displays of location, pedal controls, reaches etc. All those aspects should be taken into account in the ergonomic design of vehicle interior, in order to achieve satisfactory driving tasks in terms of safety, driver feedback, and driving tasks execution in a comfortable manner. Numerous studies have researched those aspects in order to improve driving task performance through ergonomic design.

A survey by Fatollahzadeh, (2006) indicates that the anthropometrical characteristics of truck drivers have a significant effect on the perceived comfort that influences a driver's performance. Fatollahzadeh, (2006) also notes that the interaction between the driver's mental view of the surroundings and infrastructure and vehicle displays have a vital role in performing the task. In addition, the quality of the interaction and the options that drivers select to handle driving tasks depend on their knowledge, education, and experience, which are considered to be the main factors in handling a task appropriately and safely.

Park et al. (2000) investigated the relations among drivers' physical dimensions, their driving posture, and preferred seat adjustments after collecting data on 43 drivers (24 males and 19 females) from Korea, representing a range of percentiles (5^{th} – 95^{th}). All the gathered anthropometry data was based on ISO 3635 (1981) and the Korean Standards Association (KSA, 7004, 1989) and found that there is no significant difference in mean and standard deviation from the Korean standard. Park et al. (2000) showed there was a difference in preferred driving postures between Koreans and Caucasians. The same study (Park et al., 2000) found a strong positive correlation between knee angle and shoulder angle (r=0.762, p<0.01), and a strong positive correlation between knee angle and foot-calf angle (r=0.720, p<0.01). For instance, the trunk-thigh angle was related to all postural angles (p<0.05). Therefore, the trunk angle increases as the knee angle, elbow angle, foot-calf angle, and shoulder angle are increased, but the knee angle and foot-calf angle are not correlated with the elbow angle. A laboratory study of 68 adult drivers, found that seat height, steering wheel position, and seat cushion angle, have considerable effects on posture, and concluded that a driver adapts to changes in the vehicle and seat geometry through limb posture, while torso posture remains fairly constant (Reed et al., 2000).

A static analysis study of the car driver posture that assessed the biomechanical features in the interaction between the driver and the seat, by using an optoelectronic system for motion capture and suitable matrices of pressure sensors, found the lumbar flexion angle to be an indicator of postural comfort, and the same angle for all the participants is described by Andreoni et al. (2002). Andreoni et al. (2002) claim that a multi-factor method should be applied to the study of car driver posture and propose to consider the lumbar flexion angle as an indicator of postural comfort.

In an optimization study, Spasojević-Brkić et al. (2014a), Klarin et al. (2009), and Klarin et al., (2011) discuss an adaptation of the passenger car to driver, including the limits of anthropometric measurements and technical limitations of the car, in order to improve the comfort, safety, and efficiency of vehicle operation. Serbian drivers' data were used to propose an original methodology for interior space modelling that uses point "0" as the origin point of a coordinate system with *x*, *y* and *z*-axes of the person-vehicle system, and show that the anthropometric measures of length have mechanical and mathematical functions that determine the width of interior space together with shoulder width measure, while the floor-ceiling height of a vehicle is primarily affected by the anthropometric measurements of seating height and lower leg, so that the interior space necessary to accommodate the driver of a passenger vehicle comfortably is 1,250mm in height with a width of 926mm needed for knee spread. The width space needed for foot control at the level of the pedals is about 460mm wide and 200mm high, the distance needed between the clutch pedal and the break is 50mm, and the distance needed between the brake pedal and accelerator pedal is 60mm (Klarin et al., 2009).

Fazlollahtabar, (2010) has studied seat comfort in order to quantify consumers' preferences by means of a multi-criteria decision-making technique, which is composed of the Analytical Hierarchy Procedure (AHP), Entropy method, and Technical for Order Preference by Similarity to an Ideal Solution (TOPSIS). Fazlollahtabar (2010) pointed out two categories of criteria: (1) The physiological ergonomics criteria which are quantified by means of the electromyography device (Bush et al. 1995; Lee and Ferraiudo 1993; Sheridan et al. 1991), which deals with muscles, joints, skin, and vertebral discs, (2) The anthropometric ergonomics criteria, which are vital aspects of comfortable seating (Akerbom, 1949), since seat designs adopt a range of appropriate anthropometric dimensions typically to the 5th percentile female and the 95th percentile male, (3) The subjective perceptions of comfort criteria. In this respect, the apex of the lumbar contour should be positioned between 105 and 150mm from the H-point, and 471mm should accommodate the 95th percentile female buttock - to - popliteal length of 440mm, which is just about 305mm from the H-point (Reed, 1994; Fazlollahtabar, 2010).

By applying the principle of anthropometric accommodation, the minimum cushion width must exceed the 95^{th} percentile female sitting hip breadth of 432mm (Gordon et al., 1997; Reed, 1994).

Chung et al. (2004) have described many previous studies that relate to driving postures which considered the most important variables of driver space such as Philipport et al. (1984), who pointed out that the steering wheel position affects the driver's posture. Imeman (1993) investigated adjustable pedals through broad anthropometric data sources, including the wide variations of people. In addition, Shin et al. (1997) proposed adjustable pedals to control the safe space between the pedal and the upper body of shorter women. These studies lead to the conclusion that the automotive industry is required to accommodate ergonomic data in order to develop products that consider the physical characteristics of users; otherwise, these products will not be comfortable and satisfactory. In order to achieve a proper driving posture, the industry must ensure wide visibility, easy reach for all car control and displays, in addition to the ergonomic details available and the assessment criteria used to analyze and evaluate the interaction between the driver and the car (Andreoni et al., 2002). In a vehicle seat comfort study, by Kolich et al. (2004) a statistical model was used (stepwise multiple linear regression) and compared to an artificial neural network and found that the neural network approach has higher (r^2) values (0.8 vs. 0.713), and low average error values (1.192-1.779). The author mentioned the artificial neural network in another option to predict the vehicle seat comfort, and it can be used, despite the fact that this approach of modelling has not been widely used by ergonomists (Kolich et al., 2004).

A survey of auto seat design (Reed, 1994) has pointed out recommendations for improved comfort, and divided seat design parameters associated with seat comfort into three groups: (1) Feel parameters that are related to the physical contact between the sitter and the seat, including the pressure distribution and upholstery properties, (2) Support parameters that affect the posture of the occupant, including seat contours and adjustments, (3) The fit parameter level, determined based on noting the limiting values among the 5^{th} percentile-female and the 95^{th} percentile-male, for particular anthropometric dimensions. For instance, the 95^{th} percentile-female hip width is used as a specification limit since it's greater than the 95^{th}

percentile-male, and in the same way, the minimum cushion width would be chosen to be greater than the 95th percentile-female seated hip breadth of 432mm (Gordon et al., 1989). Grandjean (1980) suggests a cushion width of 480mm in order to accommodate the clothing of the sitter. Other authors specify the hip width as illustrated in Table 2.3.

Table 2.3 Comparative analysis of surveys in determining hip width for auto seat design (Reed, 1994).

Reference	Hip width(mm)	Clarification
Chaffin & Anderson (1991)	457	A study of 143 women aged 50-64years 95th percentile.
Schneider et al. (1985)	439	A study of 25 males of driver anthropometry 95th percentile by stature and weight.
Grandjien (1980)	480	Recommended as minimum clearance at the hips to accommodate large females with clothing and an allowance for leg splay
Maertens (1993)	500	Authors do not specify the position at which this dimension is measured

While the cushion length analysis is more complicated than the cushion width, due to the fact that it is constrained by the buttock-to-popliteal length of the small women segment of the population, the previous studies stated convergent values as shown in Table 2.4 (Reed, 1994).

Table 2.4 Comparative analysis of surveys in determining cushion length for the auto seat design (Reed, 1994).

Reference	Length cushion (mm)	Remarks
Gordon (1989)	440	5th percentile women buttock-to-popliteal length
Chaffin& Anderson (1991)	330-470	For general chair design, measured from the furthest forward contact point on the backrest to the front edge of the chair
Keegan (1964)	432	
Grabdjean (1980)	440-550	
Maestrten (1993)	380	

Furthermore, Rebiffe (1969) pointed that the most important posture angles for comfort, as defined in Figure 2.11, are the back, trunk/thigh, and knee angles, which represent the relative orientation of the trunks, thigh, and leg. The author recommends ranges for those body segment angles as given in Table 2.5. Table 2.6 summarizes the recommended fit parameter levels, which are linear (Reed, 1994).

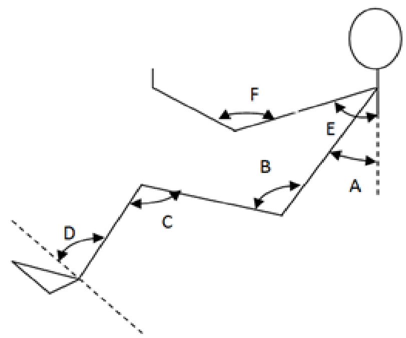

Figure 2.11 Definitions of posture angles in Rebiff (1969)

Table 2.5 Recommended range of body segments angles according to Rebiffe (1996)

Angle	*Recommended Range (degrees)
A - Back	20-30
B - Trunk/Thigh	95-120
C - Knee	95-135
D - Ankle	90-110
E - Upper arm	10-45*
F - Elbow	80-120

*These values are on hand support and seat back configuration.

Table 2.6 Recommended dimensions ranges of different fit parameter levels (Reed, 1994)

Parameter	Recommended dimension range (mm)	
	Should not be less than	Should not be more than
1 - Cushion width		
1-1 - Actual width H-Point	432	-
1-2 - Clearance at H-point	500	-
1-3 - Width at front of cushion	500	-
2. Cushion Length		
2.1 Forward of H-point on thigh line	-	305
3 . Backrest Width		
3.1 At waist 220mm above H-point	360	-
3.2 At chest 318mm above H-point	456	-
3.3 Height of side bolsters above H-point	-	288
4. Backrest height	410	550

Reed (2000) has found that the seat cushion angle, seat height, and steering wheel position, seat height, and seat cushion angle have significant effects on driving posture, which is mostly independent of body size, and gender. In this study, the authors define the posture variable as in Table 2.7.

Table 2.7 Posture variables definitions (Reed, 2000)

Variable	Definition
Hip-X	Fore-aft distance from the mean hip joint location to the ball-of-foot reference point
Hip-to-eye angle	Angle in the side view (*x*, *z*) plane of the vector from the mean hip joint to the center eye point with respect to vertical
Center eye point	An eye location estimates on the body centerline with the fore-aft coordinate of the infraorbital landmark, the lateral coordinate of the glabella landmark, and the vertical coordinate of the corner-eye landmark
Pelvis angle, thorax angle, head angle	x, z (side view) plane angle of the respective segment with respect to vertical
Lumbar flexion	Pelvis angle minus thorax angle
Cervical flexion	Head angle minus thorax angle
Elbow angle	Angle between the arm and forearm segments in the plane of the segments; smaller values indicate greater flexion
Knee angle	Angle between the thigh and leg segments in the plane of the segments; smaller values indicate greater flexion

The results of effects of steering wheel position and seat cushion angle as given by Reed, (2000) are as in Table 2.8.

Table 2.8 Effects of steering wheel position and seat cushion angle (Reed, 2000)

Variable	Normalized Steering Wheel Position (–100 to +100 mm)	Seat Cushion Angle (11°–18°)
Hip-X (mm)	89.6	–6.0
Hip-to-eye angle	3.1	0.59
Lumbar flexion	-	2.0
Cervical flexion	-	-
Elbow angle	–26.5	-
Knee angle	16.3	–3.6

In the Serbian drivers' population study, the maximum width needed for accommodation along the *x*-axis is 169mm, at lowest level of seat, and 1,013mm along the *y*-axis, with the upper-leg angle of 26º between the axis of symmetry and the corresponding plane for leg room (Klarin et al., 2011). In addition, the authors stated that the hip width in sitting position has significant effects on the seat width, while the shoulder width effects the hand control and car width. The authors concluded that the Serbian population of drivers (male and female) characterized by slightly variation at hip width in sitting position, in all percentiles as shown in Table 2.9, shows the average difference of hip width among the male and female drivers of about 20.6675mm (Klarin et al., 2011)

Table 2.9 Hip width of Serbian drivers' population (Klarin et al., 2011)

Percentile	Hip width of males (mm)	Hip width of females (mm)	Difference (mm)
5^{th}	320.13	299.47	20.66
50^{th}	390.70	370.02	20.68
95^{th}	461.24	440.57	20.67
99^{th}	490.44	469.78	20.66

With shoulder width there is a high variation for the same population, as shown in Table 2.10, with an average difference of 84.1mm. This indicates that the male drivers' shoulder width is greater than shoulder width of female drivers for this population.

Table 2.10 Shoulder width of Serbian drivers' population (Klarin et al., 2011)

Percentile	Shoulder width of male drivers (mm)	Shoulder width of female drivers (mm)	Difference (mm)
5^{th}	392.76	355.61	37.15
50^{th}	471.21	412.26	58.95
95^{th}	549.66	468.91	80.75
99^{th}	651.92	492.37	159.55

The vehicle manufacturers tend to make an effort to widen the perceived space as an alternative of physical space, which is difficult to extend due to cost and physical constraints. In this regard, a study was conducted of the vehicle interior space design in terms of the driver–passengers' physical effect based on illusory design, to examine the effects of car interior design including optical illusions for three parts of the car, the instrument panel, the door-trim armrest, and the a-pillars, using 3D image projection. The results show that these three parts of the car can make in-vehicle spaces seem larger than the original design (Yang et al., 2015).

The interior vehicle space modelling and design has been studied and researched from different aspects and points of view in previous studies, such as sitting posture, seat comfort, and accommodation of vehicle drivers in terms of anthropometric dimensions. Fatollahzadeh,

(2006) found that anthropometric characteristics of a truck driver have significant effect on perceived comfort, while Park et al. (2000) found a difference in preferred driving posture between two different ethnicities - Koreans and Caucasian. Such studies lead to the conclusions that each work place design and modelling in terms of comfort depends upon the anthropometric characteristics of users, and that the nationalities can have a significant effect on workplace design and modelling since there are differences in anthropometric characteristics. Authors Reed (1994), Chung et al. (2004) and Reed (2000) agreed that seat cushion angle, seat height, and steering position have significant effect on the comfort of a driving posture. On the other side, the 5th percentile women and the 95th percentile men approach assists the designer in selecting the appropriate anthropometric dimensions among the percentiles that are ergonomically fit for an occupant. For instance, it is recommended that the 95th percentile women hip width should be used as a limit dimension of cushion width since it’s greater than the 95th percentile men, and so on in the same context (Reed, 1994).

2.3 Crane cabin interior space modelling

Cranes are a central component of many operations. They are used in the construction industry to move materials, in the manufacturing industry to transport and assemble heavy equipment, in the maritime industry for shipbuilding and maintenance and in the railroad industry to load/unload cargos etc. (Milazzo et al., 2016; Fang et al., 2016; Sanfilippo et al., 2016; and Dotoli et al., 2017). Occupational fatalities and injuries caused by the operation of cranes pose a serious public problem (Aneziris et al., 2008). When properly operated, cranes contribute substantially to the efficient progress of work, but they also have the potential to cause enormous loss of life and property (Raviv et al., 2017). Some estimates suggest that cranes are involved in up to one-third of all construction and maintenance fatalities (Neitzel et al., 2001). A tipped, dropped, or mishandled load can create lethal injuries, non-lethal permanent injuries and recoverable injuries (Aneziris et al., 2008). This risk of loss is not limited only to those directly involved in construction operations, but also to pedestrians and other workers who could be injured or killed (Neitzel et al., 2001). Obviously, these kinds of accidents also have huge cost implications (Lee et al., 2006). Mobile cranes have the highest accident rates, while North America is considered to be the part of the world where the most accidents take place (Milazzo et al., 2016). Worldwide accident records over the last 5 years show that under existing regulations regarding crane safety, rates of injuries/illness could be considered as constant all over the world while poor human performance as an influential factor is a growing trend (Milazzo et al., 2016; Tam and Fung, 2011).

Crane operators remain in cabins for the entire working day (Fung et al., 2016; and Bongers et al., 1988). Tight schedules usually hinder the implementation of site safety measures as shown in the example of a construction site in China (Fung et al., 2016). Construction sites have special safety regulations provided by large number of various bodies (Chandler and Delgado, 2001). The space within the crane cabin is adequate for only 18.5 % of operators, while 28.9 % of them feel extremely uncomfortable (Spasojević-Brkić et al., 2014b).

A large number of standards, issued at the national or international level, by government, military, manufacturing or other organizations, could be implemented in crane cabin design. Chandler and Delgado (2001) prepared guidelines covering all existing standards for overhead cranes in order to aid human factors engineers in evaluating the existing cranes during accident investigations or safety reviews. For instance, the standard ISO 8566-5 (1992) defines the necessary crane cabin dimensions as 1300×900×1600 mm.

Crane operators spend long hours operating cranes and often work under pressure. They spend at least 6 and often up to 8 hours a day working in shifts in a static sedentary position in cabins that are often located high above the ground (Fung et al., 2016; Bongers et al., 1988; Chandler and Delgado, 2001; Kushwaha, and Kane, 2016; Ray and Tewari, 2012; Le et al., 2014; and Shapira et al., 2014). Accordingly, the ergonomic design of crane cabin is vital to prevent the occupational diseases of crane operators, which can be achieved through a better understanding of the anthropometric characteristics of crane operators (Ray and Tewari, 2012). The crane operators' job in current crane cabins demands frequent body twisting to reach controls and see the load, deep sideways bending and exposure to vibrations due to load stopping (Bongers et al., 1988; Shapira et al., 2014; Bovenzi et al., 2002; Reed and Flannagan, 2000; and Kittusamy et al., 2004). The physical demands of the crane operator's job include forceful and/or repetitive movement and an awkward and static posture of various body segments under vibrations exposure. On the mental level, they have to keep an eye on their work and be aware of the position of the hook and the object in relation to other equipment, the building and other personnel (Zunjic et al., 2015; and Kittusamy et al., 2004).

Kushwaha and Kane (2016) noticed in their sample of 27 operators that all of them continuously suffered from some kind of a musculoskeletal disorder. Neck, upper back and lower back pain, thigh/hip and knee pain were the most frequently reported disorders (Kushwaha and Kane, 2016). Burdorf and Zonderman (1990) carried out a survey among 33 crane operators in a steel factory and recommended that persons with a history of back complaints not seek employment as crane operators because further vibrations caused by crane movement would exacerbate their health problems. Zunjic et al. (2015) also noticed that crane operators complained about fatigue, discomfort and pain, mostly located in the back, neck and shoulders. Bovenzi et al. (2002) found there were 40-60% of operators with a 12-month prevalence of lower back pain. Kittusamy and Buchholz (2004) further argued that awkward posture during the operation of heavy construction equipment was a consequence of improper cabin design and work procedures. Kittusamy and Buchholz (2004) emphasized that the poor visibility of the task, limited room in the cabin, excessive force required to operate levers/pedals, and improper seat designs were some of the characteristics of a poorly designed cabin. Compared to other operators, taller crane operators (over 170 cm) are probably the most vulnerable workers because they have a more forward-flexed posture, which induces a very high flexion-relaxation response and ligaments tension (Ray and Tewari, 2012; Lee et al., 2014). Carragee et al. (2008) have presented the conclusion that among workers in manual occupations, the annual prevalence of neck pain varied from 16.5% among spinning industry production line workers in Lithuania to 74% in Swedish crane operators, who are among the tallest in Europe, the prevalence of neck pain mostly commencing at the interface between the operator and workplace due to workplace risk factors that are ergonomically not yet adapted (Côté et al., 2009). Ray and Tewari (2012) studied 23 body dimensions of 21 crane operators to minimize the anthropometric mismatch within the enclosed workspace. They found many mismatches even among the 50th percentile Indian crane operator population on site with the existing work system. Using the example of the crane cabin manufactured by Mac Gregor that operates in Sweden, Nordin and Olson, (2008) have discussed crane operators' comfort and concluded that the given cabin was not suitable for the majority of users due to inadequate posture, the incorrect placement of regulators and indicators, and the poor visual field of an operator. The uncomfortable working positions, which often limit the unconstrained performance of working movements, together with the mental effort needed to ensure as good a vision field as possible, forces the operator to work more slowly and hence decreases productivity and safety (Zunjic et al., 2015). Veljkovic et al. (2015) have conducted an evaluation of crane cabin safety and ergonomic characteristics based on data collected for benchmarking analysis in the Swedish port. Six crane cabin types were examined regarding eight characteristics divided in three groups: operator-control devices interaction, safety and anthropometric adjustment according to needs weighting data. Analysis of those data shows that only 52.5% of operator-control devices interaction issues, 75% of safety and 60% of anthropometric adjustment issues are satisfied in current designs and the authors conclude that contemporary crane cabins designs still do not satisfy operator needs in the fields of both safety and ergonomics and according to that future research are expected to fulfill those aims.

2.4 Conclusion

As different rules, regulations and standards on the safety of machinery indicate – the application of the principles of ergonomics are helpful.

Planning the area of a driver or a crane operator, dimensioning and positioning of the control elements must be based on data on the anthropometric characteristics of the driver or operator. By designing a workplace and space without using the anthropometric characteristics of the population that will use this workplace, it is impossible to realize the conditions in which the driver's population will feel comfortable and secure. In fact, the loads that can arise while driving a vehicle are mainly associated with a highly uncomfortable, irregular driver's position as a consequence of the non-conformity of the dimensions of the vehicle cabin and the positions of the control elements of the vehicle with the anthropometric characteristics of the driver. It is very important to determine the anthropometric characteristics of the population, which is of particular importance for the ergonomic parameters of the vehicles that are aimed at ensuring the safety and protection of drivers in traffic.

As previous research has pointed out, the adaptation of vehicles to people, depends on many factors in addition to the large importance of anthropometric adaptation, because it depends on the possible placement of a person in the vehicle, and thus the comfort, safety and efficiency of vehicle operation. The driver in driving conditions is in a sitting position, which requires special adaptation of the visual angle and position of the human body in the seat of the vehicle and the position of the dimensions and form and place of the commands and cursors.

Previous research has pointed out that crane operators' strenuous work postures and different occupational diseases in current crane cabin spaces stem from the incompatibility between the anthropometric characteristics of operators and the dimensions and designer solutions of contemporary cabins. The need to increase the well-being of crane operators and avoid discomfort could be fulfilled through anthropometric optimization.

Previous research shows that all anthropometric measures of a particular person do not correspond to the same percentile, so that the quality of the obtained results with the use of percentile decreases depending on the number of critical dimensions and correlations. In recent years, the traditional percentile approach has been criticized by some authors for the decrease in accommodation when two or more dimensions are involved in a design, although others still refer to this approach in the literature. This tendency is important to bear in mind even if only a few authors use multivariate approaches such as principal components analysis (Bittner 1987; Gordon et al., 1997; and Zehner et al., 1993). There is a real practical problem that lies in the fact that such percentiles are inadequate, and when the design problem requires several dimensions for proper fitting, this problem results in less than 90% of the population fit. Different multivariate approaches have been proposed up to now, but without results that enabled their wider application. The main reason for that is the fact that thus far there has been a weak connection between multivariate approaches and interior space modeling techniques.

For these reasons, further usage and development of a multivariate analysis that better interprets the data related to anthropometric measures and provides more precise results for the design of ergonomically adapted products seems to be promising. The multivariate analysis offers an approach to defining the real design boundaries that are needed in cases where it is important to use several different anthropometric measures at the same time, as in the case of vehicles and crane cabins, and accordingly it will be applied herein. Furthermore, anthropometric characteristics analysis is needed in the field of crane operators and drivers too, all with the aim to make them feel comfortable in their interior environment through optimal working posture usage that prevents injuries and improves safety and facilitates task execution in a more productive way.

3 ANALYSIS OF SIGNIFICANT DIFFERENCES IN SERBIAN AND LIBYAN ANTHROPOMETRIC MEASUREMENTS BASED ON GENDER, OCCUPATION, AND NATIONALITY

3.1 Introduction

This chapter aim to verify the hypothesis H_{01} that claims that the anthropometric measurements of Serbian and Libyan drivers as well as crane operators show significant differences depending on gender, occupation and nationality. This hypothesis is based on the assumption that gender, age, occupation, and nationality have a significant effect on anthropometric measurements as shown in previous research (Huang et al, 2010; Locke et al, 2014; Fatollahzadeh, 2006; and Hsiao et al, 2002). Serbian and Libyan context analysis on anthropometric matters has not been found in available research sources. To check the hypothesis that the anthropometric measurements of Serbian and Libyan drivers and crane operators (both male and female) show significant differences depending on gender, occupation and nationality, appropriate statistical tests have been performed on data collected in Serbia and Libya. The aim is to examine significant differences in anthropometric measurements between surveyed populations in order to identify which anthropometric measurements are influenced by gender, occupation, or nationality and to find the pattern that exists with the aim to help designers to accommodate persons in certain spaces. Such analysis of differences in anthropometric measurements among populations can be a valuable tool for user design, since the focus in design must be the end user, rather than the product itself (Barnum, 2010).

3.2 Different nationalities and gender anthropometric measurements data in design

It is well known that anthropometric measurements depend on gender, race, age, occupation (Huang et al., 2010; Beydoun, and Wang, 2009), nationality, and nutrition (Fatollahzadeh, 2006). For instance, a study aimed at updating the minimum aircraft seating standards concluded that there were changes in anthropometric characteristics over time, so seat dimensions need to be reviewed in order to provide adequate accommodation for contemporary frames (Quigley et al, 2001). Quigley et al. (2001) have also provided the percentiles values of anthropometric data of the nationalities of Europe, on the one hand (Table 3.1), and Japan, China and the U.S., on the other (Table 3.2), which show the various differences in the standing height, body weight, etc., between European nationalities, and other nationalities.

Table 3.1 European nationalities anthropometric data percentiles values (Quigley et.al. 2001)

Country	percentile	*WEI*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*
Germany	5th Female	52	1529	807	462	551	425	355
	95th Male	105	1865	977	588	681	547	497
	99th Male	118	1910	1000	606	706	576	546
England	5th Female	49	1515	800	457	541	411	343
	95th Male	103	1870	979	591	677	537	485
	99th Male	117	1918	1004	610	704	564	533
France	5th Female	46	1518	818	462	527	390	331
	95th Male	93	1846	977	581	646	517	437
	99th Male	104	1894	1001	599	668	542	473

Table 3.2 U.S., Chinese, and Japanese nationalities' anthropometric data percentiles values and standard deviations (Quigley et al, 2001)

Country	percentile	*WEI*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*
U.S.A.	5th Female	47	1517	801	403	396	416	342
	95th Male	113	1877	983	513	482	563	522
	99th Male	130	1925	1008	532	500	608	584
China	5th Female	40	1461	782	415	486	358	305
	95th Male	74	1792	965	548	609	483	395
	99th Male	82	1834	990	567	634	508	428
Japan	5th Female	43	1474	793	424	499	383	325
	95th Male	75	1781	970	537	609	487	404
	99th Male	84	1820	995	552	632	508	429

Consequently, the nationality and gender disparities are recommended to be further studied (Beydoun, and Wang, 2009). With that goal, for instance, Guan et al. (2012) have noted that anthropometric measurements (that represent width) also change over time across a 25-year period. This has also been confirmed by Klarin et al. (2011). Klarin et al, (2011) have shown that the height of drivers has increased, whereas other dimensions, i.e. foot length, shoulder width, and hip width have varied too in this time frame. Therefore, the use of up to date anthropometric data is recommended (Brkić et al., 2015) in contemporary design issues, and gender, nationality and occupation also have vital importance in anthropometric measurements analysis and in design as well. The prediction model that uses linear regression is more effective both in cost and time and is more widely used than the trial and error approach, which is prone to measurement errors related to reliability and validity (Kolich et al., 2004).

3.3 Serbian and Libyan data basic information

In this study, static dimensions were used in data gathering, since the main goal of the research is the modeling of the interior space of the workplace, such as the interior vehicle or crane cabin, in order to develop a model which will ensure the comfort and safety of the driver or operator. After data collection, the samples characteristics are summarized in Table 3.3 and Table 3.4. Table 3.3 shows information about 1,197 Serbian participants - car drivers (males and females) and crane operators (only males). Their anthropometric measurements and weight data were collected in 2015, using the static anthropometry method as illustrated in Figure 3.1 (all crane operators had drivers` licenses). In the same way and at the same time (2015), a sample of 400 Libyan participants was gathered, as shown in Table 3.4 for the purpose of vehicle interior space modelling and crane cabin interior space modeling.

Table 3.3 Serbian data information

Gender	Car driver	*Mean* age	*SD*	Crane operators	*Mean* age	*SD*	Total Participants
Male drivers	921	43.17	13.058	83	48.48	10.07	1004
Female drivers	193	38.15	11.30	-	-	-	193
Total	1114	-	-	83	-	-	1197

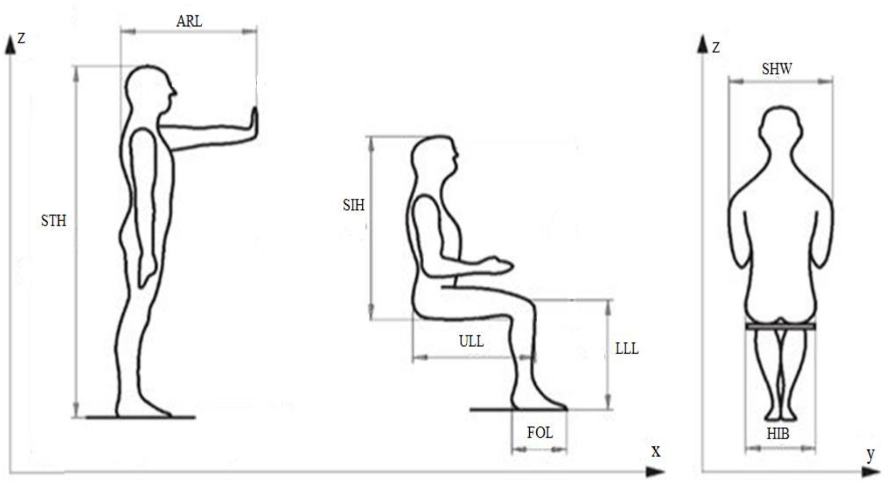

Figure 3.1 Diagrams of body dimensions as measured in the National Health Survey (Klarin et al., 2011)

Table 3.4 Libyan data information

Gender	Car drivers	*Mean* age	*SD*	Crane operators	*Mean* age	*SD*	Total Participants
Male drivers	300	33.7	11.468	50	42.36	7.907	350
Female drivers	50	32.86	11.264	-	-	-	50
Total	400	-	-	50	-	-	450

3.4 Analysis of anthropometric measurement differences – Serbian and Libyan data

Statistical analysis is performed on anthropometric samples, to investigate the patterns of anthropometric measurement differences. Such analysis assesses variations between target samples, which are different in gender, nationality and occupation and provide more information that would be useful for ergonomic design, which takes into consideration the source of anthropometric variations. In order to verify whether there are any significant differences between anthropometric measurements in the collected samples (Serbian and Libyan), we have started with descriptive statistics calculations on eight anthropometric measurements, which are foot length (*FOL*), standing height (*STH*), sitting height (*SIH*), lower leg length (*LLL*), upper leg length (*ULL*), shoulder width (*SHW*), hip breadth (*HIB*), arm length

(*ARL*) and body weight (*WEI*). The main goal was to explore the existence of data patterns and the behavior of samples through central tendency measures.

Consequently, the effect of gender, occupation, and nationality is compared as well, to explore the correlation between anthropometric measurements. The significance of differences between samples of the collected anthropometric data using the *z* test is also tested. The analysis was conducted in order to identify whether there is a degree of difference in anthropometric measurements between the participants who are different in gender, occupation, and nationality, as could be expected according to the results of previous studies conducted on data of other populations (Huanget al., 2010; Beydoun and Wang, 2009; and Fatollahzadeh, 2006).

3.5 Data analysis procedure and results

The procedures followed for statistical analysis methods are applied herein are:

- Descriptive statistics on collected data,
- Regression and correlation analysis between anthropometric measurements on Serbian and Libyan collected data and
- Hypothesis testing for difference between anthropometric measurements between Serbian and Libyan collected data, using the *z* test for difference of means.

Descriptive statistics includes sample sizes, means, medians, minimal and maximal values with their ranges, coefficient of variation and Kolmogorov test for normality. The last conclusion of type of data for anthropometric measures is presented based on results of the coefficient of variation and Kolmogorov test as parametric or non-parametric.

Since all measurements are parametric, this enabled conducting the linear regression and correlation analysis, which include coefficient of correlations, coefficients of determination, as well as significance of regression and correlations. Criteria for correlation coefficient (Brkić et al., 2016) are:

$|r| \in [0.0, 0.5)$ There is no correlation

$|r| \in [0.5, 0.7)$ There is a weak correlation (*)

$|r| \in [0.7, 0.9)$ There is a strong correlation (**)

$|r| \in [0.9, 1.0)$ There is an absolute correlation (***)

In order to compare anthropometric measurements between different nationalities, for all examined groups of participants, the *Z* tests for difference of means were conducted between Serbian and Libyan samples. The following criteria was used to assess differences (Brkić et al., 2016):

If $p>0.05$ no significant difference (*n.s.*)
If $p<0.05$ low difference (>)
If $p<0.01$ strong difference (>>)
If $p<0.001$ absolute difference (>>>).

3.5.1 Statistical examination of data for Serbian and Libyan male drivers

Descriptive statistics, regression analysis, and test of difference between means are performed as in the following sections for the samples in order to explore the relationships and source of variation between the anthropometric dimensions. Regression graphs where at least one correlation exists are depicted with regression lines, while otherwise only scatter plots are drawn for the observed sample.

3.5.1.1 Descriptive statistics

Descriptive statistics for Serbian and Libyan male drivers are presented in Table 3.5 and Table 3.6 (the eight anthropometric measures and body weight). The mean and median values of Serbian male drivers are higher than the values of Libyan male drivers, except the shoulder width (with an equal value of median 470mm and mean 471.35mm), and foot length (with an equal value in median 275mm).

Table 3.5 Descriptive statistics for Serbian male drivers

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG.*	*VT*
WEI	921	86.617	86	47	125	78	11.693	13.50	0.1498	1	*n.s.*	parameter
STH	921	1811.26	1800	1640	1995	355	74.657	4.12	0.1668	1	*n.s.*	parameter
SIH	921	917.218	920	780	1020	240	47.064	5.13	0.1551	1	*n.s.*	parameter
LLL	921	593.613	600	470	690	220	35.754	6.02	0.1615	1	*n.s.*	parameter
ULL	921	636.228	635	490	800	310	45.544	7.16	0.204	1	*n.s.*	parameter
SHW	921	471.356	470	390	630	240	46.728	9.91	0.1535	1	*n.s.*	parameter
HIB	921	391.097	390	310	590	280	43.749	11.19	0.2434	1	*n.s.*	parameter
ARL	921	706.488	700	500	830	330	46.213	6.54	0.1882	1	*n.s.*	parameter
FOL	921	281.612	275	250	320	70	12.577	4.47	0.1765	1	*n.s.*	parameter

Table 3.6 Descriptive statistics for Libyan male drivers

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG.*	*VT*
WEI	300	82.910	83	44	125	81	14.149	17.07	0.1907	1	*n.s.*	parameter
STH	300	1749.517	1750	1570	1900	330	63.104	3.61	0.1871	1	*n.s.*	parameter
SIH	300	855.483	860	730	970	240	43.493	5.08	0.1919	1	*n.s.*	parameter
LLL	300	543.050	540	450	670	220	34.425	6.34	0.1516	1	*n.s.*	parameter
ULL	300	582.767	580	500	720	220	37.166	6.38	0.2407	1	*n.s.*	parameter
SHW	300	471.350	470	380	640	260	45.440	9.64	0.1661	1	*n.s.*	parameter
HIB	300	365.620	360	230	570	340	59.192	16.19	0.2018	1	*n.s.*	parameter
ARL	300	633.053	610	540	800	260	72.291	11.42	0.2220	1	*n.s.*	parameter
FOL	300	275.833	275	265	300	35	9.115	3.30	0.2126	1	*n.s.*	parameter

3.5.1.2 Correlation between anthropometric measurement for Serbian and Libyan male drivers

Correlation between anthropometric measurements for Serbian and Libyan male drivers are presented at Table 3.7 and Table 3.8. The following main points could be concluded from the correlation pattern of Serbian and Libyan male drivers:

1 - There are common patterns of correlation between Serbian and Libyan samples of male drivers as follows:

a) Body weight has a non-significant correlation with standing height, sitting height, lower leg length, upper leg length, arm length, and foot length.

b) Standing height has a non-significant correlation with shoulder width and hip breadth, while a low correlation exists with lower leg length (Serbian sample r=0.577, r^2=33.29%, Libyan sample, r=0.568, r^2=32.26%), and upper leg length (Serbian sample r=0.522, r^2=27.25%, Libyan sample, r=0.549, r^2=30.14%).

c) Arm length has a non-significant correlation with foot length, whereas hip breadth has a non-significant correlation with foot length and arm length.

2 - There are different patterns of correlations between both samples, which can be summarized as:

a) The body weight of Serbian male drivers has a non-significant correlation with shoulder width, but in the Libyan sample it has a weak correlation (r=0.515, r^2=26.52%). Body weight also has a weak correlation with hip breadth in the Serbian sample (r=0.510, r^2=26.52%). The Libyan sample has a non-significant correlation with hip breadth, and, in the same way, the sitting height for the Serbian sample has a weak correlation with arm length (r=0.602, r^2=36.2%), as does the lower leg length with the arm length (r=0.520, r^2=27.04%). In Libyan sample, the sitting height and the lower leg length have a non-significant correlation with arm length.

c) The standing height with arm length and foot length have a weak correlation (r=0.550, r^2=30.25% r=0.596, r^2=35.25% respectively). In the Libyan sample, neither arm length nor foot length have a significant correlation with standing height. Moreover, the standing height and the sitting height in Serbian sample have a strong correlation (r=0.731, r^2=53.44%), while there is a weak correlation for these same measurements in the Libyan sample (r=0.541, r^2=29.7%).

The relationship between the anthropometric dimensions exhibited through the values of correlation, shows that Serbian male drivers have twelve different dimensions with significant correlation, while in the Libyan sample only six different anthropometric dimensions have significant correlation. In addition, the differences in the correlation relationship among the dimensions of two samples may give guidance that nationality has a role in such anthropometric variations (Fatollahzadeh, 2006). Figures 3.2 - 3.12. provide representative scatter plots for both Serbian and Libyan male drivers where at least one regression line exists (a correlation of any statistical significance).

Table 3.7 The correlation between anthropometric measurements for Serbian male drivers

Comparison	r	r² (%)	SIG.	Comparison	r	r² (%)	SIG.
WEI vs. *STH*	0.410	16.81	*n.s*	*SIH* vs. *LLL*	0.440	19.36	*n.s.*
WEI vs. *SIH*	0.293	8.58	*n.s*	*SIH* vs. *ULL*	0.362	13.10	*n.s.*
WEI vs. *LLL*	0.326	10.63	*n.s*	*SIH* vs. *SHW*	0.301	9.06	*n.s.*
WEI vs. *ULL*	0.358	12.82	*n.s*	*SIH* vs. *HIB*	0.099	0.98	*n.s.*
WEI vs. *SHW*	0.422	17.81	*n.s*	*SIH* vs. *ARL*	0.602	36.24	*
WEI vs. *HIB*	0.510	26.01	*	*SIH* vs. *FOL*	0.395	15.60	*n.s.*
WEI vs. *ARL*	0.278	7.73	*n.s*	*LLL* vs. *ULL*	0.645	41.60	*
WEI vs. *FOL*	0.363	13.18	*n.s*	*LLL* vs. *SHW*	0.289	8.35	*n.s*
STH vs. *SIH*	0.731	53.44	**	*LLL* vs. *HIB*	0.146	2.13	*n.s*
STH vs. *LLL*	0.577	33.29	*	*LLL* vs. *ARL*	0.520	27.04	*
STH vs. *ULL*	0.522	27.25	*	*LLL* vs. *FOL*	0.405	16.40	*n.s*
STH vs. *SHW*	0.269	7.24	*n.s*	*ULL* vs. *SHW*	0.380	14.44	*n.s*
STH vs. *HIB*	0.084	0.71	*n.s*	*ULL* vs. *HIB*	0.253	6.40	*n.s*
STH vs. *ARL*	0.550	30.25	*	*ULL* vs. *ARL*	0.492	24.21	*n.s*
STH vs. *FOL*	0.596	35.52	*	*ULL* vs. *FOL*	0.413	17.06	*n.s*
ARL vs. *FOL*	0.386	14.90	*n.s.*	*SHW* vs. *HIB*	0.610	37.21	*
HIB vs. *ARL*	0.066	0.44	*n.s.*	*SHW* vs. *ARL*	0.317	10.05	*n.s.*
HIB vs. *FOL*	0.147	2.16	*n.s.*	*SHW* vs. *FOL*	0.165	2.72	*n.s.*

Table 3.8 The correlation between anthropometric measurements for Libyan male drivers

Comparison			r	r² (%)	SIG.	Comparison			r	r² (%)	SIG.
WEI	vs.	*STH*	0.201	4.04	*n.s.*	*SIH*	vs.	*LLL*	0.238	5.66	*n.s.*
WEI	vs.	*SIH*	0.201	4.04	*n.s.*	*SIH*	vs.	*ULL*	0.231	5.34	*n.s.*
WEI	vs.	*LLL*	0.262	6.86	*n.s.*	*SIH*	vs.	*SHW*	0.182	3.31	*n.s.*
WEI	vs.	*ULL*	0.293	8.58	*n.s.*	*SIH*	vs.	*HIB*	0.140	1.96	*n.s.*
WEI	vs.	*SHW*	0.515	26.52	*	*SIH*	vs.	*ARL*	0.169	2.86	*n.s.*
WEI	vs.	*HIB*	0.413	17.06	*n.s.*	*SIH*	vs.	*FOL*	0.207	4.28	*n.s.*
WE	vs.	*ARL*	0.055	0.30	*n.s.*	*LLL*	vs.	*ULL*	0.698	48.72	*
WEI	vs.	*FOL*	0.342	11.7	*n.s.*	*LLLL*	vs.	*SHW*	0.303	9.18	*n.s.*
STH	vs.	*SIH*	0.541	29.27	*	*LLL*	vs.	*HIB*	0.215	4.62	*n.s.*
STH	vs.	*LLL*	0.568	32.26	*	*LLL*	vs.	*ARL*	0.186	3.46	*n.s.*
STH	vs.	*ULL*	0.549	30.14	*	*LLL*	vs.	*FOL*	0.404	16.32	*n.s.*
STH	vs.	*SHW*	0.166	2.76	*n.s.*	*ULL*	vs.	*SHW*	0.292	8.53	*n.s.*
STH	vs.	*HIB*	0.122	1.49	*n.s.*	*ULL*	vs.	*HIB*	0.248	6.15	*n.s.*
STH	vs.	*ARL*	0.139	1.932	*n.s.*	*ULL*	vs.	*ARL*	0.189	3.57	*n.s.*
STH	vs.	*FOL*	0.410	16.81	*n.s.*	*ULL*	vs.	*FOL*	0.330	10.89	*n.s.*
ARL	vs.	*FOL*	0.020	0.04	*n.s.*	*SHW*	vs.	*HIB*	0.593	35.16	*
HIB	vs.	*ARL*	0.321	10.30	*n.s.*	*SHW*	vs.	*FOL*	0.195	3.80	*n.s.*
HIB	vs.	*FOL*	0.058	0.34	*n.s.*	*SHW*	vs.	*ARL*	0.110	1.21	*n.s.*

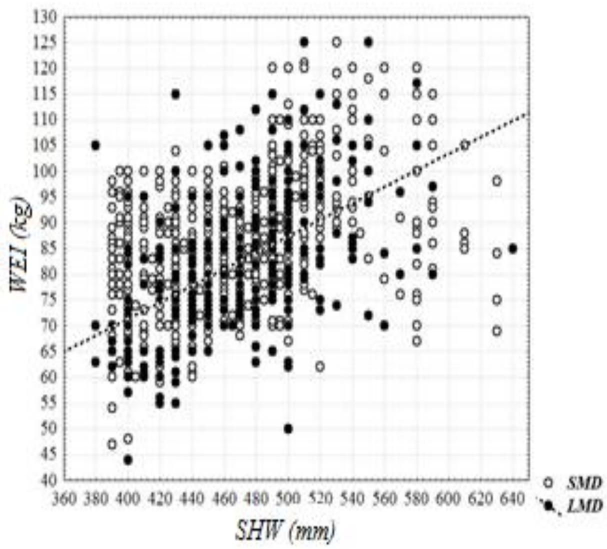

Figure 3.2 Regression between *WEI* and *SHW* for *SMD* and *LMD*

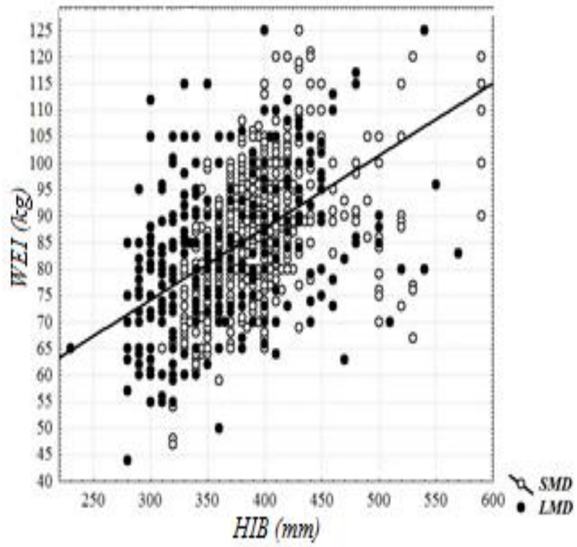

Figure 3.3 Regression between *WEI* and *HIB* for *SMD* and *LMD*

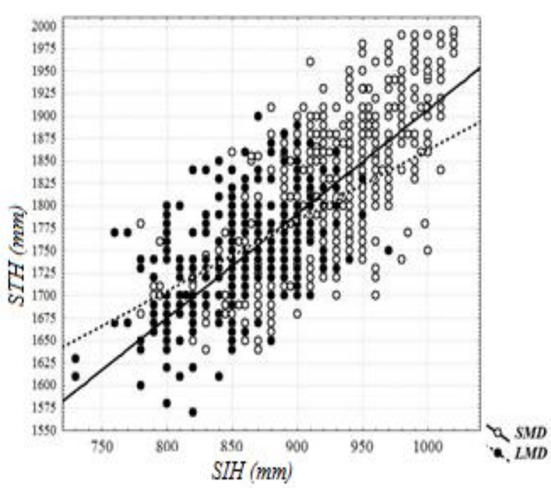

Figure 3.4 Regression between *STH* and *SIH* for *SMD* and *LMD*

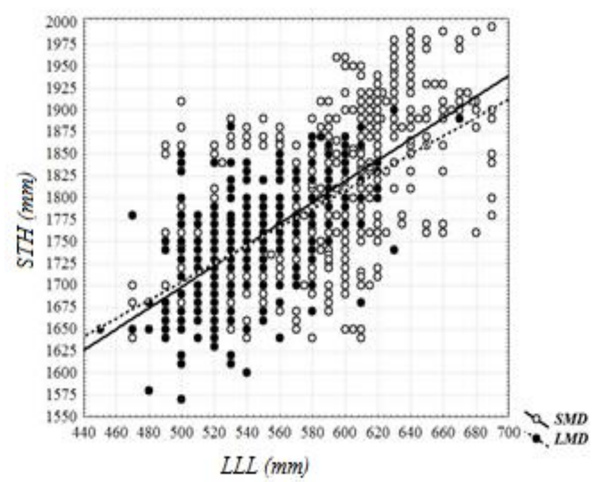

Figure 3.5 Regression between *STH* and *LLL* for *SMD* and *LMD*

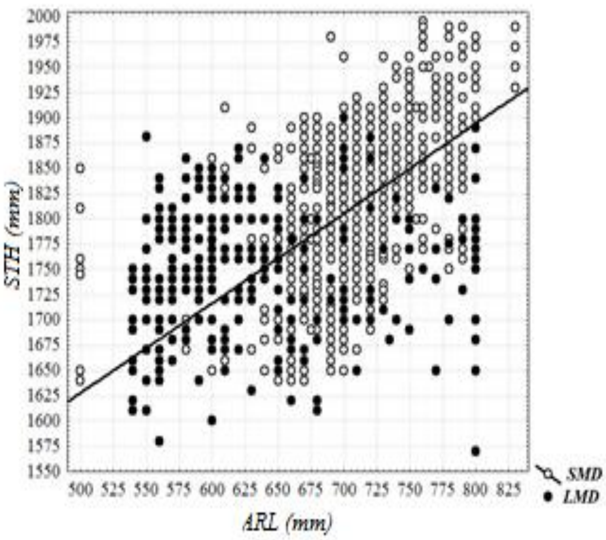

Figure 3.6 Regression between *STH* and *ARL* for *SMD* and *LMD*

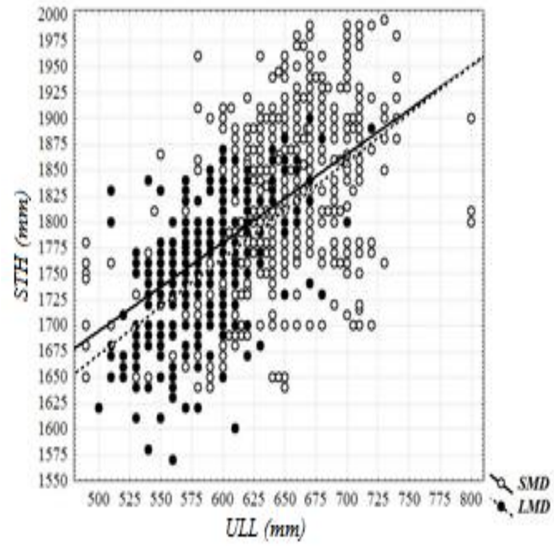

Figure 3.7 Regression between *STH* and *ULL* for *SMD* and *LMD*

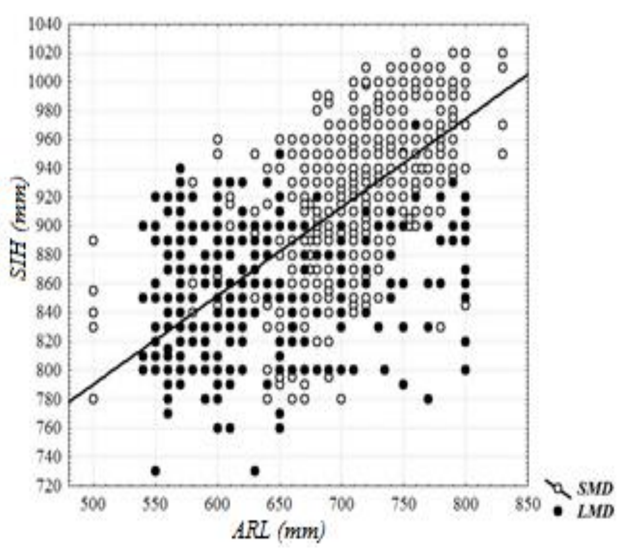

Figure 3.8 Regression between *SIH* and *ARL* for *SMD* and *LMD*

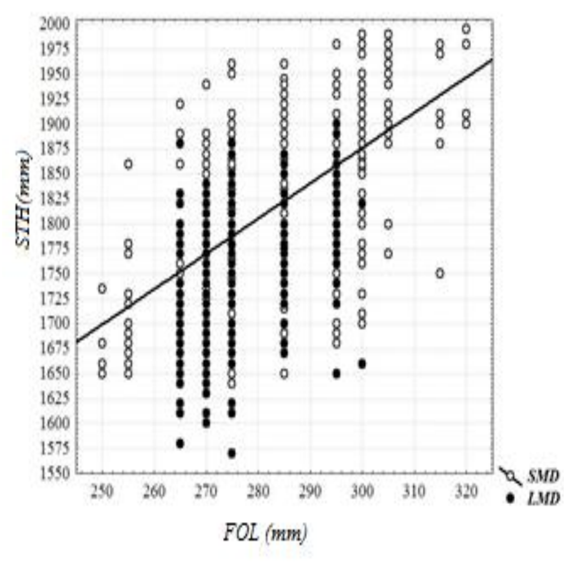

Figure 3.9 Regression between *STH* and *FOL* for *SMD* and *LMD*

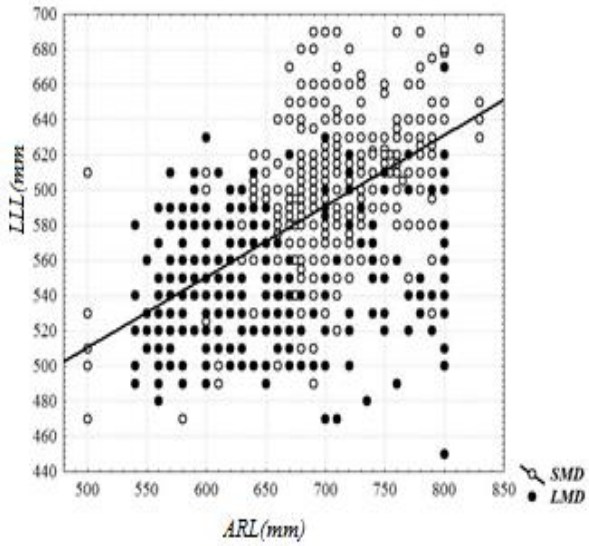

Figure 3.10 Regression between *LLL* and *ARL* for *SMD* and *LMD*

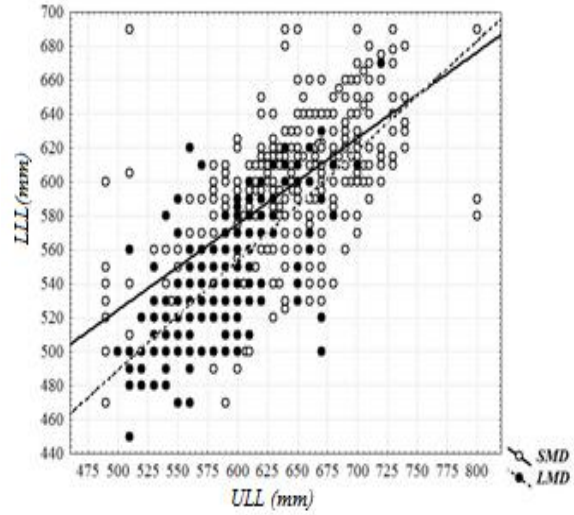

Figure 3.11 Regression between *LLL* and *ULL* for *SMD* and *LMD*

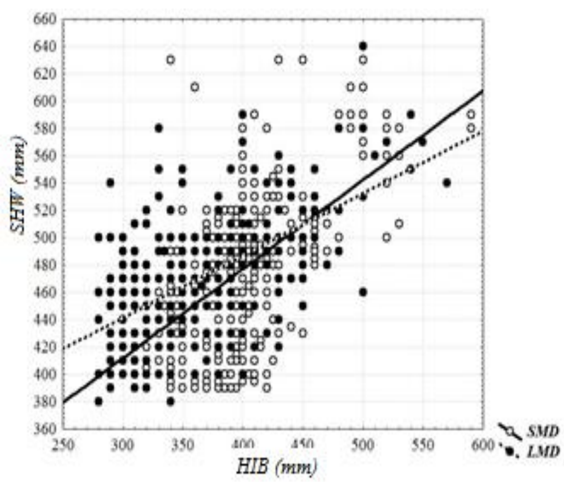

Figure 3.12 Regression between *SHW* and *HIB* for *SMD* and *LMD*

3.5.1.3 Comparisons of means between anthropometric measurements between Serbian and Libyan male drivers

Serbian male drivers and Libyan male drivers' anthropometric measurements were compared and the results are shown in Table 3.9.

Table 3.9 Comparison between Serbian male derivers and Libyan male drivers

z test	*p* value	*p*
WEI SMD>>>WEI LMD	0	p<0.001
STH SMD>>>STH LMD	0	p<0.001
SIH SMD >>>SIH LMD	0	p<0.001
LLL SMD >>>LLL LMD	0	p<0.001
ULL SMD>>>ULL LMD	0	p<0.001
SHW SMD = SHW LMD	1	*n.s.*
HIB SMD>>>HIB LMD	0	p<0.001
ARL SMD >>>ARL LMD	0	p<0.001
FOL SMD>>>FOL LMD	0	p<0.001

From Table 3.9 it can be concluded that between Serbian and Libyan male drivers there is no significant difference except in shoulder width measurement, while the other compared measurements have absolute statistical differences in that Serbian dimensions have statistically significantly larger measurements than Libyan male drivers at p<0.001, with p values equaling 0 for all comparisons. Therefore, the conclusion can be drawn that Serbian male drivers in general have larger anthropometric measurements than Libyan male drivers. Figures 3.13 - 3.15 illustrate those differences of means.

Figure 3.13 Ratio between *SHW* means for *SMD* and *LMD*

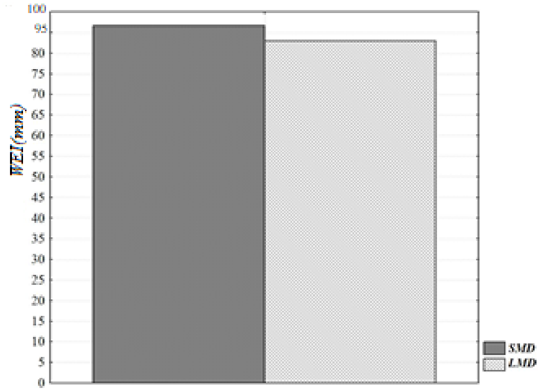

Figure 3.14 Ratio between WEI means for SMD and LMD

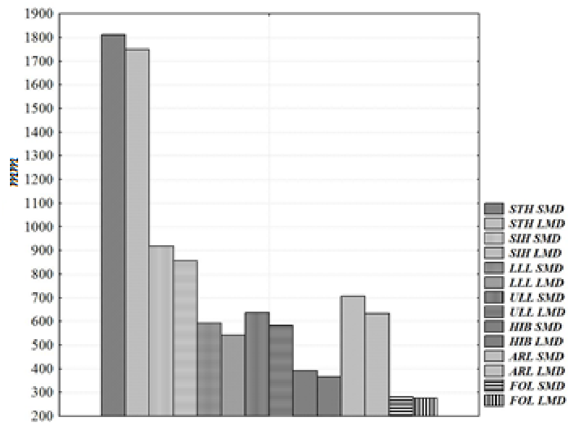

Figure 3.15 Ratio between means of anthropometric measurements between *SMD* and *LMD*

3.5.2 Statistical examination of data for Serbian and Libyan crane operators

The Serbian sample of 83 operators and the Libyan sample of 50 operators have been tested and examined to explore the relationship and variations between the anthropometric measurements.

3.5.2.1 Descriptive statistics

In Table 3.10, and Table 3.11, the results of the descriptive statistics of Serbian and Libyan crane operators sample were presented, and it can be seen that the mean and median values of the Serbian sample are greater than the values of the Libyan sample. However, the mean value of shoulder width in Serbian crane operators is a little bit less than in Libyan operators.

Table 3.10 Descriptive statistics for Serbian crane operators

Dimensio	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG.*	*VT*
WEI	83	84.916	82	65	110	45	11.636	13.70	0.2862	1	*n.s.*	parameter
STH	83	1768.19	1765	1630	1937	307	68.210	3.86	0.2694	1	*n.s.*	parameter
SIH	83	907.313	910	750	1020	270	56.749	6.25	0.2134	1	*n.s.*	parameter
LLL	83	587.169	585	490	770	280	40.176	6.84	0.2441	1	*n.s.*	parameter
ULL	83	618.229	615	520	710	190	36.350	5.88	0.1894	1	*n.s.*	parameter
SHW	83	478.349	480	380	580	200	48.520	10.14	0.2718	1	*n.s.*	parameter
HIB	83	401.313	395	300	590	290	58.629	14.61	0.2785	1	*n.s.*	parameter
ARL	83	704.554	700	495	800	305	50.892	7.22	0.1843	1	*n.s.*	parameter
FOL	83	297.422	296	259	321	62	12.524	4.21	0.3668	1	*n.s.*	parameter

Table 3.11 Descriptive statistics for Libyan crane operators

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v(%)	*D*	*p*	*SIG.*	*VT*
WEI	50	78.70	80	55	96	41	10.428	13.25	0.2799	1	*n.s.*	parameter
STH	50	1701.40	1700	1570	1830	260	58.554	3.44	0.3050	1	*n.s.*	parameter
SIH	50	829.40	840	700	900	200	47.827	5.77	0.1812	1	*n.s.*	parameter
LLL	50	534.60	530	460	600	140	36.545	6.84	0.2222	1	*n.s.*	parameter
ULL	50	559.00	560	500	630	130	32.779	5.86	0.1908	1	*n.s.*	parameter
SHW	50	489.00	470	410	620	210	53.918	11.03	0.1590	1	*n.s.*	parameter
HIB	50	382.00	370	300	490	190	49.652	13.00	0.2375	1	*n.s.*	parameter
ARL	50	642.40	650	450	800	350	82.054	12.77	0.1565	1	*n.s.*	parameter
FOL	50	273.70	270	255	295	40	9.248	3.38	0.1901	1	*n.s.*	parameter

3.5.2.2 Regression and correlation between anthropometric measurements for Serbian and Libyan crane operators

In the Libyan sample, a weak correlation exists only between standing height and foot length (r=0.516, r^2=26.63%), shoulder width and hip breadth (r=0.649, r^2=42.12), and lower leg length and hip breadth (r=0.516, r^2=26.63%). All other measurements have a non-significant correlation. But for the Serbian sample there is a strong correlation (Table 3.12) between standing height and sitting height, and shoulder width and hip breadth (r=0.752, r^2=56.55%, and r=0.760, r^2=57.76% respectively) Four measurements have weak correlations (Table 3.13). This leads to the conclusion that in the Serbian sample there are a larger number of significant correlations than in the Libyan sample. Further illustration of the regression between the anthropometric measurements of the two samples is given in Figures 3.16–3.23, wherein different patterns of significant and non-significant correlations confirm the analytical results.

Table 3.12 The correlation between anthropometric measurements for Serbian crane operators

Comparison			*r*	r^2 (%)	*SIG.*	Comparison			*R*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.410	16.81	*n.s.*	*SIH*	vs.	*LLL*	0.313	9.80	*n.s.*
WEI	vs.	*SIH*	0.171	2.92	*n.s.*	*SIH*	vs.	*ULL*	0.265	7.02	*n.s.*
WEI	vs.	*LLL*	0.404	16.32	*n.s.*	*SIH*	vs.	*SHW*	0.086	0.74	*n.s.*
WEI	vs.	*ULL*	0.460	21.16	*n.s.*	*SIH*	vs.	*HIB*	0.207	4.28	*n.s.*
WEI	vs.	*SHW*	0.495	24.50	*n.s.*	*SIH*	vs.	*ARL*	0.642	41.22	*
WEI	vs.	*HIB*	0.600	36.00	*	*SIH*	vs.	*FOL*	0.005	0.00	*n.s.*
WEI	vs.	*ARL*	0.280	7.84	*n.s.*	*LLL*	vs.	*ULL*	0.487	23.72	*n.s.*
WEI	vs.	*FOL*	0.227	5.15	*n.s.*	*LLL*	vs.	*SHW*	0.448	20.07	*n.s.*
STH	vs.	*SIH*	0.752	56.55	**	*LLL*	vs.	*HIB*	0.423	17.89	*n.s.*
STH	vs.	*LLL*	0.430	18.49	*n.s.*	*LLL*	vs.	*ARL*	0.570	32.49	*
STH	vs.	*ULL*	0.339	11.49	*n.s.*	*LLL*	vs.	*FOL*	0.047	0.22	*n.s.*
STH	vs.	*SHW*	0.188	3.53	*n.s.*	*ULL*	vs.	*SHW*	0.450	20.25	*n.s.*
STH	vs.	*HIB*	0.025	0.06	*n.s.*	*ULL*	vs.	*HIB*	0.385	14.82	*n.s.*
STH	vs.	*ARL*	0.614	37.70	*	*ULL*	vs.	*ARL*	0.412	16.97	*n.s.*
STH	vs.	*FOL*	0.049	0.24	*n.s.*	*ULL*	vs.	*FOL*	0.079	0.62	*n.s.*
ARL	vs.	*FOL*	0.084	0.71	*n.s.*	*SHW*	vs.	*HIB*	0.760	57.76	**
HIB	vs.	*ARL*	0.045	0.20	*n.s.*	*SHW*	vs.	*ARL*	0.341	11.63	*n.s.*
HIB	vs.	*FOL*	0.021	0.04	*n.s.*	*SHW*	vs.	*FOL*	0.122	1.49	*n.s.*

Table 3.13 The correlation between anthropometric measurements for Libyan crane operators

Comparison			*r*	r^2 (%)	*SIG.*	Comparison			*R*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.257	6.60	*n.s.*	*SIH*	vs.	*LLL*	0.184	3.39	*n.s.*
WEI	vs.	*SIH*	0.203	4.12	*n.s.*	*SIH*	vs.	*ULL*	0.052	0.27	*n.s.*
WEI	vs.	*LLL*	0.162	2.62	*n.s.*	*SIH*	vs.	*SHW*	0.241	5.81	*n.s.*
WEI	vs.	*ULL*	0.175	3.06	*n.s.*	*SIH*	vs.	*HIB*	0.128	1.64	*n.s.*
WEI	vs.	*SHW*	0.291	8.41	*n.s.*	*SIH*	vs.	*ARL*	0.250	6.25	*n.s.*
WEI	vs.	*HIB*	0.352	12.39	*n.s.*	*SIH*	vs.	*FOL*	0.328	10.76	*n.s.*
WE	vs.	*ARL*	0.204	4.16	*n.s.*	*LLL*	vs.	*ULL*	0.478	22.85	*n.s.*
WEI	vs.	*FOL*	0.315	9.92	*n.s.*	*LLL*	vs.	*SHW*	0.305	9.30	*n.s.*
STH	vs.	*SIH*	0.314	9.92	*n.s.*	*LLL*	vs.	*HIB*	0.516	26.63	*
STH	vs.	*LLL*	0.422	17.81	*n.s.*	*LLL*	vs.	*ARL*	0.046	0.21	n.s.
STH	vs.	*ULL*	0.399	15.92	*n.s.*	*LLL*	vs.	*FOL*	0.326	10.63	n.s.
STH	vs.	*SHW*	0.005	0.00	*n.s.*	*ULL*	vs.	*SHW*	0.184	3.39	n.s.
STH	vs.	*HIB*	0.259	6.71	*n.s.*	*ULL*	vs.	*HIB*	0.297	8.82	n.s.
STH	vs.	*ARL*	0.131	1.716	*n.s.*	*ULL*	vs.	*ARL*	0.196	3.84	n.s.
STH	vs.	*FOL*	0.516	26.63	*	*ULL*	vs.	*FOL*	0.373	13.91	n.s.
ARL	vs.	*FOL*	0.025	0.00	*n.s.*	*SHW*	vs.	*HIB*	0.649	42.12	*
HIB	v.	*ARL*	0.042	0.00	*n.s.*	*SHW*	vs.	*ARL*	0.038	0.14	*n.s.*
HIB	vs.	*FOL*	0.135	1.82	*n.s.*	*SHW*	vs.	*FOL*	0.130	1.69	*n.s.*

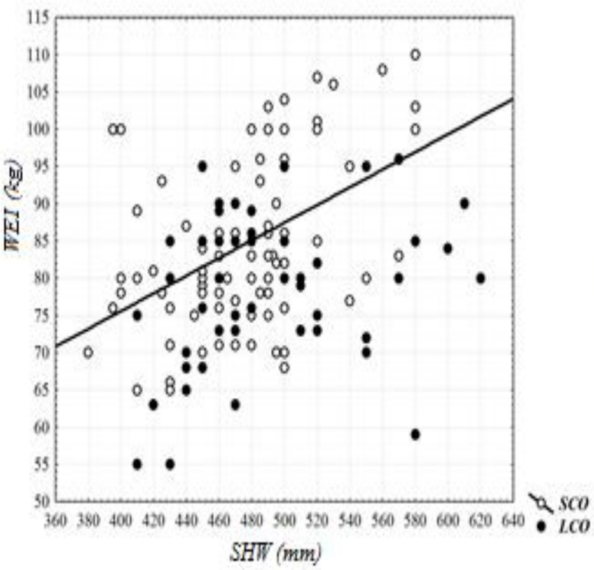

Figure 3.16 Regression between *WEI* and *SHW* for *SCO* and *LCO*

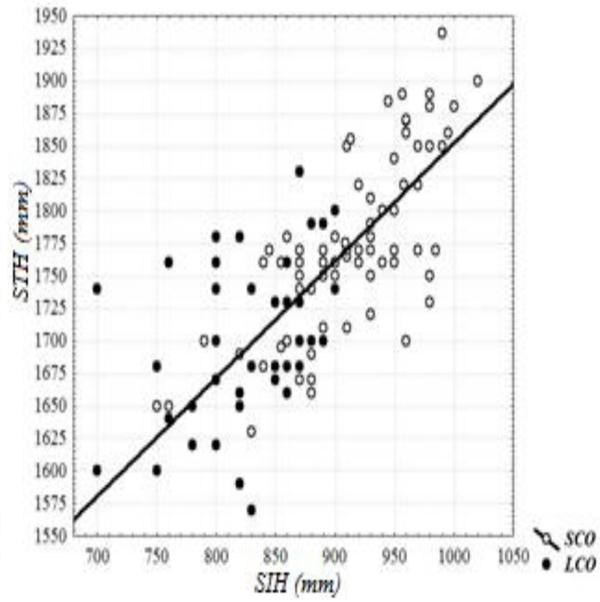

Figure 3.17 Regression between *STH* and *SIH* for *SCO* and *LCO*

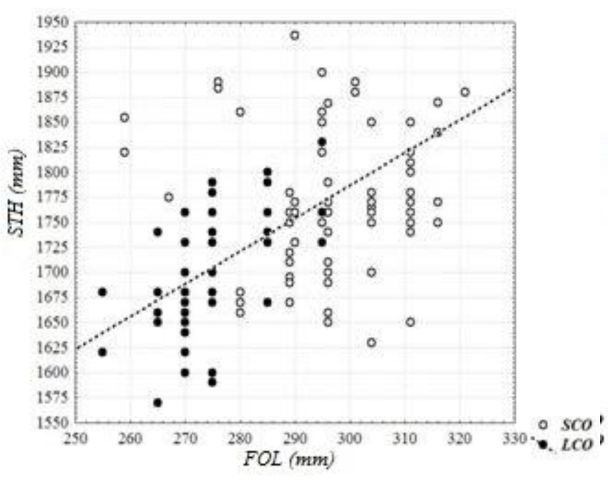

Figure 3.18 Regression between *STH* and *FOL* for *SCO* and *LCO*

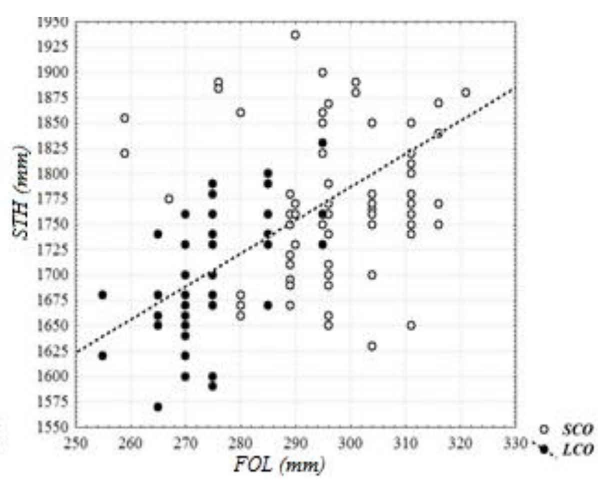

Figure 3.19 Regression between *STH* and *ARL* for *SCO* and *LCO*

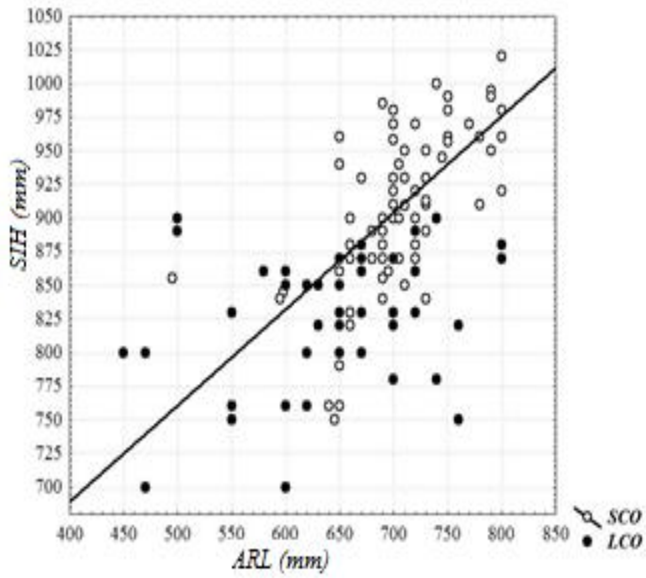

Figure 3.20 Regression between *SIH* and *ARL* for *SCO* and *LCO*

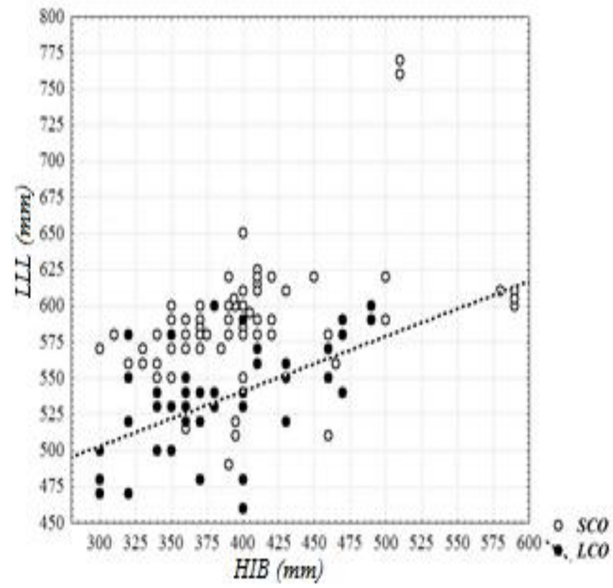

Figure 3.21 Regression between *LLL* and *HIB* for *SCO* and *LCO*

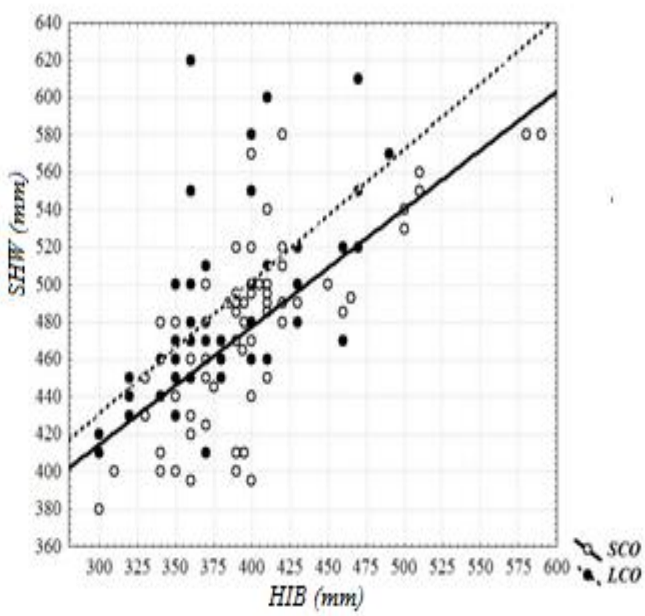

Figure 3.22 Regression between *SHW* and *HIB* for *SCO* and *LCO*

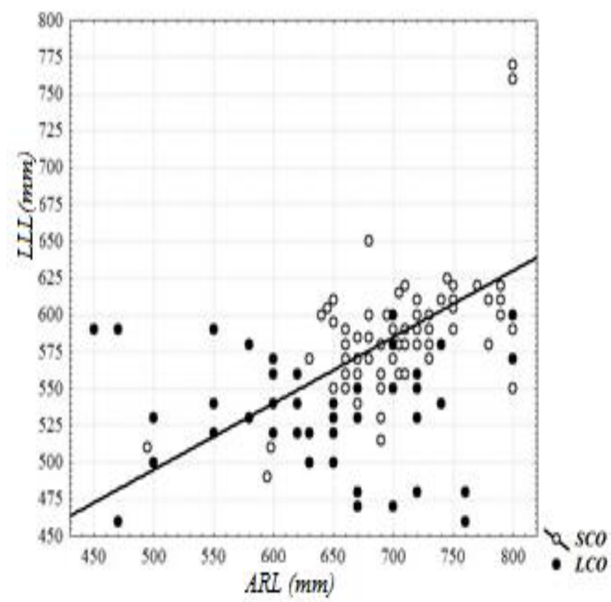

Figure 3.23 Regression between *LLL* and *ARL* for *SCO* and *LCO*

3.5.2.3 Comparisons of means between anthropometric measurements between Serbian and Libyan crane operators

The sample of Serbian crane operators (*N*=83 males) and the Libyan sample of crane operators (*N*=50 males) were tested and absolute differences are at significance $p<0.001$, for all anthropometric measurements other than hip breadth and shoulder width. The Serbian crane operators have larger values of measured variables than Libyan crane operators in all measurements, except in hip breadth, where there are statistically low significant differences ($p<0.05$ and p-value =0.0426).

In addition, there is no significant difference in shoulder width, level with p-value=0.2517, as can be seen from Table 3.14, which corresponds with results to male drivers (Table 3.9), except hip breadth. Figures 3.24-3.27 show significant differences between anthropometric measurements and confirm the results given in Table 3.14.

Table 3.14 Comparison between Serbian male derivers and Libyan crane operators

z test	*p* value	*p*
WEI SCO>>>WEI LCO	0.0010	$p<0.001$
STH SCO >>>STH LCO	0	$p<0.001$
SIH SCO>>>SIH LCO	0	$p<0.001$
LLL SCO>>>LLL LCO	0	$p<0.001$
ULL SCO>>>ULL LCO	0	$p<0.001$
SHW SCO = SHW *LCO*	0.2517	n.s.
HIB SCO>HIB LCO	0.0426	$p<0.05$
ARL SCO>>>ARL LCO	0	$p<0.001$
FOL SCO>>>FOL LCO	0	$p<0.001$

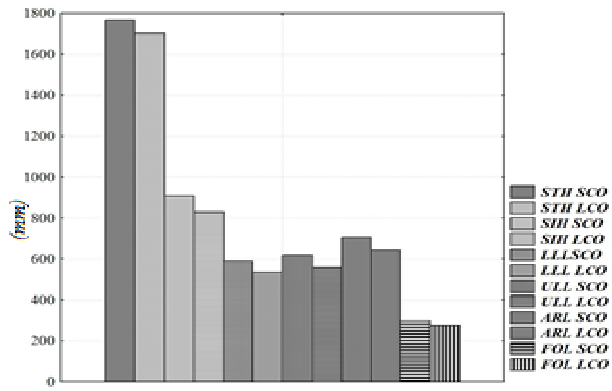

Figure 3.24 Ratio between means for *SCO* and *LCO*

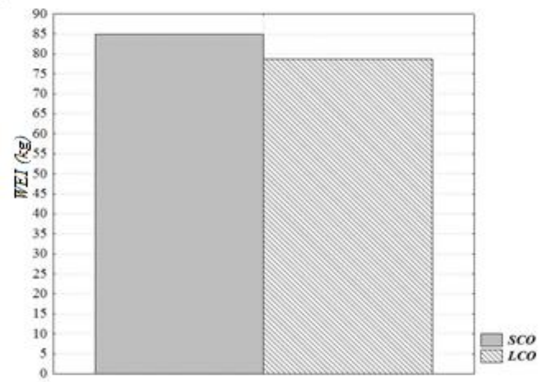

Figure 3.25 Ratio between *WEI* means for *SCO* and *LCO*

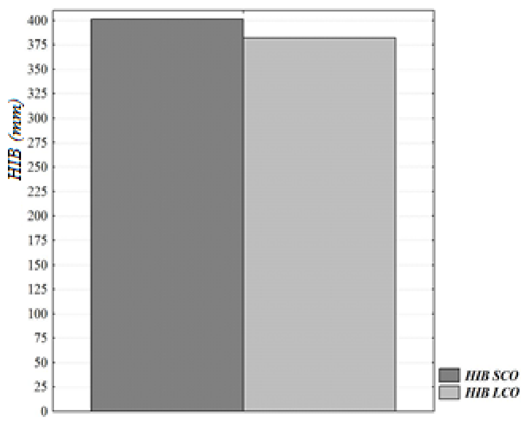

Figure 3.26 Ratio between *HIB* means for *SCO* and *LCO*

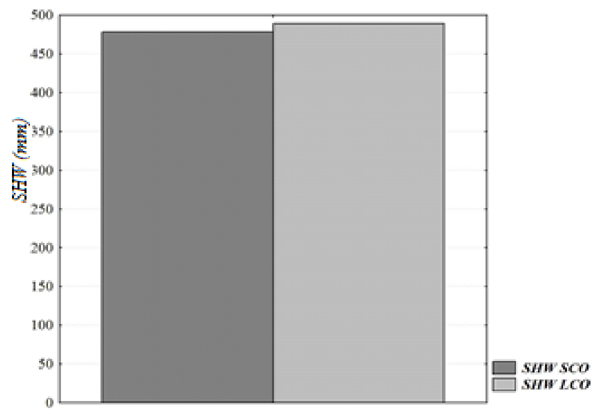

Figure 3.27 Ratio between *SHW* means for *SCO* and *LCO*

3.5.3 Statistical examination of data for Serbian and Libyan males

The Serbian and Libyan male samples are composed from male drivers and crane operators **(***n*= 1004, *n*= 350 respectively**)**, examined to verify the patterns of data and how anthropometric measurements are affected**.**

3.5.3.1 Descriptive statistics

Descriptive statistics of anthropometric measurements for Serbian and Libyan male samples are presented in Tables 3.15 and 3.16. The mean and median values show that data in the Serbian sample have higher values than in the Libyan sample, excluding shoulder width, which has very close values. All data are normally distributed.

Table 3.15 Descriptive statistics of Serbian males

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG*	*VT*
WEI	1004	86.476	86.0	47	125	78	11.692	13.52	0.2749	1	*n.s.*	parameter
STH	1004	1807.699	1800.0	1630	1995	365	75.057	4.15	0.2133	1	*n.s.*	parameter
SIH	1004	916.399	920.0	750	1020	270	47.984	5.24	0.1452	1	*n.s.*	parameter
LLL	1004	593.081	595.0	470	770	300	36.162	6.10	0.2366	1	*n.s.*	parameter
ULL	1004	634.740	630.0	490	800	310	45.113	7.11	0.2017	1	*n.s.*	parameter
SHW	1004	471.934	470.0	380	630	250	46.894	9.94	0.1689	1	*n.s.*	parameter
HIB	1004	391.941	390.0	300	590	290	45.216	11.54	0.2833	1	*n.s.*	parameter
ARL	1004	706.328	700.0	495	830	335	46.594	6.60	0.1644	1	*n.s.*	parameter
FOL	1004	282.919	285.0	250	321	71	13.300	4.70	0.2819	1	*n.s.*	parameter

Table 3.16 Descriptive statistics of Libyan males

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v(%)	*D*	*p*	*SIG.*	*VT*
WEI	350	82.309	82	44	125	81	13.746	16.70	0.2530	1	*n.s.*	parameter
STH	350	1742.643	1740	1570	1900	330	64.632	3.71	0.1935	1	*n.s.*	parameter
SIH	350	851.757	850	700	970	270	45.004	5.28	0.2618	1	*n.s.*	parameter
LLL	350	541.843	540	450	670	220	34.808	6.42	0.2051	1	*n.s.*	parameter
ULL	350	579.371	580	500	720	220	37.465	6.47	0.2260	1	*n.s.*	parameter
SHW	350	473.871	470	380	640	260	47.068	9.93	0.2319	1	*n.s.*	parameter
HIB	350	367.960	360	230	570	340	58.145	15.80	0.2298	1	*n.s.*	parameter
ARL	350	634.389	620	450	800	350	73.711	11.62	0.2298	1	*n.s.*	parameter
FOL	350	275.529	275	255	300	45	9.151	3.32	0.1674	1	*n.s.*	parameter

3.5.3.2 Regression and correlation between anthropometric measurement of Serbian and Libyan males

Serbian males (male drivers and crane operators, *N*=1004) have a significant correlation between twelve different measurements, while Libyan males (male drivers and crane operators, *N*=350) have correlations between six different anthropometric measurements only. This means that the Libyan sample has fewer significant correlations than the Serbian sample, as shown in Tables 3.17 and 3.18. The patterns of correlations are almost the same as described in male drivers for both samples (Serbian and Libyan). Further illustration of the regression and correlations of anthropometric measurements is presented in Figures 3.28 – 3.36.

Table 3.17 The correlations between anthropometric measurements for Serbian males

Comparison			*r*	r^2 (%)	*SIG.*	Comparison			*r*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.411	16.89	*n.s.*	*SIH*	vs.	*LLL*	0.428	18.32	*n.s.*
WEI	vs.	*SIH*	0.282	7.95	*n.s.*	*SIH*	vs.	*ULL*	0.355	12.60	*n.s.*
WEI	vs.	*LLL*	0.334	11.16	*n.s.*	*SIH*	vs.	*SHW*	0.276	7.62	*n.s.*
WEI	vs.	*ULL*	0.366	13.40	*n.s.*	*SIH*	vs.	*HIB*	0.116	1.35	*n.s.*
WEI	vs.	*SHW*	0.425	18.06	*n.s.*	*SIH*	vs.	*ARL*	0.606	36.72	*
WEI	vs.	*HIB*	0.513	26.32	*	*SIH*	vs.	*FOL*	0.317	10.05	*n.s.*
WEI	vs.	*ARL*	0.279	7.78	*n.s.*	*LLL*	vs.	*ULL*	0.632	39.94	*
WEI	v.	*FOL*	0.319	10.18	*n.s.*	*LLL*	vs.	*SHW*	0.301	9.06	*n.s.*
STH	vs.	*SIH*	0.730	53.29	**	*LLL*	vs.	*HIB*	0.175	3.06	*n.s.*
STH	vs.	*LLL*	0.564	31.81	*	*LLL*	vs.	*ARL*	0.525	27.56	*
STH	vs.	*ULL*	0.519	26.94	*	*LLL*	vs.	*FOL*	0.335	11.22	*n.s.*
STH	vs.	*SHW*	0.253	6.40	*n.s.*	*ULL*	vs.	*SHW*	0.377	14.21	*n.s.*
STH	vs.	*HIB*	0.066	0.44	*n.s.*	*ULL*	vs.	*HIB*	0.253	6.40	*n.s.*
STH	vs.	*ARL*	0.549	30.14	*	*ULL*	vs.	*ARL*	0.483	23.33	*n.s.*
STH	vs.	*FOL*	0.466	21.72	*n.s.*	*ULL*	vs.	*FOL*	0.331	10.96	*n.s.*
ARL	vs.	*FOL*	0.321	10.30	*n.s.*	*SHW*	vs.	*HIB*	0.626	39.19	*
HIB	vs.	*ARL*	0.063	0.40	*n.s.*	*SHW*	vs.	*ARL*	0.318	10.11	*n.s.*
HIB	vs.	*FOL*	0.142	2.02	*n.s.*	*SHW*	vs.	*FOL*	0.147	2.16	*n.s.*

Table 3.18 The correlations between anthropometric measurements of Libyan males

Comparison			*r*	r^2 (%)	*SIG.*	Comparison			*r*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.226	5.11	*n.s.*	*SIH*	vs.	*LLL*	0.241	5.81	*n.s.*
WEI	vs.	*SIH*	0.216	4.67	*n.s.*	*SIH*	vs.	*ULL*	0.242	5.86	*n.s.*
WEI	vs.	*LLL*	0.256	6.55	*n.s.*	*SIH*	vs.	*SHW*	0.078	0.61	*n.s.*
WEI	vs.	*ULL*	0.296	8.70	*n.s.*	*SIH*	vs.	*HIB*	0.081	0.66	*n.s.*
WEI	vs.	*SHW*	0.460	21.16	*n.s.*	*SIH*	vs.	*ARL*	0.170	2.89	*n.s.*
WEI	vs.	*HIB*	0.392	15.37	*n.s.*	*SIH*	vs.	*FOL*	0.237	5.62	*n.s.*
WE	vs.	*ARL*	0.067	0.45	*n.s.*	*LLL*	vs.	*ULL*	0.667	44.49	*
WEI	vs.	*FOL*	0.343	11.76	*n.s.*	*LLL*	vs.	*SHW*	0.288	8.29	*n.s.*
STH	vs.	*SIH*	0.533	28.41	*	*LLL*	vs.	*HIB*	0.242	5.86	*n.s.*
STH	vs.	*LLL*	0.548	30.03	*	*LLL*	vs.	*ARL*	0.143	2.04	*n.s.*
STH	vs.	*ULL*	0.558	31.14	*	*LLL*	vs.	*FOL*	0.397	15.84	*n.s.*
STH	vs.	*SHW*	0.099	0.98	*n.s.*	*ULL*	vs.	*SHW*	0.237	5.66	*n.s.*
STH	vs.	*HIB*	0.106	1.12	*n.s.*	*ULL*	vs.	*HIB*	0.223	4.97	*n.s.*
STH	vs.	*ARL*	0.121	1.46	*n.s.*	*ULL*	vs.	*ARL*	0.121	1.46	*n.s.*
STH	vs.	*FOL*	0.429	18.4	*n.s.*	*ULL*	vs.	*FOL*	0.344	11.83	*n.s.*
ARL	vs.	*FOL*	0.024	0.06	*n.s.*	*SHW*	vs.	*HIB*	0.601	36.12	*
HIB	vs.	*ARL*	0.273	7.51	*n.s.*	*SHW*	vs.	*ARL*	0.176	3.1	*n.s.*
HIB	vs.	*FOL*	0.059	0.350	*n.s.*	*SHW*	vs.	*FOL*	0.058	0.34	*n.s.*

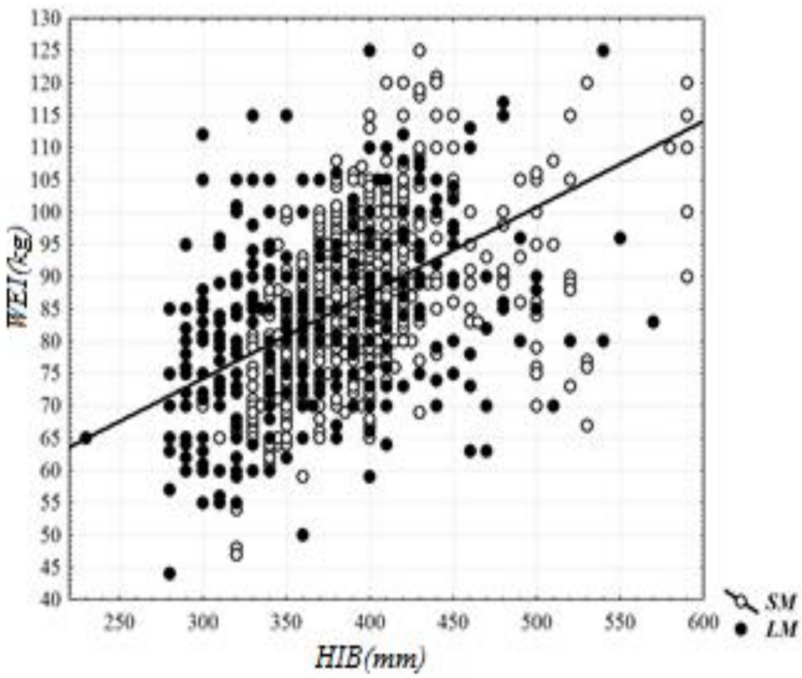

Figure 3.28 Regression between *WEI* and *HIB* for *SM* and *LM*

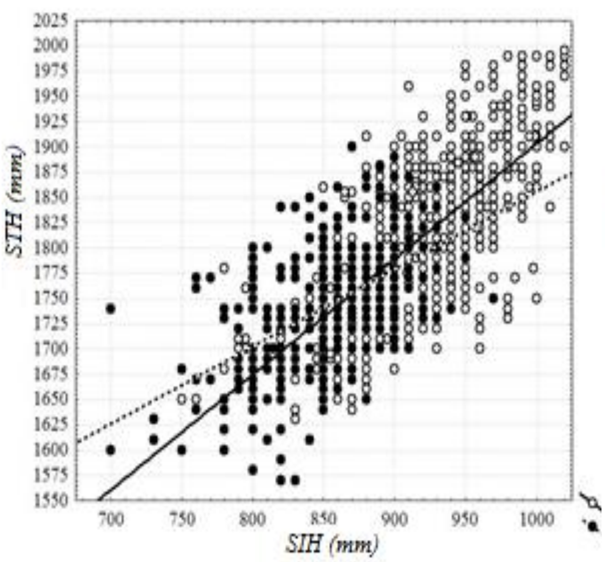

Figure 3.29 Regression between *STH* and *SIH* for *SM* and *LM*

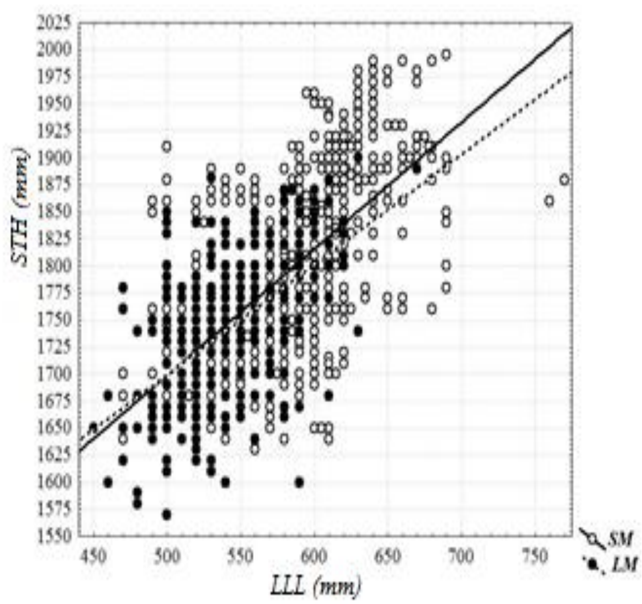

Figure 3.30 Regression between *STH* and *LLL* for *SM* and *LM*

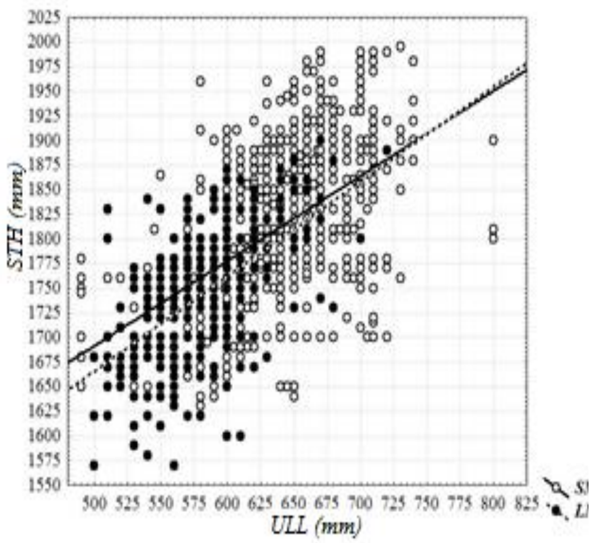

Figure 3.31 Regression between *STH* and *ULL* for *SM* and *LM*

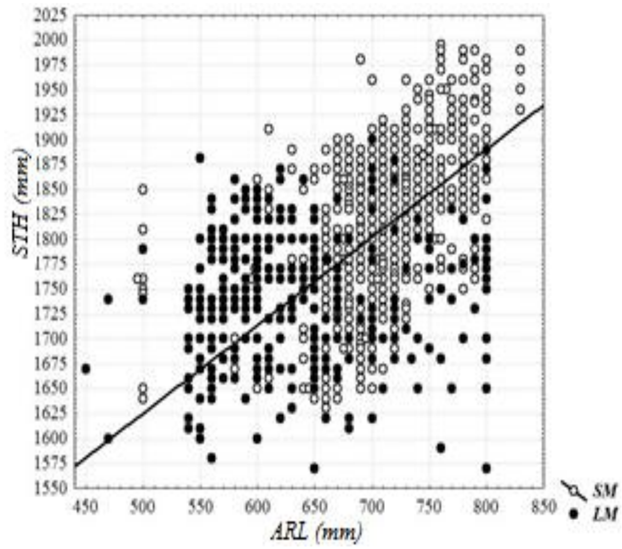

Figure 3.32 Regression between *STH* and *ARL* for *SM* and *LM*

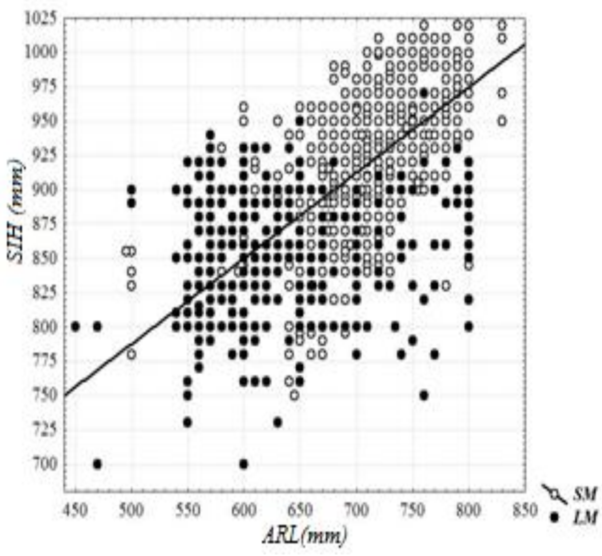

Figure 3.33 Regression between *SIH* and *ARL* for *SM* and *LM*

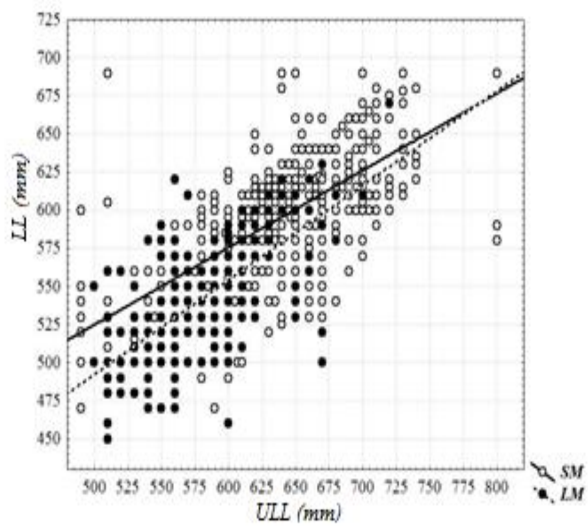

Figure 3.34 Regression between *LLL* and *ULL* for *SM* and *LM*

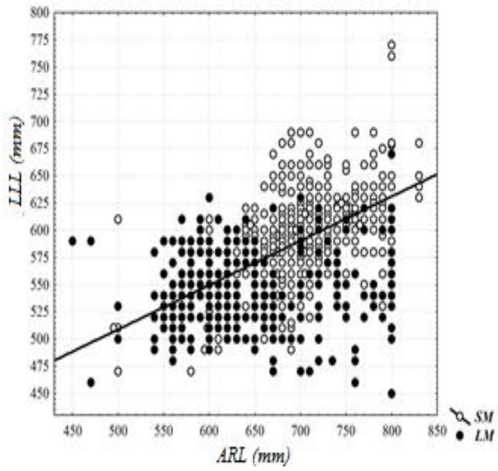

Figure 3.35 Regression between *LLL* and *ARL* for *SM* and *LM*

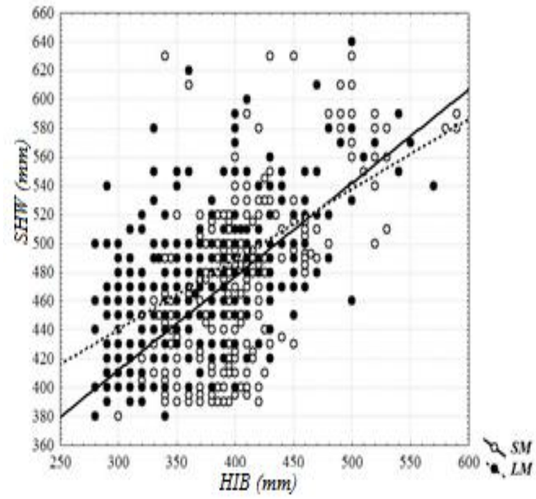

Figure 3.36 Regression between *SHW* and *HIB* for *SM* and *LM*

3.5.3.3 Comparisons of means between anthropometric measurements between Serbian and Libyan males

It was found, as in Table 3.19, that there are absolute significant differences between Serbian and Libyan males, at a significance level of $p<0.001$, for all measurements, except shoulder width, where there is no significant difference with p-value=0.5063. of the samples for male drivers. Figures 3.37-3.39, illustrate the significant differences between the means anthropometric measurements of the samples for male drivers.

Table 3.19 Comparison between Serbian and Libyan male drivers

z test	*p* value	*p*
WEI SM>>>WEI LM	0	$p<0.001$
STH SM >>>STH LM	0	$p<0.001$
SIH SM>>>SIH LM	0	$p<0.001$
LLL SM>>>LLL LM	0	$p<0.001$
ULL SM>>>ULL LM	0	$p<0.001$
SHW SM = SHW LM	0.5063	*n.s.*
HIB SM>>>HIB LM	0	$p<0.001$
ARL SM>>>ARL LM	0	$p<0.001$
FOL SM>>>FOL LM	0	$p<0.001$

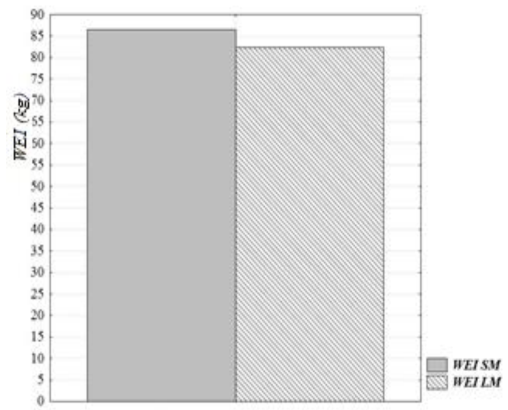

Figure 3.37 Ratio between *WEI* means for *SM* and *LM*

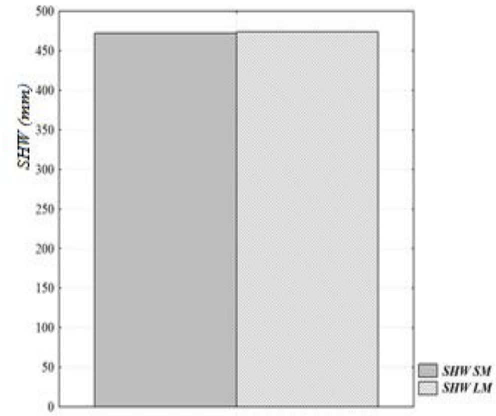

Figure 3.38 Ratio between *SHW* means for *SM* and *LM*

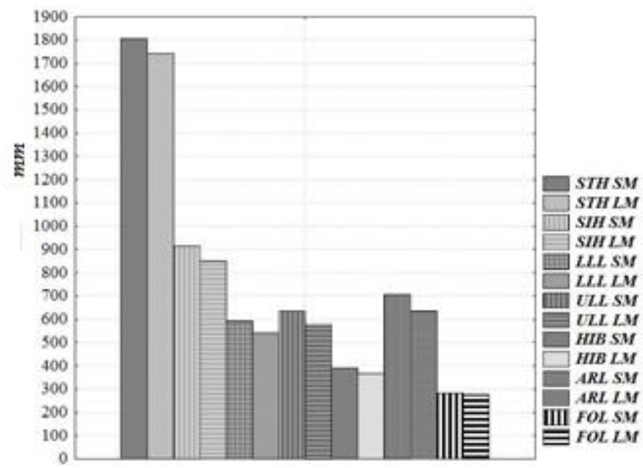

Figure 3.39 Ratio between means of anthropometric measurements between *SMD* and *LMD*

3.5.4 Statistical examination of data for Serbian and Libyan female drivers

A sample of female drivers from Serbia (n=193) and Libya (n=50), are examined to identify the behavior and effect of gender on the anthropometric measurements, and how far is it from a male one. Such information is valuable in the design of the interior space of vehicles and other equipment or machines that are driven or used by females.

3.5.4.1 Descriptive statistics

The body weight, hip breadth, and foot length measurements in Libyan female drivers have greater values than those of Serbian female drivers, while the opposite is true for arm length and standing height, as in Tables 3.20 and 3.21.

Table 3.20 Descriptive statistics for Serbian female drivers

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG.*	*VT*
WEI	193	65.539	64.0	45.000	115.000	70.0	11.565	17.65	0.238	1	*n.s.*	parameter
STH	193	1694.38	1700.0	1520.00	1880.00	360.0	61.465	3.63	0.138	1	*n.s.*	parameter
SIH	193	866.088	870.0	560.000	950.000	390.0	44.943	5.19	0.1973	1	*n.s.*	parameter
LLL	193	557.409	560.0	370.000	710.000	340.0	36.297	6.51	0.2986	1	*n.s.*	parameter
ULL	193	592.627	590.0	384.000	780.000	396.0	50.368	8.50	0.2702	1	*n.s.*	parameter
SHW	193	412.596	400.0	358.000	580.000	222.0	34.391	8.34	0.2711	1	*n.s.*	parameter
HIB	193	370.036	360.0	290.000	520.000	230.0	42.700	11.54	0.1535	1	*n.s.*	parameter
ARL	193	652.202	650.0	410.000	795.000	385.0	47.296	7.25	0.2651	1	*n.s.*	parameter
FOL	193	249.793	255.0	225.000	285.000	60.0	13.108	5.25	0.1849	1	*n.s.*	parameter

Table 3.21 Descriptive statistics for Libyan female drivers

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_v (%)	*D*	*p*	*SIG.*	*VT*
WEI	50	73.140	73.5	54	90	36	9.394	12.84	0.1731	1	*n.s.*	parameter
STH	50	1663.780	1660.0	1510	1780	270	53.796	3.23	0.168	1	*n.s.*	parameter
SIH	50	824.400	845.0	670	960	290	73.656	8.93	0.1444	1	*n.s.*	parameter
LLL	50	512.800	500.0	450	630	180	41.652	8.12	0.226	1	*n.s.*	parameter
ULL	50	565.800	570.0	490	670	180	41.654	7.36	0.1716	1	*n.s.*	parameter
SHW	50	402.800	400.0	340	500	160	30.973	7.69	0.1945	1	*n.s.*	parameter
HIB	50	386.600	390.0	320	460	140	31.727	8.21	0.1955	1	*n.s.*	parameter
ARL	50	617.400	620.0	530	680	150	36.579	5.92	0.1782	1	*n.s.*	parameter
FOL	50	252.40	255.0	230	175	45	13.141	5.21	0.188	1	*n.s.*	parameter

3.5.4.2 Regression and correlation between anthropometric measurement of Serbian and Libyan female drivers

There is a weak significant correlation on body weight with hip breadth and shoulder width, and between lower leg length and upper leg length and shoulder width and hip breadth for both samples. The standing height has a significant correlation with sitting height, lower leg, and upper leg length in Libyan sample, and only with foot length in Serbian sample, as in Tables 3.22 and 3.23. Illustration of regression and correlation patterns is given in Figures 3.40–3.49.

.Table 3.22 The correlation between anthropometric measurements of Serbian female drivers

Comparison			R	r² (%)	SIG.	Comparison			r	r² (%)	SIG.
WEI	vs.	*STH*	0.315	9.92	*n.s.*	*SIH*	vs.	*LLL*	0.399	15.92	*n.s.*
WEI	vs.	*SIH*	0.140	1.96	*n.s.*	*SIH*	vs.	*ULL*	0.290	8.41	*n.s.*
WEI	vs.	*LLL*	0.282	7.95	*n.s.*	*SIH*	vs.	*SHW*	0.097	0.94	*n.s.*
WEI	vs.	*ULL*	0.351	12.32	*n.s.*	*SIH*	vs.	*HIB*	0.124	1.54	*n.s.*
WEI	vs.	*SHW*	0.548	30.03	*	*SIH*	vs.	*ARL*	0.221	4.88	*n.s.*
WEI	vs.	*HIB*	0.658	43.3	*	*SIH*	vs.	*FOL*	0.110	1.21	*n.s.*
WEI	vs.	*ARL*	0.316	9.99	*n.s.*	*LLL*	vs.	*ULL*	0.692	47.89	*
WEI	vs.	*FOL*	0.516	26.63	*	*LLL*	vs.	*SHW*	0.122	1.49	*n.s.*
STH	vs.	*SIH*	0.422	17.81	*n.s.*	*LLL*	vs.	*HIB*	0.080	0.64	*n.s.*
STH	vs.	*LLL*	0.469	22.00	*n.s.*	*LLL*	vs.	*ARL*	0.361	13.03	*n.s.*
STH	vs.	*ULL*	0.435	18.92	*n.s.*	*LLL*	vs.	*FOL*	0.333	11.09	*n.s.*
STH	vs.	*SHW*	0.270	7.29	*n.s.*	*ULL*	vs.	*SHW*	0.314	9.86	*n.s.*
STH	vs.	*HIB*	0.192	3.69	*n.s.*	*ULL*	vs.	*HIB*	0.185	3.42	*n.s.*
STH	vs.	*ARL*	0.450	20.25	*n.s.*	*ULL*	vs.	*ARL*	0.462	21.34	*n.s.*
STH	vs.	*FOL*	0.594	35.28	*	*ULL*	vs.	*FOL*	0.359	12.89	*n.s.*
ARL	vs.	*FOL*	0.366	13.40	*n.s.*	*SHW*	vs.	*HIB*	0.626	39.19	*
HIB	vs.	*ARL*	0.382	14.59	*n.s.*	*SHW*	vs.	*ARL*	0.502	25.20	*
HIB	vs.	*FOL*	0.403	16.24	*n.s.*	*SHW*	vs.	*FOL*	0.417	17.39	*n.s.*

Table 3.23 The correlations between anthropometric measurements of Libyan female drivers

Comparison			r	r²	SIG.	Comparison			R	r² (%)	SIG.
WEI	vs.	*STH*	0.094	0.88	*n.s.*	*SIH*	vs.	*LLL*	0.468	21.90	*n.s.*
WEI	vs.	*SIH*	0.072	0.52	*n.s.*	*SIH*	vs.	*ULL*	0.486	23.62	*n.s.*
WEI	vs.	*LLL*	0.079	0.62	*n.s.*	*SIH*	vs.	*SHW*	0.089	0.79	*n.s.*
WEI	vs.	*ULL*	0.048	0.23	*n.s.*	*SIH*	vs.	*HIB*	0.068	0.46	*n.s.*
WEI	vs.	*SHW*	0.638	40.70	*	*SIH*	vs.	*ARL*	0.219	4.80	*n.s.*
WEI	vs.	*HIB*	0.810	65.61	**	*SIH*	vs.	*FOL*	0.117	1.37	*n.s.*
WEI	vs.	*ARL*	0.228	5.20	*n.s.*	*LLL*	vs.	*ULL*	0.815	66.42	**
WEI	vs.	*FOL*	0.368	13.54	*n.s.*	*LLL*	vs.	*SHW*	0.108	1.17	*n.s.*
STH	vs.	*SIH*	0.704	49.56	**	*LLL*	vs.	*HIB*	0.003	0.00	*n.s.*
STH	vs.	*LLL*	0.541	29.27	*	*LLL*	vs.	*ARL*	0.289	8.35	*n.s.*
STH	vs.	*ULL*	0.521	27.14	*	*LLL*	vs.	*FOL*	0.118	1.39	*n.s.*
STH	vs.	*SHW*	0.053	0.28	*n.s.*	*ULL*	vs.	*SHW*	0.010	0.01	*n.s.*
STH	vs.	*HIB*	0.162	2.62	*n.s.*	*ULL*	vs.	*HIB*	0.026	0.07	*n.s.*
STH	vs.	*ARL*	0.216	4.67	*n.s.*	*ULL*	vs.	*ARL*	0.289	8.35	*n.s.*
STH	vs.	*FOL*	0.117	1.369	*n.s.*	*ULL*	vs.	*FOL*	0.024	0.06	*n.s.*
ARL	vs.	*FOL*	0.190	3.61	*n.s.*	*SHW*	vs.	*HIB*	0.695	48.30	*
HIB	vs.	*ARL*	0.240	5.76	*n.s.*	*SHW*	vs.	*ARL*	0.193	3.72	*n.s.*
HIB	vs.	*FOL*	0.380	14.44	*n.s.*	*SHW*	vs.	*FOL*	0.442	19.54	*n.s.*

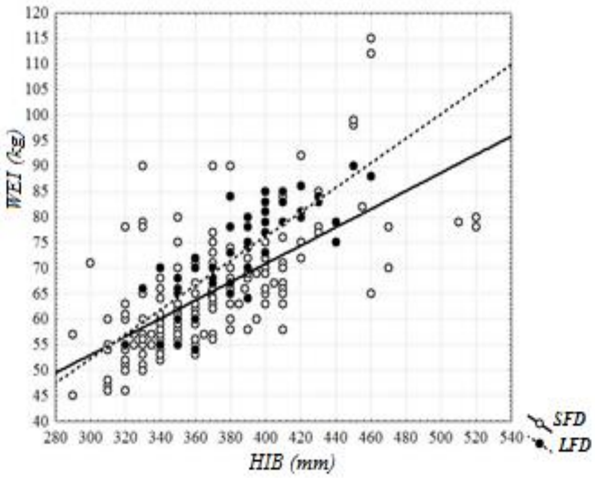

Figure 3.40 Regression between *WEI* and *HIB* for *SFD* and *LFD*

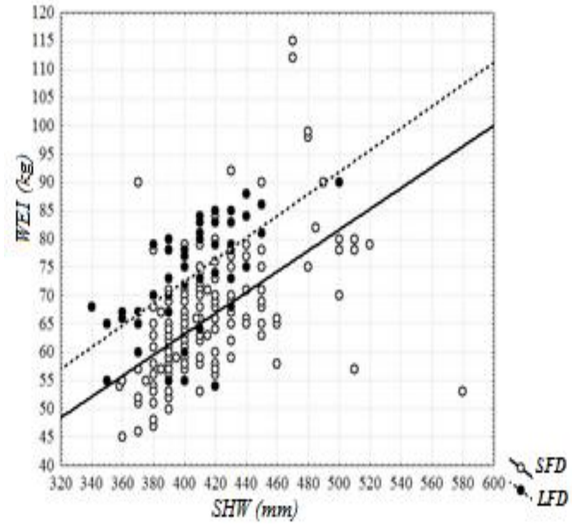

Figure 3.41 Regression between *WEI* and *SHW* for *SFD* and *LFD*

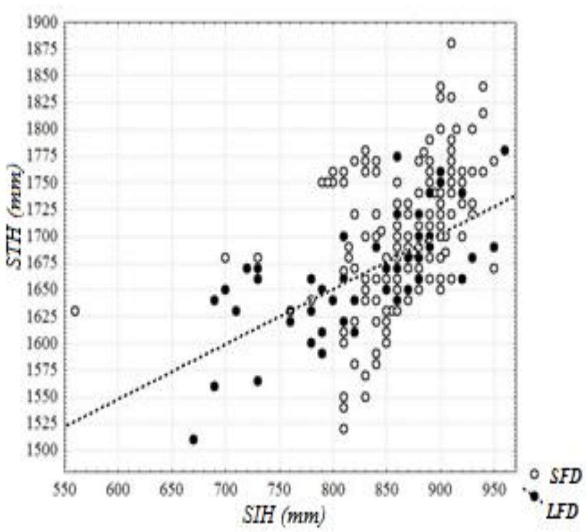

Figure 3.42 Regression between *STH* and *SIH* for *SFD* and *LFD*

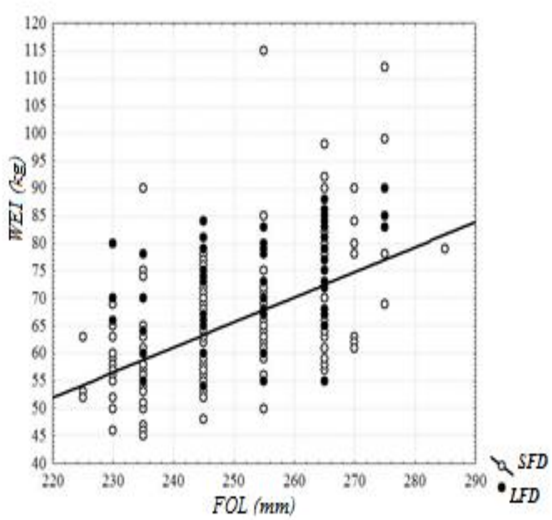

Figure 3.43 Regression between *WEI* and *FOL* for *SFD* and *LFD*

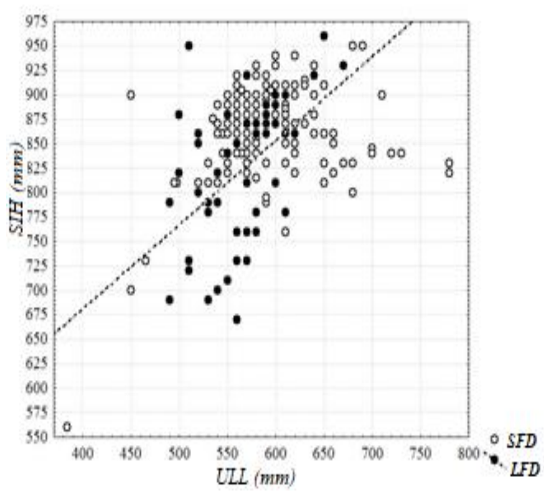

Figure 3.44 Regression between *STH* and *ULL* for *SFD* and *LFD*

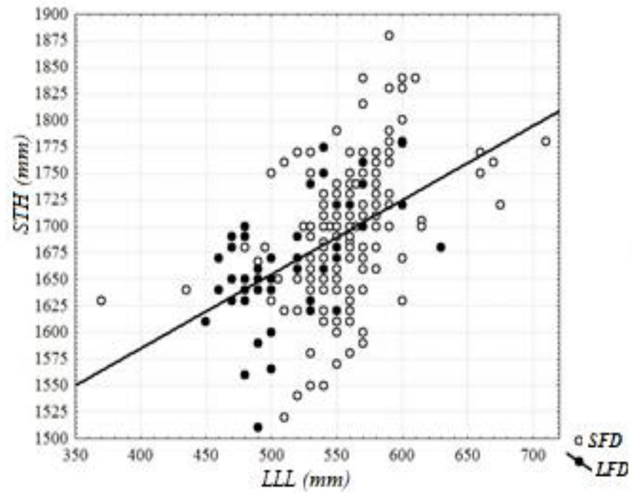

Figure 3.45 Regression between *STH* and *LLL* for *SFD* and *LFD*

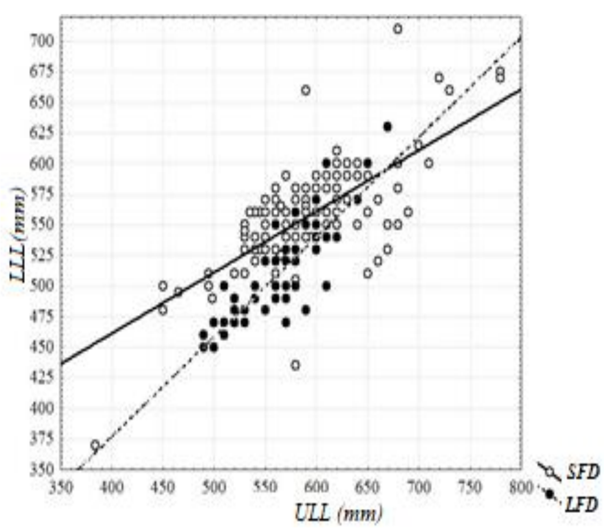

Figure 3.46 Regression between *LLL* and *ULL* for *SFD* and *LFD*

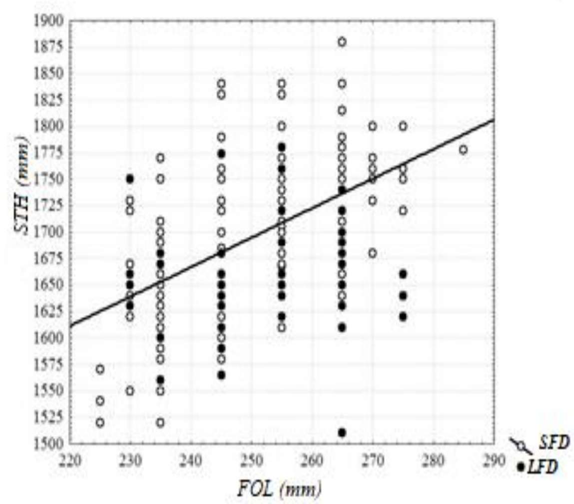

Figure 3.47 Regression between *STH* and *FO*L for *SFD* and *LFD*

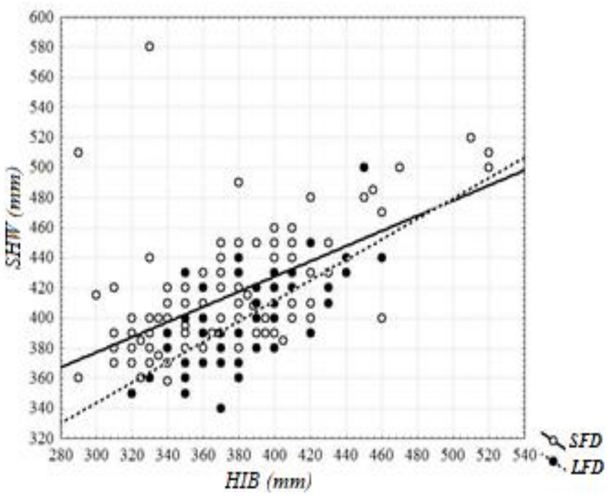

Figure 3.48 Regression between *SHW* and *HIB* for *SFD* and *LFD*

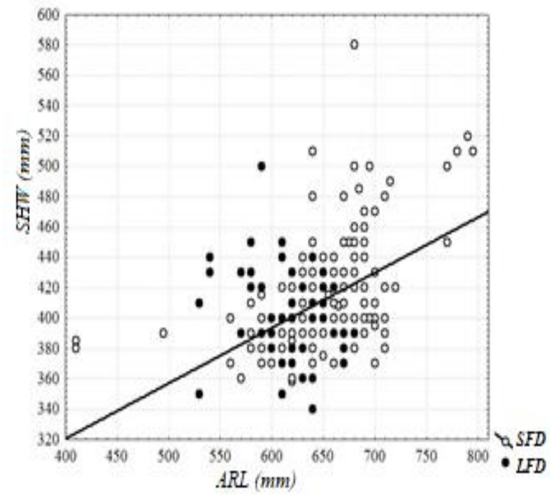

Figure 3.49 Regression between *SHW* and *ARL* for *SFD* and *LFD*

3.5.4.3 Comparisons of means between the anthropometric measurements of Serbian and Libyan female drivers

Serbian female drivers have an absolute significant difference in body weight at a significant level $p<0.001$ with p-values =0, which means that they have lower body weight than Libyan female drivers. A similar conclusion cold be drawn for Serbian hip breadth which has a strong significance level of $p<0.01$ with p-value=0.0023. Regarding all other anthropometric measurements, Serbian females have larger measurements than Libyan females at a significance level $p<0.001$ with p values close to zero, as shown in Table 3.24, except in shoulder width, where there is no significant difference with p-value=0.0517 and foot length with p-value=0.215. Figures 3.50 - 3.51 illustrate the differences in hip breadth values and body weight, where Libyan females have greater mean values than Serbian female drivers. Figure 3.52 illustrates shoulder width and foot length that have no significant differences, and Figure 3.53 depicts the rest of the mean value differences of anthropometric measurements, which confirms the obtained results.

Table 3.24 Comparison between Serbian and Libyan female drivers

z test	*p* value	*p*
WEI SFD<<< WEI LFD	0	p<0.001
STH SFD>>>STH LFD	0.0005	p<0.001
SIH SFD>>>SIH LFD	0.0001	p<0.001
LLL SFD>>>LLL LFD	0	p<0.001
ULL SFD>>>ULL LFD	0.0001	p<0.001
SHW SFD=SHW LFD	0.0517	*n.s.*
HIB SFD<<HIB LFD	0.0023	p<0.01
ARL SFD>>>ARL LFD	0	p<0.001
FOL SFD=FOL LFD	0.2105	*n.s.*

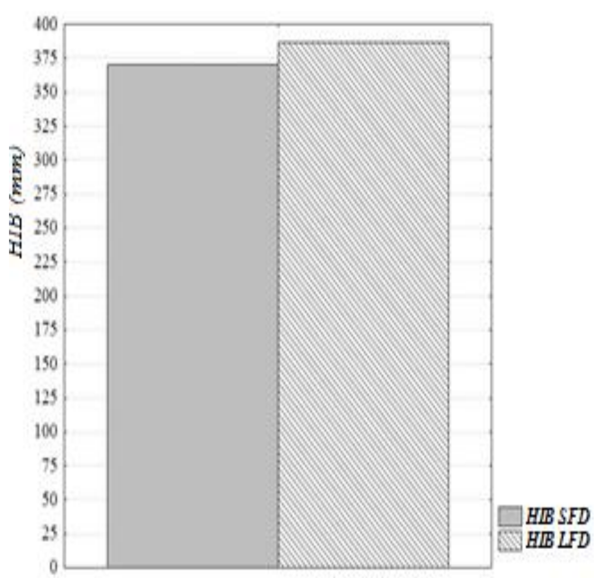

Figure 3.50 Ratio between *HIB* means for *SFD* and *LFD*

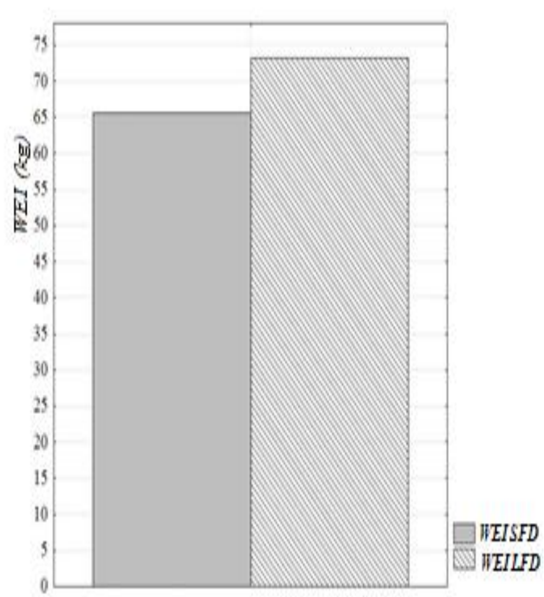

Figure 3.51 Ratio between *WEI* means for *SFD* and *LFD*

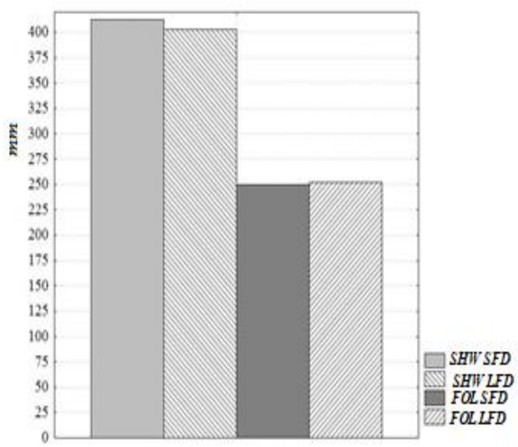

Figure 3.52 Ratios between *SHW* and *FOL* means for *SFD* and *LFD*

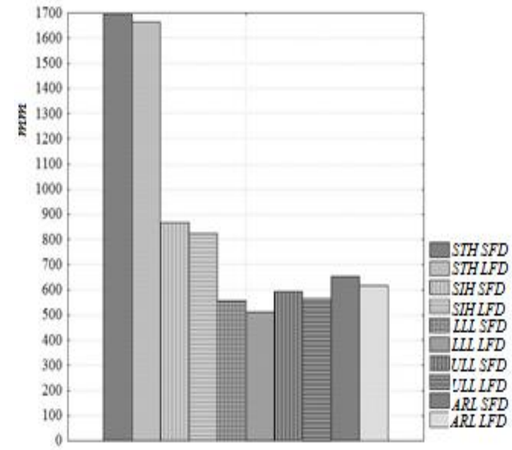

Figure 3.53 Ratios between means of anthropometric measurements for *SFD* and *LFD*

3.5.5 Statistical examination of data for all Serbian and Libyan participants

All participants were combined into one sample according to their nationality. The Serbian sample was formed of male drivers, female drivers, and crane operators *N*= 921+193+83=1197, and the same was done with the Libyan sample *N*=300+50+50=400. This analysis was conducted to explore the effect of large mixed data on the anthropometric measurements, and their patterns, which facilitates the interior space design of vehicles and cabins used by both males and females, in order to establish a model that could be fit to multi-users.

3.5.5.1 Descriptive statistics

As can be seen from Table 3.25 and Table 3.26, the mean and median values show that the Serbian sample has higher values than the Libyan sample, excluding shoulder width which has very close values, meaning that the Serbian sample has larger anthropometric measurements than the Libyan sample has.

Table 3.25 Descriptive statistics for all Serbians participants

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_V (%)	*D*	*p*	*SIG.*	*VT*
WEI	1197	83.100	84	45	125	80	13.980	16.82	0.2350	1	*n.s.*	parameter
STH	1197	1789.428	1780	1520	1995	475	84.078	4.70	0.2055	1	*n.s.*	parameter
SIH	1197	908.287	910	560	1020	460	50.969	5.61	0.1527	1	*n.s.*	parameter
LLL	1197	587.329	590	370	770	400	38.476	6.55	0.2372	1	*n.s.*	parameter
ULL	1197	627.950	625	384	800	416	48.519	7.73	0.1923	1	*n.s.*	parameter
SHW	1197	462.367	460	358	630	272	50.106	10.84	0.2013	1	*n.s.*	parameter
HIB	1197	388.409	390	290	590	300	45.522	11.72	0.3028	<0.200	*n.s.*	parameter
ARL	1197	697.601	700	410	830	420	50.757	7.28	0.1821	1	*n.s.*	parameter
FOL	1197	277.578	275	225	321	96	18.013	6.49	0.1879	1	*n.s.*	parameter

Table 3.26 Descriptive statistics for all Libyans participants

Dimension	*N*	*Mean*	*Med.*	*Min.*	*Max.*	*R*	*SD*	c_V (%)	*D*	*p*	*SIG.*	*VT*
WEI	400	81.163	80.0	44	125	81	13.614	16.77	0.139	1	*n.s.*	parameter
STH	400	1732.785	1740.0	1510	1900	390	68.492	3.95	0.232	1	*n.s.*	parameter
SIH	400	848.338	850.0	670	970	300	50.198	5.92	0.194	1	*n.s.*	parameter
LLL	400	538.213	540.0	450	670	220	36.950	6.87	0.159	1	*n.s.*	parameter
ULL	400	577.675	580.0	490	720	230	38.223	6.62	0.219	1	*n.s.*	parameter
SHW	400	464.988	467.5	340	640	300	51.083	10.99	0.252	1	*n.s.*	parameter
HIB	400	370.290	360.0	230	570	340	55.847	15.08	0.157	1	*n.s.*	parameter
ARL	400	632.265	620.0	450	800	350	70.345	11.13	0.196	1	*n.s.*	parameter
FOL	400	272.64	275.0	230	300	70	12.374	4.54	0.252	1	*n.s.*	parameter

3.5.5.2 Regression and correlation between anthropometric measurement for all Serbian and Libyan participants

The correlation results show that the measurements of the sample for the Serbian population have more statistically significant correlations than the Libyan sample has, as in Tables 3.27 and 3.28.

Table 3.27 The correlations between anthropometric measurements of all Serbian participants

Comparison			*R*	r^2 (%)	*SIG.*	Comparison			*r*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.561	31.47	*	*SIH*	vs.	*LLL*	0.495	24.50	*n.s.*
WEI	vs.	*SIH*	0.403	16.24	*n.s.*	*SIH*	vs.	*ULL*	0.419	17.56	*n.s.*
WEI	vs.	*LLL*	0.443	19.62	*n.s.*	*SIH*	vs.	*SHW*	0.353	12.46	*n.s.*
WEI	vs.	*ULL*	0.463	21.44	*n.s.*	*SIH*	vs.	*HIB*	0.043	0.18	*n.s.*
WEI	vs.	*SHW*	0.569	32.38	*	*SIH*	vs.	*ARL*	0.611	37.33	*
WEI	vs.	*HIB*	0.537	28.84	*	*SIH*	vs.	*FOL*	0.442	19.54	*n.s.*
WEI	vs.	*ARL*	0.435	18.92	*n.s.*	*LLL*	vs.	*ULL*	0.681	46.38	*
WEI	vs.	*FOL*	0.588	34.57	*	*LLLL*	vs.	*SHW*	0.383	14.67	*n.s.*
STH	vs.	*SIH*	0.738	54.46	**	*LLL*	vs.	*HIB*	0.209	4.37	*n.s.*
STH	vs.	*LLL*	0.618	38.19	*	*LLL*	vs.	*ARL*	0.565	31.92	*
STH	vs.	*ULL*	0.572	32.72	*	*LLL*	vs.	*FOL*	0.462	21.34	*n.s.*
STH	vs.	*SHW*	0.415	17.22	*n.s.*	*ULL*	vs.	*SHW*	0.450	20.25	*n.s.*
STH	vs.	*HIB*	0.518	26.83	*	*ULL*	vs.	*HIB*	0.281	7.90	*n.s.*
STH	vs.	*ARL*	0.621	38.56	*	*ULL*	vs.	*ARL*	0.543	29.48	*
STH	vs.	*FOL*	0.644	41.47	*	*ULL*	vs.	*FOL*	0.450	20.25	*n.s.*
ARL	vs.	*FOL*	0.488	23.81	*n.s.*	*SHW*	vs.	*HIB*	0.630	39.69	*
HIB	vs.	*ARL*	0.171	2.92	*n.s.*	*SHW*	vs.	*ARL*	0.452	20.43	*n.s.*
HIB	vs.	*FOL*	0.251	6.30	*n.s.*	*SHW*	vs.	*FOL*	0.413	17.06	*n.s.*

Table 3.28 The correlations between anthropometric measurements of all Libyan participants

Comparison			*R*	r^2 (%)	*SIG.*	Comparison			*r*	r^2 (%)	*SIG.*
WEI	vs.	*STH*	0.267	7.13	*n.s.*	*SIH*	vs.	*LLL*	0.320	10.24	*n.s.*
WEI	vs.	*SIH*	0.202	4.08	*n.s.*	*SIH*	vs.	*ULL*	0.302	9.12	*n.s.*
WEI	vs.	*LLL*	0.278	7.73	*n.s.*	*SIH*	vs.	*SHW*	0.130	1.69	*n.s.*
WEI	vs.	*ULL*	0.278	7.73	*n.s.*	*SIH*	vs.	*HIB*	0.039	0.15	*n.s.*
WEI	vs.	*SHW*	0.509	25.91	*	*SIH*	vs.	*ARL*	0.175	3.06	*n.s.*
WEI	vs.	*HIB*	0.375	14.06	*n.s.*	*SIH*	vs.	*FOL*	0.271	7.34	*n.s.*
WE	vs.	*ARL*	0.070	0.49	*n.s.*	*LLL*	vs.	*ULL*	0.692	47.89	*
WEI	vs.	*FOL*	0.395	15.60	*n.s.*	*LLL*	vs.	*SHW*	0.348	12.11	*n.s.*
STH	vs.	*SIH*	0.563	31.70	*	*LLL*	vs.	*HIB*	0.179	3.20	*n.s.*
STH	vs.	*LLL*	0.584	34.11	*	*LLL*	vs.	*ARL*	0.165	2.72	*n.s.*
STH	vs.	*ULL*	0.551	30.36	*	*LLL*	vs.	*FOL*	0.420	17.64	*n.s.*
STH	vs.	*SHW*	0.248	6.15	*n.s.*	*ULL*	vs.	*SHW*	0.241	5.81	*n.s.*
STH	vs.	*HIB*	0.040	0.16	*n.s.*	*ULL*	vs.	*HIB*	0.184	3.42	*n.s.*
STH	vs.	*ARL*	0.146	2.13	*n.s.*	*ULL*	vs.	*ARL*	0.138	1.90	*n.s.*
STH	vs.	*FOL*	0.510	26.01	*	*ULL*	vs.	*FOL*	0.294	8.64	*n.s.*
ARL	vs.	*FOL*	0.020	0.04	*n.s.*	*SHW*	vs.	*HIB*	0.483	23.33	*n.s.*
HIB	vs.	*ARL*	0.243	5.90	*n.s.*	*SHW*	vs.	*ARL*	0.178	3.17	*n.s.*
HIB	vs.	*FOL*	0.001	0.00	*n.s.*	*SHW*	vs.	*FOL*	0.355	12.60	*n.s.*

Further illustration of regression and correlations are depicted in Figures 3.54 – 3.68.

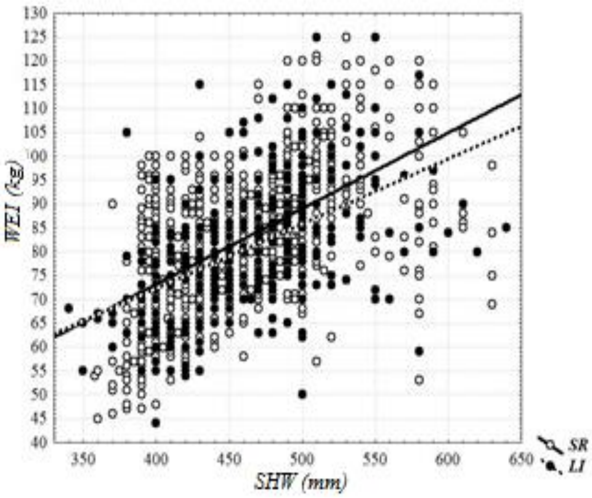

Figure 3.54 Regression between *WEI* and *SHW* for *SR* and *LI*

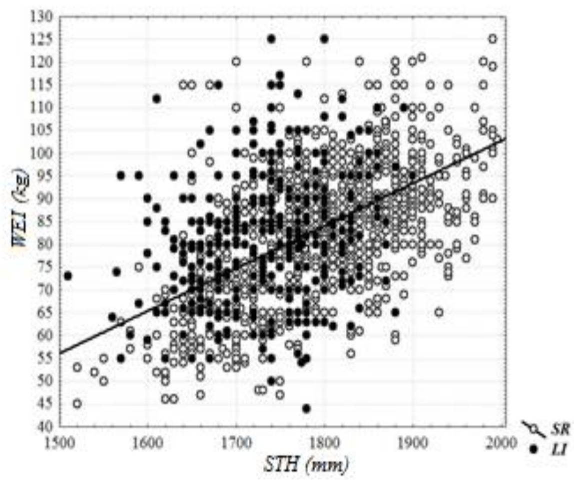

Figure 3.55 Regression between *WEI* and *STH* for *SR* and *LI*

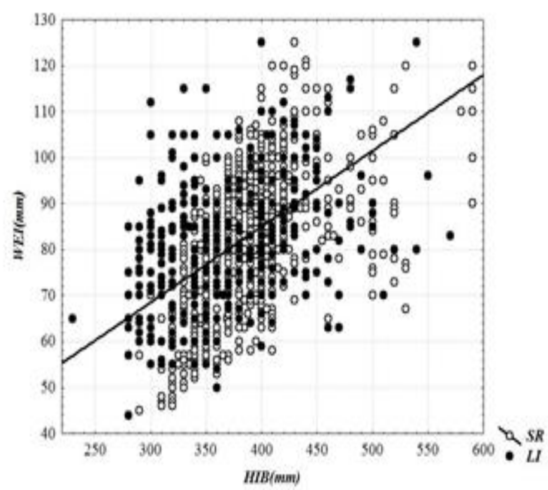

Figure 3.56 Regression between *WEI* and *HIB* for SR and *LI*

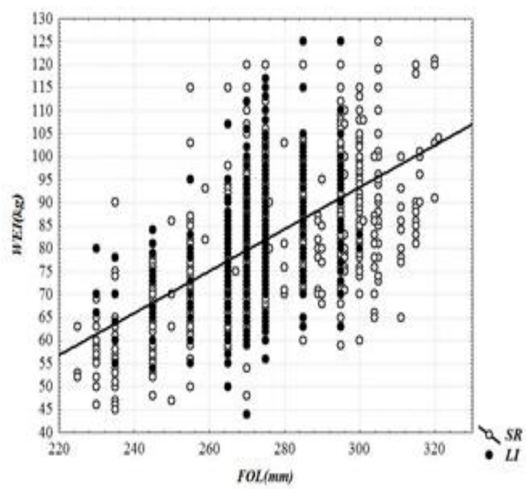

Figure 3.57 Regression between *WEI* and *FOL* for *SR* and *LI*

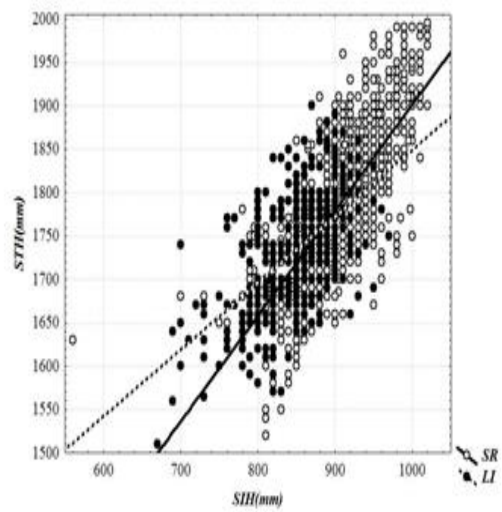

Figure 3.58 Regression between *STH* and *SIH* for *SR* and *LI*

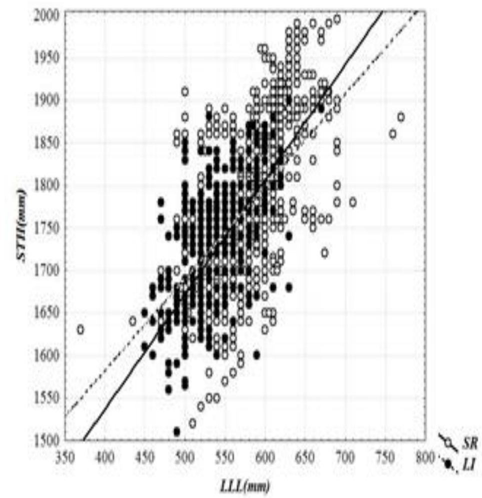

Figure 3.59 Regression between *STH* and *LLL* for *SR* and *LI*

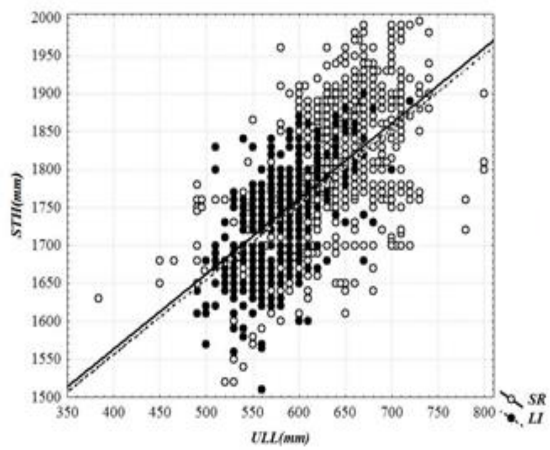

Figure 3.60 Regression between *STH* and *ULL* for *SR* and *LI*

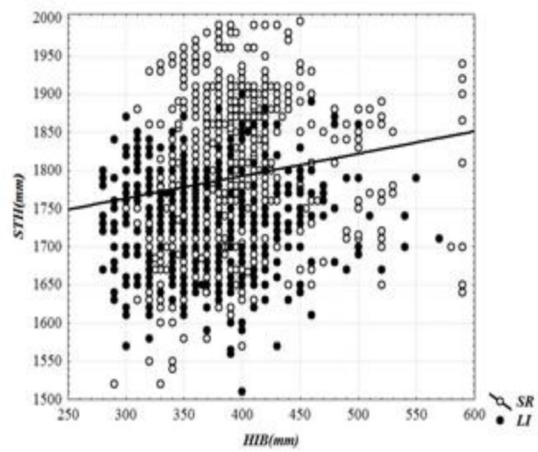

Figure 3.61 Regression between *STH* and *HIB* for *SR* and *LI*

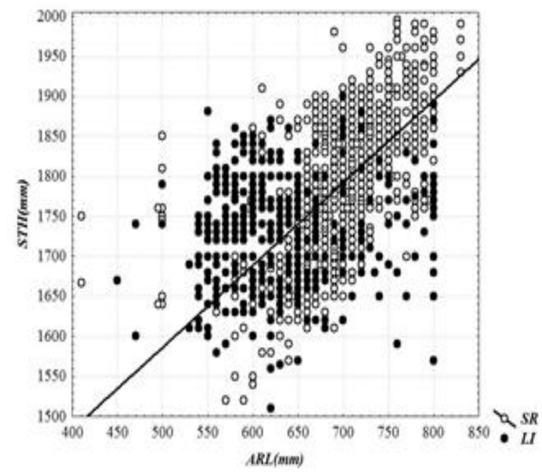

Figure 3.62 Regression between *STH* and *ARL* for *SR* and *LI*

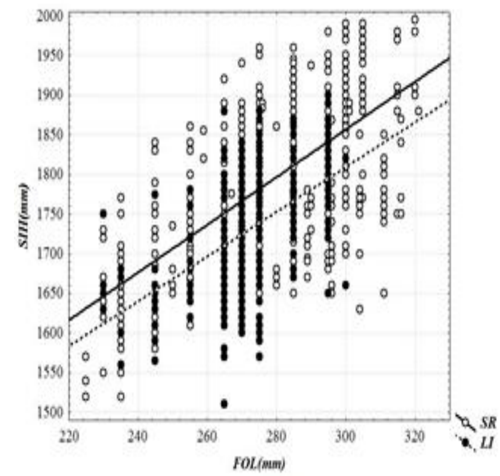

Figure 3.63 Regression between *SIH* and *FOL* for *SR* and *LI*

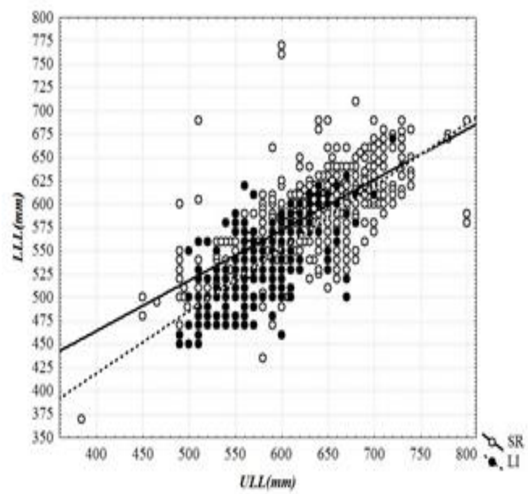

Figure 3.64 Regression between *LLL* and *ULL* for *SR* and *LI*

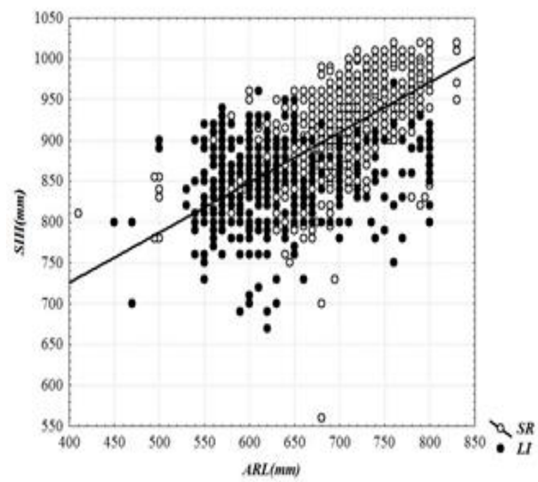

Figure 3.65 Regression between *SIH* and *ARL* for *SR* and *LI*

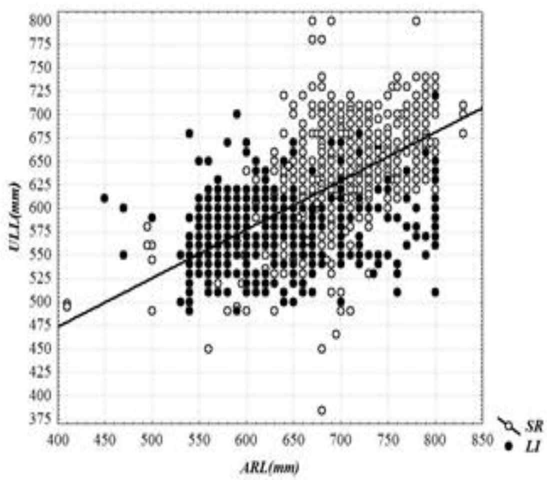

Figure 3.66 Regression between *ULL* and *ARL* for *SR* and *LI*

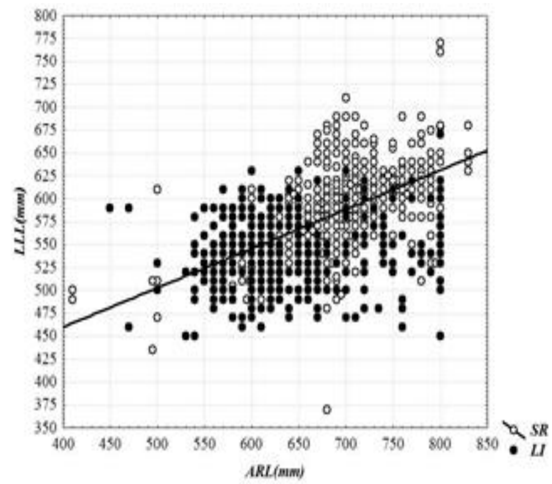

Figure 3.67 Regression between *LLL* and *ARL* for *SR* and *LI*

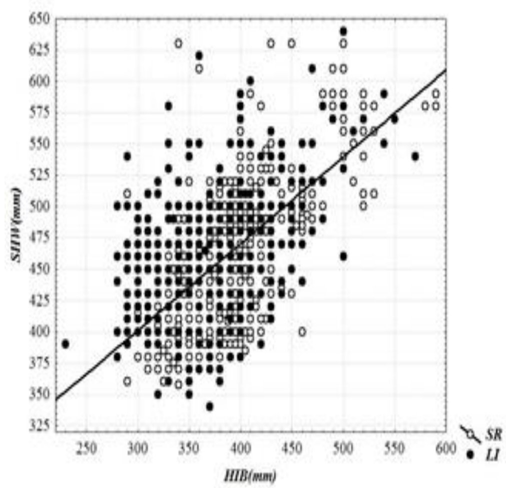

Figure 3.68 Regression between *SHW* and *HIB* for *SR* and *LI*

3.5.5.3 Comparison of means between anthropometric measurements of all Serbian and Libyan participants

This comparison was done in order to investigate and verify the effect of the mixed gender and occupation selection on the anthropometric measurements with nationality as the only difference. Absolute, significant differences were again found between all compared anthropometric measurements at a significance level of $p<0.001$, with p-values=0. Body weight showed a strong significance difference at level of $p<0.01$ (p-value=0.0052), and shoulder width again had no significant difference with *p*-value=0.3132. The test indicates that the Serbian sample has larger anthropometric measurements than the Libyan sample, as shown in Table 3.29, whereas Figure 3.69 shows that there is no significant difference in mean values of shoulder width and the difference in body weight as shown in Figure 3.70. Figure 3.71 represents the ratio between means and clearly illustrates the differences between the rest of measurements and confirms the captured results.

Table 3.29 Comparison between all Serbian and Libyan participants

z test	*p* value	*p*
WEI SR >> WEI LI	0.0052	p<0.01
STH SR >>> STH LI	0	p<0.001
SIH SR >>> SIH LI	0	p<0.001
LLL SR >>> LLL LI	0	p<0.001
ULL SR >>> ULL LI	0	p<0.001
SHW SR = SHW LI	0.3132	*n.s.*
HIB SR >>> HIB LI	0	p<0.001
ARL SR >>> ARL LI	0	p<0.001
FOL SR >>> FOL LI	0	p<0.001

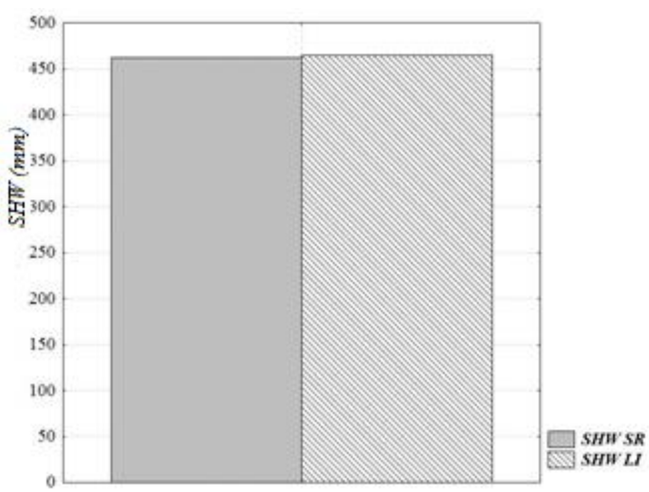

Figure 3.69 Ratio between *SHW* means for *SR* and *LI*

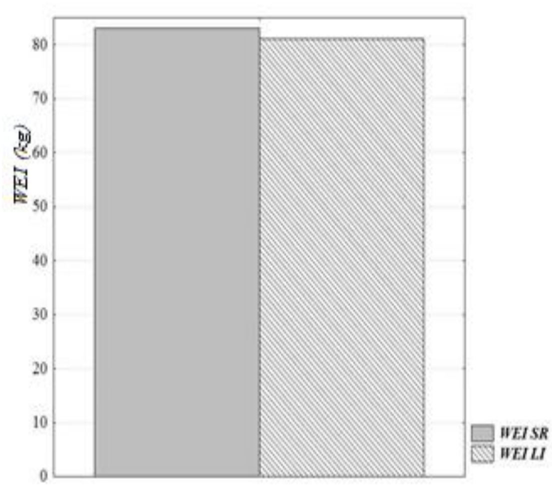

Figure 3.70 Ratio between *WEI* means for *SR* and *LI*

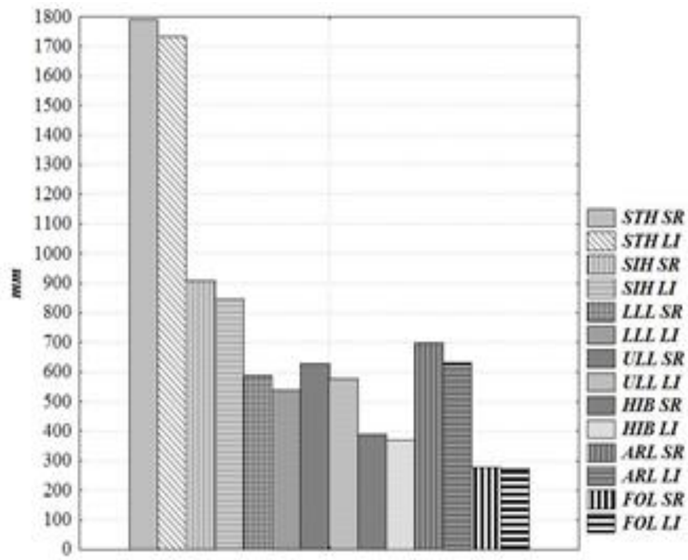

Figure 3.71 Ratio between *WEI* means for *SR* and *LI*

3.5.6 Comparison of means of anthropometric measurements based on gender and occupation

In order to study the effect of gender and occupation on the anthropometric measurements, the means of measurements of related samples were tested. The results are presented in the following sections.

3.5.6.1 Comparison of means based on occupation for Serbian and Libyan samples

Serbian samples have significant differences only in three measurements while six measurements have no significant differences as shown in Table 3.30 and Figure 3.72. Table 3.31 shows reverse results for the Libyan sample. The arm length and lower leg length have no significant differences in either samples, and the standing height in both samples have an absolute difference (p value =0, $p<0.001$).

Table 3.30 Comparison between Serbian male drivers and Serbian crane operators

z test	*p value*	*p*
WEI SMD = WEI SCO	0.2023	*n.s.*
STH SMD >>> STH SCO	0	$p<0.001$
SIH SMD = SIH SCO	0.1230	*n.s.*
LLL SMD = LLL SCO	0.1576	*n.s.*
ULL SMD >>> ULL SCO	0	$p<0.001$
SHW SMD = SHW SCO	0.2074	*n.s*
HIB SMD =HIB SCO	0.1212	*n.s.*
ARL SMD = ARL SCO	0.7389	*n.s.*
FOL SMD <<< FOL SCO	0	$p<0.001$

Table 3.31 Comparison between Libyan male drivers and Libyan crane operators

z test	*p value*	*P*
WEI LMD > WEI LCO	0.0125	$p<0.05$
STH LMD >>> STH LCO	0	$p<0.001$
SIH LMD >>> SIH LCO	0.0003	$p<0.001$
LLL LMD = LLL LCO	0.127	*n.s.*
ULL LMD >>> ULL LCO	0	$p<0.001$
SHW LMD < SHW LCO	0.0286	$p<0.05$
HIB LMD < HIB LCO	0.0359	$p<0.05$
ARL LMD = ARL LCO	0.4483	*n.s.*
FOL LMD = FOL LCO	0.1308	*n.s.*

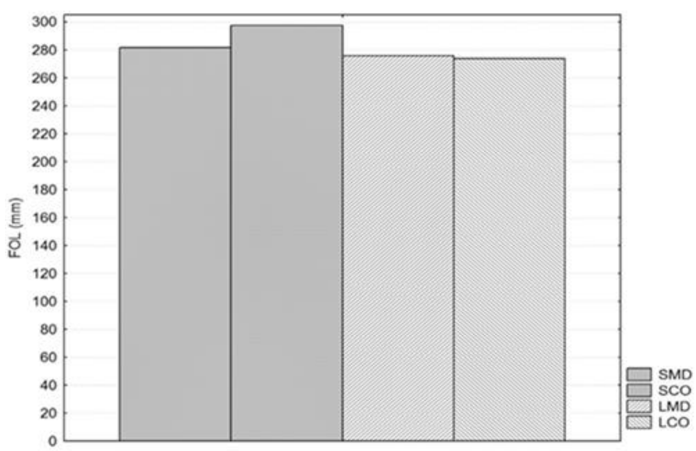

Figure 3.72 Ratio between *FOL* means of Serbian and Libyan male drivers and crane operators

3.5.6.2 Comparison of means based on gender for Serbian and Libyan samples

Tables 3.32 and 3.33 address absolute differences in all measurements of both samples, other than upper leg and sitting height in the Libyan sample, which have strong differences, and weak differences in arm length. Figure 3.73 depict differences in hip breadth for the tested samples. As can be seen, gender has more effect and a stronger influence on anthropometric measurements than occupation has.

Table 3.32 Comparison between Serbian male drivers and Serbian female drivers

z test	*p value*	*p*
WEI SMD >>> WEI SFD	0	$p<0.001$
STH SMD >>> STH SFD	0	$p<0.001$
SIH SMD >>> SIH SFD	0	$p<0.001$
LLL SMD >>> LLL SFD	0	$p<0.001$
ULL SMD >>> ULL SFD	0	$p<0.001$
SHW SMD >>> SHW SFD	0	$p<0.001$
HIB SMD >>>HIB SFD	0	$p<0.001$
ARL SMD >>> ARL SFD	0	$p<0.001$
FOL SMD >>> FOL SFD	0	$p<0.001$

Table 3.33 Comparison between Libyan male drivers and Libyan female drivers

z test	*p value*	*p*
WEI LMD >>> WEI LFD	0	$p<0.001$
STH LMD >>> STH LFD	0	$p<0.001$
SIH LMD >> SIH LFD	0.0037	$p<0.01$
LLL LMD >>> LLL LFD	0	$p<0.001$
ULL LMD >> ULL LFD	0.0068	$p<0.01$
SHW LMD >>> SHW LFD	0	$p<0.001$
HIB LMD <<<HIB LFD	0.0002	$p<0.001$
ARL LMD > ARL LFD	0	$p<0.05$
FOL LMD >>> FOL LFD	0	$p<0.001$

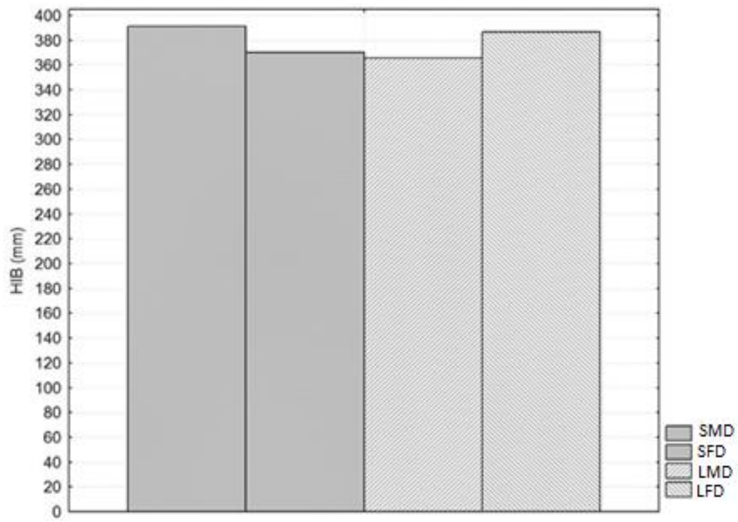

Figure 3.73 Ratio between *HIB* means of Serbian and Libyan male drivers and female drivers

3.6 Changes in anthropometric measurements over time

The literature review shows that there are changes that have taken place over time in anthropometric measurements, and that they should therefore be constantly monitored (Klarin et al., 2011). Consequently, it is interesting to verify the changes that may take place within the anthropometric measurements over time. The data for the years 1997, 2004 and 2009 (Spasojević et al., 2014a), were compared with the latest data from 2015 (Tables 3.34 and 3.35 respectively). A sample of these data is plotted in Figures 3.74 - 3.80, which illustrate the variation trends over time of the anthropometric measurements for both males and females. It is remarkable that during the long periods of time i.e. 1997-2015 or 2004-2015 there was an increasing trend noted in the 99th percentile (2004-2015, Figure 3.74, and 1997-2015, Figure 3.78) and the reverse was the case during short periods of time i.e. 2004-2009 or 2009-2015 as in Figure 3.76.

Table 3.34 Serbian males' anthropometric measurements changes over time (Spasojević Brkić et al., 2014a),

Percentiles		1997	2004	2009	2015	Percentiles		1997	2004	2009	2015
WEI	*P5*	-	62.2	67.23	68	*SHW*	*P5*	449	403	392.76	400
	P50	-	83.1	86.37	86		*P50*	488	469	471.21	470
	P95	-	104	105.40	105		*P95*	527	534	549.66	570
	P99	-	113	113.31	119.8		*P99*	543	562	651.92	590
STH	*P5*	1667	1664	1609.9	1690	*HIB*	*P5*	356	323	320.16	340
	P50	1788.2	1785	1810.67	1800		*P50*	398	371	390.70	390
	P95	1909.4	1906	1930.6	1940		*P95*	440	420	461.24	470
	P99	1959.6	1956	1980.3	1980		*P99*	453	439	490.44	590
SIH	*P5*	886	852	834.7	840	*ARL*	*P5*	580.4	573	629.62	640
	P50	937.6	923	916.01	920		*P50*	659	674	705.72	700
	P95	988.6	994	997.32	990		*P95*	737.6	774	781.82	790
	P99	1009.7	1023	1030.98	1010		*P99*	770.2	811	813.32	800
LLL	*P5*	510.9	420	533.75	530	*ESH*	*P5*	-	798	-	750
	P50	557.9	559	593.51	600		*P50*	-	864	-	820
	P95	604.9	627	653.27	650		*P95*	-	930	-	900
	P99	624.4	652	678.01	680		*P99*	-	954	-	920
ULL	*P5*	573.4	584	557.79	570	*FOL*	*P5*	-	260	293.81	265
	P50	633.7	665	636.87	635		*P50*	-	279	310.93	275
	P95	693.9	746	715.95	710		*P95*	-	298	328.05	300
	P99	718.8	779	748.68	738		*P99*	-	305	335.14	315

Table 3.35 Serbian females' anthropometric measurements changes over time (Spasojević Brkić et al., 2014a)

Percentiles		1997	2004	2009	2015	Percentiles		1997	2004	2009	2015
WEI	*P5*	53.2	48.6	46.34	41.6	*SHW*	*P5*	372	337.2	355.61	370
	P50	63.1	69.1	65.57	64		*P50*	408	406.9	412.26	400
	P95	73	89.7	84.80	84.4		*P95*	444	473.6	468.91	482
	P99	77.1	97	92.76	112.2		*P99*	459.2	502	492.37	510.8
STH	*P5*	1599.9	1585.6	1590.96	1600	*HIB*	*P5*	360.7	296.2	299.47	320
	P50	1676.2	1689.6	1693.33	1700		*P50*	387	356.9	370.02	360
	P95	1752.5	1793.6	1795.70	1794		*P95*	413.3	417.6	440.57	457
	P99	1676.2	1831	1838.08	1840		*P99*	424.2	439	469.78	520
SIH	*P5*	826.8	758.7	792.67	810	*ARL*	*P5*	584	481.7	573.73	590
	P50	865.6	872.7	866.51	870		*P50*	632	590.8	652.06	650
	P95	904.4	986.7	940.35	924		*P95*	680	699.9	730.35	710
	P99	920.5	1028	970.92	950		*P99*	700	739	762.75	780.8
LLL	*P5*	474.7	458.2	497.00	510	*ESH*	*P50*	-	710	-	688.5
	P50	510.9	518.4	556.93	560		*P95*	-	817	-	774.3
	P95	547.1	579	616.86	600		*P99*	-	924	-	859.3
	P99	562.1	600	641.67	670.4		*P50*	-	962	-	883.5
ULL	*P5*	525.1	460.8	510.72	530	*FOL*	*P5*	239.8	230.3	261.90	230
	P50	579.4	590.4	592.18	590		*P50*	252	257.6	277.76	255
	P95	633.7	720	673.64	680		*P95*	264.2	284.9	293.62	270
	P99	656.2	767	707.36	734		*P99*	269.2	295	300.18	275

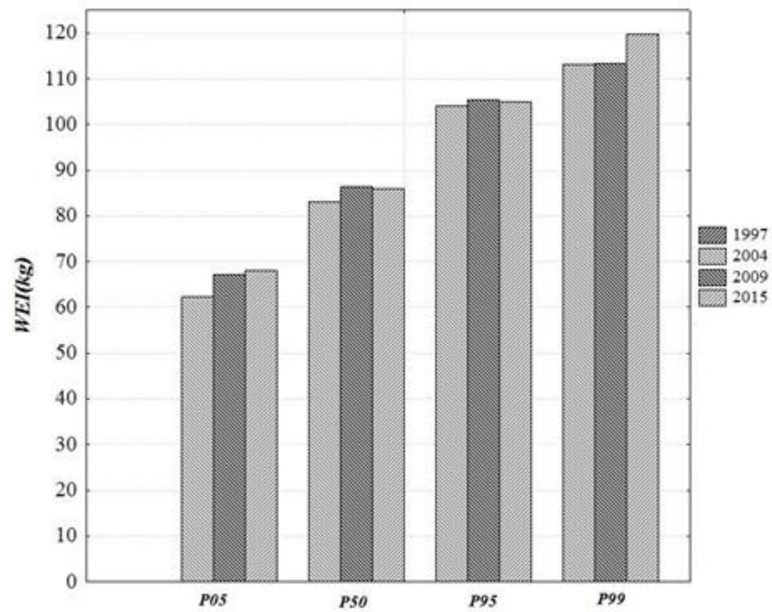

Figure 3.74 Body weight changes of Serbian males over time

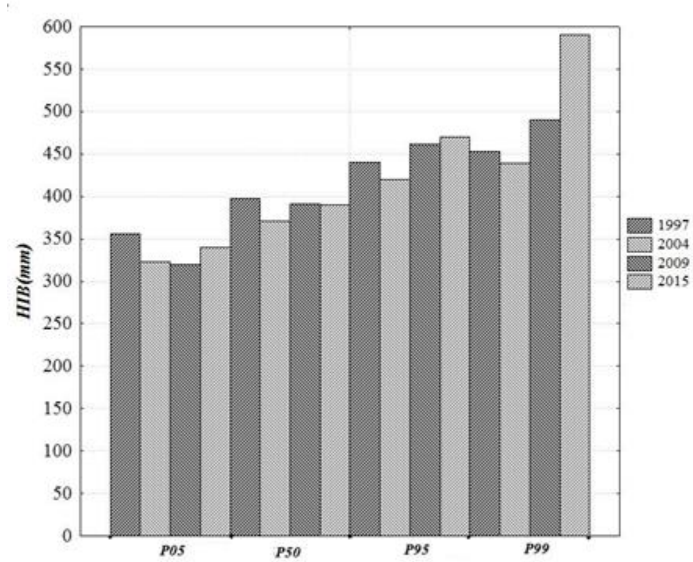

Figure 3.75 Hip breadth changes of Serbian males over time

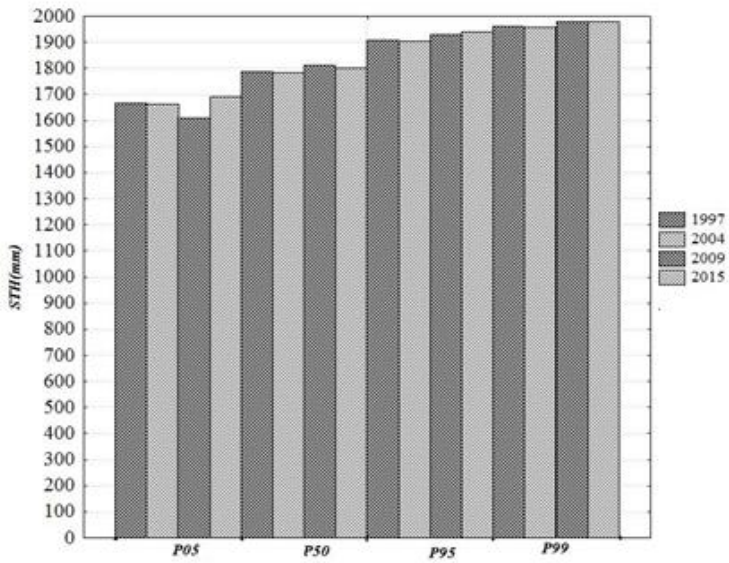

Figure 3.76 Standing height changes of Serbian males over time

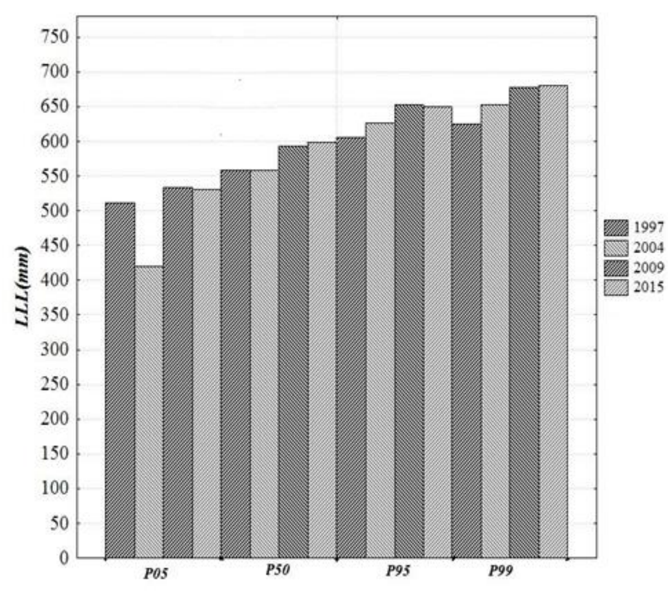

Figure 3.77 Lower leg length changes of Serbian males over time

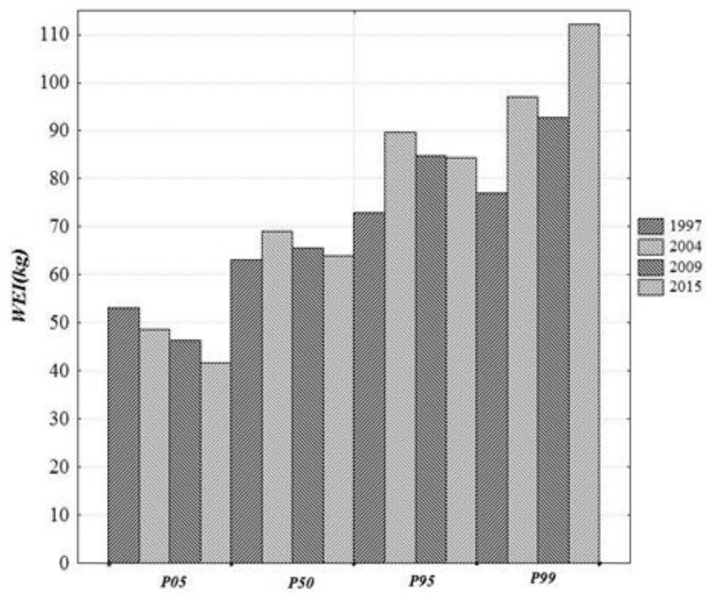

Figure 3.78 Body weight changes of Serbian females over time

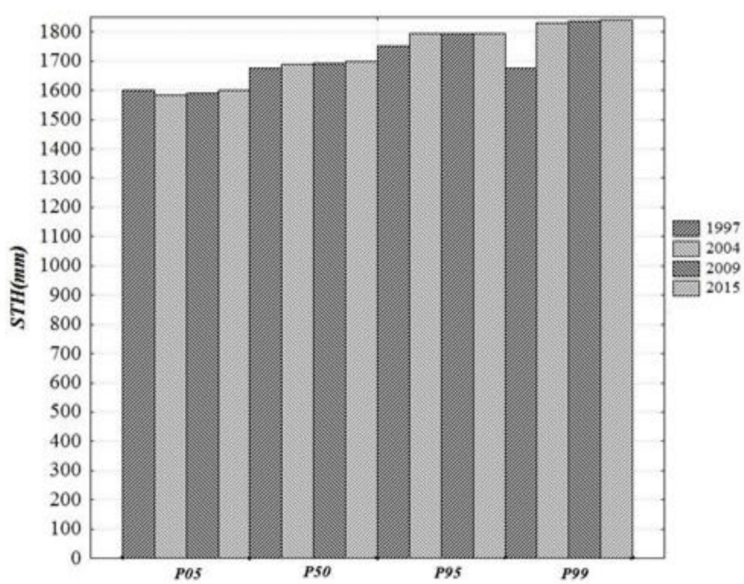

Figure 3.79 Standing height changes of Serbian females over time

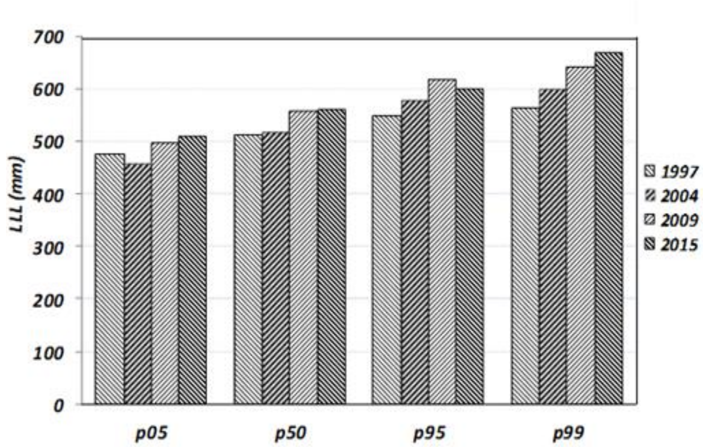

Figure 3.80 Lower leg length changes of Serbian females over time

3.7 Discussion and conclusion

3.7.1 Relationships between anthropometric measurements - discussion and conclusions

The correlation analysis has shown that different patterns among different populations, such as those subjected herein, exists, based on criteria such as nationality, gender, and occupation. Such information is very important and valuable in design according to user needs. The correlation between anthropometric measurements provides one of the initial assumptions for designers as to what extent the body measurements are correlated and can be affected by each other, i.e., body weight versus hip breadth, and shoulder width versus hip breadth, (one increases, the other increase) etc. Significant correlations between measurements provide beneficial guidance to the designer in designing the interior space through the results on relations between anthropometric dimensions that are output of this thesis.

Results on patterns of correlations between anthropometric measurements that are presented in different populations covered by this survey are summarized in Table 3.36, showing the strength of relationship between the anthropometric measurements, which have different patterns from one sample to another due to different nationality, occupation, and gender.

Table 3.36 Different patterns of correlations between anthropometric measurements that are presented in different populations covered by this survey.

Sample	No correlations $\lvert r\rvert \in [0.0, 0.5)$	Weak correlations $\lvert r\rvert \in [0.5, 0.7)$	Strong correlations $\lvert r\rvert \in [0.7, 0.9)$	Absolute correlations $\lvert r\rvert \in [0.9, 1.0)$
Serbian males	1-*WEI* vs. *STH, SIH, LLL, ULL, SHW, ARL, FOL* 2-*STH* vs. *SHW, HIB, FOL* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, FOL* 6-*LLL* vs. *SHW, HIB, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *HIB* 2--STH vs. LLL, *ULL, ARL* 3-*SIH* vs. *ARL* 4-*LLL* vs. *ULL, ARL* 5-*SHW* vs. *HIB*	1- *STH* vs. *SIH*	None
Libyan males	1-*WEI* vs. *STH, SIH, LLL, ULL, SHW, HIB, ARL, FOL* 2-*STH* vs. *SHW, HIB, ARL, FOL* 3-*ARL* vs. *FOL* *4-HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *SHW, ARL, HIB, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*STH* vs. *SIH, LLL, ULL* 2-*LLL* vs. *ULL* 3-*SHW* vs. *HIB*	None	None
Serbian male drivers	1-*WEI vs. STH, SIH, LLL, ULL, SHW, ARL, FOL* *2-STH* vs. *SHW, HIB* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, FOL* 6-*LLL* vs. *SHW, HIB, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *HIB* 2-*STH* vs. *LLL, ULL, ARL, FOL* 3-*SIH* vs. *ARL* 4-*LLL* vs. *ULL, ARL* 5-*SHW* vs. *HIB*	1- *STH* vs. *SIH*	None

Table 3.36 continued.

Libyan male drivers	1-*WEI* vs. *STH, SIH, LLL, ULL, HIB, ARL, FOL* 2-*STH* vs. *SHW, HIB, ARL, FOL* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *SHW, ARL, HIB, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *SHW* 2-*STH* vs. *LLL* *, ULL, SIH,* 3-*LLL* vs. *ULL* 4-*SHW* vs. *HIB*	None	None
Serbian female drivers	1-*WEI* vs. *STH, SIH, LLL, ULL, ARL* 2-*STH* vs. *SIH, LLL, ULL, SHW, HIB, ARL3-ARL vs. FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *SHW, HIB, ARL, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *FOL*	1-*WEI* vs. *SHW* *, HIB, FOL* 2-*STH* vs. *FOL* 3-*LLL* vs. *ULL* 4-*SHW* vs. *HIB* 5- *SHW* vs. *HIB, ARL*	None	None
Libyan female drivers	1-*WEI* vs. *STH, SIH, LLL, ULL, ARL, FOL* 2-*STH* vs. *SHW, HIB, ARL, FOL* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *SHW, HIB, ARL, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *SHW* 2-*STH* vs. *LLL, ULL* 3-*SHW* vs. *HIB*	1-*WEI* vs. *HIB* 2-*STH* vs. *SIH* 3-*LLL* vs. *ULL*	None
Serbian crane operators	1-*WEI* vs. *STH, SIH, LLL, ULL, SHW, ARL, FOL* 2-*STH* vs. *LLL, ULL, SHW, HIB, FOL* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. 6-*LLL* vs. *ULL, SHW, HIB, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *HIB* 2-*STH* vs. *ARL* 3-*SIH* vs. *ARL* 4-*LLL* vs. *ARL*	1-*STH* vs. *SIH* 2-*SHW* vs. *HIB*	None

Table 3.36 continued.

Libyan crane operators	1-*WEI* vs. *STH, SIH, LLL, ULL, SHW, HIB, ARL, FOL* 2-*STH* vs. *SIH, LLL, ULL, SHW, HIB, ARL* 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *ULL, SHW, ARL, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *ARL, FOL*	1-*STH* vs. *FOL* 2-*LLL* vs. *HIB* 3-*SHW* vs. *HIB*	None	None
All Serbian participants	1-*WEI* vs. *SIH, LLL, ULL, ARL* 2-*STH* vs. SHW 3-*ARL* vs. *FOL* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, FOL* 6-*LLL* vs. *SHW, HIB, FOL* 7-*ULL* vs. *SHW, HIB, FOL* 8-*SHW* vs. *ARL, FOL*	1-*WEI* vs. *HIB, STH, SHW, FOL* 2-*STH* vs. *LLL, ULL, HIB, ARL, FOL* 3-*SIH* vs. *ARL* 4-*LLL* vs. *ULL, ARL* 5-*ULL* vs. *ARL* 6-*SHW* vs. *HIB*	1-*STH* vs. *SIH*	None
All Libyan participants	1-*WEI* vs. *STH, SIH, LLL, ULL, HIB, ARL, FOL* 2-*STH* vs. *SHW, HIB, ARL* 3-*ARL* vs. *FOL.* 4-*HIB* vs. *ARL, FOL* 5-*SIH* vs. *LLL, ULL, SHW, HIB, ARL, FOL* 6-*LLL* vs. *SHW, HIB, ARL, FOL* 7-*ULL* vs. *SHW, HIB, ARL, FOL* 8-*SHW* vs. *HIB, ARL, FOL*	1-*WEI* vs. *SHW* 2-*STH* vs. *SIH, LLL, ULL, FOL* 3-*ARL* vs. *HIB* 4-*SIH* vs. *ARL* 5-*LLL* vs. *ULL* 6- *ULL* vs. *ARL* 7-*SHW* vs. *HIB*	1-*STH* vs. *SIH*	None

As can be seen from Table 3.36, the differences in the correlations between the two nationalities show that the Serbian sample has ten correlations between measurements (nine are weak significant, one is strong) whereas the Libyan sample has fewer correlated measurements (six are weak correlations).

The crane operators have a different correlation pattern than the passenger car drivers; there are fewer correlations among anthropometric measurements in both samples.

The differences in the correlation relationships between the anthropometric measurements of crane operators in the Serbian and Libyan nationalities should be considered in interior crane cabins design.

The Serbian crane operators have five significant correlations between measurements (four are weak significant, and one is strong) which are more than the Libyan crane operators have (only three are weak significant) as shown in Table 3.36, whereas all other measurements have no significant correlations between each other. The conclusion is that nationality and occupation have a significant effect on the association of anthropometric measurements.

The male samples (male drivers and crane operators) in both nationalities maintain a similar correlation pattern as male car drivers (Table 3.36). A conclusion can be derived that there are differences in the strength of relationship between human body dimensions between males of the nationalities under consideration according to these obtained correlation values.

In female drivers' the correlation between measurements shows that standing height has a strong significant correlation with sitting height, and weak correlation with lower leg length, and upper leg length in the Libyan sample. On the other hand, the Serbian female drivers have no significant correlation between these measurements (Table 3.36). Furthermore, both samples have a weak correlation between body weight versus shoulder width, while hip breadth has a weak correlation in the Serbian sample and a strong correlation in the Libyan sample. The correlation relations for all participants (males and females), as illustrated in Table 3.36, shows that in the Serbian data, as the sample size increases, the number of significant correlations among compared measurements increases too, which is not the case in the Libyan data.

The correlation analysis of this survey leads to the conclusion that the anthropometric measurements are affected by difference in nationality, which is in line with conclusions in Fatollahzadeh (2006).

Furthermore**,** the correlation analysis of anthropometric measurements draws attention to Particular considerations in design. For example, anthropometric measurements that are not significantly correlated with each other should be considered as independent dimensions in design i.e. lower leg length and body weight, lower leg and hip breadth, or shoulder width and foot length. One the other hand, measurements that have significant correlation with each other should be considered as dependent dimensions in the design process, i.e. as standing height increases, sitting height increases too, and as body weight increases, shoulder width and hip breadth increase as well. At the same time, correlation analysis demonstrates that there are differences in the relation between anthropometric measurements, such as differences in the correlation relation result from differences in gender, nationality, and occupation. A conclusion to be drawn here is that nationalities, gender, and occupations have a significant effect on the association of anthropometric measurements.

3.7.2 Discussion of the nationality, gender, and occupation effect on the differences between anthropometric measurements

Further testing has been done in order to discover how the patterns of differences between the anthropometric measurements are affected by nationality, gender and occupation, when are the measurements not affected by nationality, gender and occupation and what are the sources of the effects of nationality, gender and occupation. These inquiries could be answered from results given in *z* tests summarized in Tables 3.37 and 3.38, as discussed below (sections 3.7.2.1, and 3.7.2.2).

3.7.3 The nationality effect on anthropometric measurements

Table 3.37 shows the summarized significant difference patterns between the two tested anthropometric measurements of different nationality as discussed in the following points:

1-The Serbian and Libyan male drivers' samples have absolute significant difference in all dimensions. The differences in mean values between the two samples (Tables 3.5, and 3.6) is 3.707 kg for body weight, whereas the other measurements vary from 5.779mm for foot length to 73.435mm for arm length as illustrated in Figure 3.14 and Figure 3.15. Excluding shoulder width, there is no significant difference between the Serbian and Libyan samples at $p<0.001$ with p-value=0 (Table 3.9), where the difference in mean values of shoulder width is 0.006mm as illustrated clearly in Figure 3.13.

2-The crane operators have a strong absolute significant difference in mean values for all measurements (Table 3.37) except hip breadth, which has a weak significant difference in mean with $p < 0.05$, p-value= 0.0426. From Tables 3.10, and 3.11, the mean difference in body weight between the two samples equal 6.216 kg. The rest of the measurements have a mean difference that varies from 23.722mm for foot length to 77.19mm for sitting height, excluding shoulder width which has no significant difference (p value=0.2517). Such mean differences are further illustrated in Figures 3.24 - 3.27.

3-The Serbian and Libyan males (a sample of male drivers and crane operators), have the same pattern of absolute significant difference of the male drivers (Table 3.37). Such differences vary from7.39mm for foot length to 71.939mm for arm length (Tables 3.15 and 3.16). The body weight has a mean difference of 4.167kg, but the shoulder width has no significant difference (p value=0.5063). Further illustration can be seen in figures 3.37-3.39.

4-As addressed in Table 3.37, all Serbian and Libyan participants have the same patterns as in point 1, with an absolute significant difference between means at $p<0.001$, p-value= 0. Only body weights have a strong significant difference (p value =0.005, $p<0.01$), and the shoulder width has no significant difference with p value= 0.3132. The mean differences of measurements are in the range of 4.94mm (foot length) to 65.356mm (arm length) according to Tables 3.25 and 3.26, as well as in Figures 3.69 - 3.71.

5- Female drivers have an absolute significant difference in all measurements except foot length and shoulder width, which have no significant differences (Table 3.37), where p values = 0.2105, and 0.0517 respectively, and the hip breadth of Serbian female drivers is smaller than Libyan hip breadth with a strong difference with p = 0.01 and p=0.0023. In addition, Serbian female drivers have a smaller body weight than Libyan female drivers have with p value=0, and p = 0.001. According to Tables 3.20 and 3.21, female driver samples have a mean difference in a range from 16.564mm (hip breadth) to 44.609mm (lower leg length), and 7.601kg for body weight. An illustration of differences is depicted in Figures 3.50-3.53.

In conclusion, it is a fact that nationality has an effect on anthropometric measurements. In this survey, the dimensions of the Serbian nationality are larger than the Libyan, except in shoulder width. These findings support the conclusions of previous studies that the nationality affect is recommended for study (Beyden, and Wang, 2009). Fatollahzadeh, 2006; Huang, et al., 2010; Locke et al., 2014; and Hsiao et al., 2002 also mention that anthropometric dimensions are affected by nationality.

Table 3.37 Summarized significant difference in anthropometric measurements between different nationalities

Sample	= no difference	> low difference	>> strong difference	>>> absolute difference
Male drivers	*SHW SMD = SHW LMD*	None	None	*WEI SMD >>> WEI LMD* *STH SMD >>> STH LMD* *SIH SMD >>> SIH LMD* *LLL SMD >>> LLL LMD* *ULL SMD >>> ULL LMD* *HIB SMD >>> HIB LMD* *ARL SMD >>> ARL LMD* *FOL SMD >>> FOL LMD*
Crane operators	*SHW SCO = SHW LCO*	*HIB SCO* *>HIB LCO*	None	*WEI SCO >>> WEI LCO* *STH SCO >>> STH LCO* *SIH SCO >>> SIH LCO* *LLL SCO >>> LLL LCO* *ULL SCO >>> ULL LCO* *ARL SCO >>> ARL LCO* *FOL SCO >>> FOL LCO*
Males	*SHW SM = SHW LM*	None	None	*WEI SM >>> WEI LM* *STH SM >>> STH LM* *SIH SM >>> SIH LM* *LLL SM >>> LLL LM* *ULL SM >>> ULL LM* *HIB SM >>>* HIB LM *ARL SM >>> ARL LM* *FOL SM >>> FOL LM*
All participant	*SHW SR = SHW LI*	None	*WEI SR >> WEI LI*	*STH SR >>>* STH LI *SIH SR >>> SIH LI* *LLL SR >>> LLL LI* *ULL SR >>> ULL LI* *HIB SR >>> HIB LI* *ARL SR >>> ARL LI* *FOL SR >>> FOL LI*
Female drivers	*SHW SFD =SHW LFD* *FOL SFD = FOL LFD*	None	*HIB SFD << HIB LFD*	*WEI SFD<<< WEI LFD* *STH SFD >>> STH LFD* *SIH SFD >>> SIH LFD* *LLL SFD >>> LLL LFD* *ULL SFD >>> ULL LFD* *ARL SFD>>> ARL LFD*

3.7.3.1 The gender and occupation effect on anthropometric measurements

Table 3.38 summarized results of the significant differences of anthropometric measurements based on gender and occupation, the pattern of the differences between the tested samples that have a different behavior from the nationality effect, as discussed below.

1-The effect of occupation on the anthropometric measurements can be seen from the tested samples of male drivers and crane operators from Table 3.38. Among the Serbian male drivers and Serbian crane operators' samples, only standing height, upper leg length, and foot length have absolute significant differences with a difference mean varying from 15.81mm for foot length to 43.067mm for standing height (Tables 3.5, and 3.10). All other measurements have no significant difference, i.e. sitting height, lower leg length, shoulder width, hip breadth, and arm length. The Libyan male drivers and Libyan crane operators have greater differences between measurements as compared to the Serbian male drivers and crane operators' sample. Only three measurements (lower leg, arm length, and foot length) have no significant differences. The other six measurements, three of them namely, body weight, shoulder width, and hip breadth have low significant differences. The other three (standing height, sitting height, and upper leg) have absolute differences (Table 3.38). Such differences between the two samples can be clearly seen from the mean difference range which is 16.38mm (hip breadth) to 48.177mm (standing height), while the body weight mean difference is 4.21kg, according to Tables 3.6, and 3.11.

2- The effect of gender on the anthropometric measurements can be seen from the tested samples of male and female drivers (as summarized in table 3.38). Both samples have absolute significant differences in all anthropometric measurements. From Tables 3.5 and 3.20 the mean difference between these measurements in the Serbian samples vary in range from 21.06mm (hip breadth) to 116.88mm (standing height), while body weight has a mean difference of 21.078kg. The Libyan male drivers and female drivers have mean differences (Tables 3.6, and 3.21) that vary in range from 15.653mm (arm length) to 85.737mm (standing height).

Table 3.38 The summarized significant differences between anthropometric measurements different in gender and occupation

Sample	= no difference	> low difference	>> strong difference	>>> absolute difference
Different occupation	WEI SMD = WEI SCO SIH SMD = SIH SCO LLL SMD = LLL SCO SHW SMD = SHW SCO HIB SMD = HIB SCO ARL SMD = ARL SCO	None	None	STH SMD >>> STH SCO ULL SMD >>> ULL SCO FOL SMD <<< FOL SCO
	LLL LMD = LLL LCO ARL LMD = ARL LCO FOL LMD = FOL LCO	WEI LMD > WEI LCO SHW LMD < SHW LCO HIB LMD < HIB LCO	None	STH LMD >>> STH LCO SIH LMD >>> SIH LCO ULL LMD >>> ULL LCO
Different gender	None	None	None	WEI SMD >>> WEI SFD STH SMD >>> STH SFD SIH SMD >>> SIH SFD LLL SMD >>> LLL SFD ULL SMD >>> ULL SFD SHW SMD >>> SHW SFD HIB SMD >>>HIB SFD ARL SMD >>> ARL SFD FOL SMD >>> FOL SFD
	None	ARL LMD > ARL LFD	SIH LMD >> SIH LF ULL LMD >> ULL LFD	WEI LMD >>> WEI LFD STH LMD >>> STH LFD LLL LMD >>> LLL LFD SHW LMD >>> SHW LFD HIB LMD <<<HIB LFD FOL LMD >>> FOL LF

From the results and discussion of this section, the following can be concluded:

1-The effect of nationality on the anthropometric measurements has more significant differences and stronger influence than do occupation and gender.

2-The occupation for the same nationality has fewer differences in measurements i.e. Serbian male drivers and Serbian crane operators, while for the Libyan population it is the reverse.

3- Gender has an absolute effect on measurements when considered within the same occupation (absolute differences).

4- There is no steady pattern for the occupation effect; rather it differs from sample to another. In contrast, the nationality effect does present a steady pattern (i.e. shoulder width has no significant difference in all tested samples that are based on nationality).

5- The hip breadth and body weight of females have different patterns from all male samples, which again indicates the gender effect.

4 MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESIGN

4.1 Preface

It is expected that the multivariate modeling application has the potential to solve problems recognized in the use of univariate methods, and accordingly, the aim here is to enable modeling in which there is proper fitting when several dimensions are in focus, which could result in coverage of more than 90% of the population. Also, there is a need to propose a method that will connect the multivariate modeling approach with interior space modeling based on biomechanics.

Those aims are going to be fulfilled in a manner which will prove the basic hypothesis:

H_{02} –By using multivariate statistics on the data of Serbian and Libyan drivers, as well as crane operators, it is possible to establish a sufficiently precise, original model for anthropometric design of the interior space of vehicles and machines.

And the auxiliary hypothesis that says:

H1 - Using an integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy.

H2 - Anthropometric measurements have mechanical and mathematical functions that determine all three dimensions of the space, taking into account over 90% of the population.

H3 - On the basis of a multivariate model for anthropometric adaptation, it is possible to give recommendations for dimensioning the interior of the crane cabin in such a way that comfortable and safe accommodation of the users is ensured.

H4 - On the basis of a multivariate model for anthropometric adaptation it is possible to determine the dimensions of the minimum required space for a driver in a passenger vehicle in such a manner that the driver has comfortable and safe accommodation.

4.2 Crane cabin and passenger vehicle interior modeling

4.2.1 The need for crane cabin interior modeling

The defined hypotheses are going to be tested in the context of the crane cabin and passenger vehicle interior space modeling. Those working spaces have been chosen due to the following facts.

Cranes are an extremely important component in many different operations such as construction, heavy industry, the process industry, the maritime industry, the railroad industry and within associated maintenance activities (Milazzo et al., 2016; Milazzo et al., 2015; Fang et al., 2016; Sanfilippo et al., 2015; and Dotoli et al., 2017). Cranes contribute significantly to effective job advancement when properly managed, but also have the potential to cause huge life and property losses, with the need to emphasize that the risk of loss is not limited to cranes alone (Raviv, et al., 2017). Occupational fatalities and injuries caused by the operation of cranes pose a serious public problem (Aneziris et al., 2008). Some estimates suggest that cranes are involved in up to one-third of all construction and maintenance fatalities (Neitzel et al., 2001). A tipped, dropped, or mishandled load can lead to lethal injuries, non-lethal permanent injuries and recoverable injuries (Aneziris et al., 2008). The risk of loss is not limited only to those directly involved in construction operations, but may also affect pedestrians, who have been killed in such accidents as well (Neitzel et al.,2001). Obviously, these kinds of accidents also have immense cost implications (Lee et al., 2006). Worldwide accident records over the last 5 years show that under existing regulation regarding crane safety, the rates of injuries/illness can be considered constant, while poor human performance can be seen as an influential factor with a growing trend (Milazzo et al., 2016). In addition, the design that provides comfort, a proper ergonomic interface with the controls and a clear visibility field for the crane operator is needed in crane cabins today, too (Milazzo, et al., 2016; and Tam and Fung, 2011). Mobile cranes are the type of cranes with the highest accident rates (Milazzo et al., 2016). The part of the world where the most accidents take place is North America (Milazzo, et al., 2016). Crane operators remain in cabins for the whole day (Fung, et al., 2016; and Bongers, et al., 1988), while tight schedules usually hinder the implementation of site safety (Fung et al., 2016). Construction sites have special safety regulations established by a large number of bodies (Chandler and Delgado, 2001).

Many procedures in the development process of crane cabins are still based on the specific experience of the manufacturers and historical guidelines that are often arbitrary and subjective, hence the need for more objective, theoretically justified and consistent models. With the aim for the design of safe and ergonomically adjusted crane cabins, up-to-date anthropometric information of the crane operator population is needed. Contemporary anthropometric characteristics (including variation in anthropometric measurements, gender, and operator fitness) and the orientation and layout of the cabinet should be considered as contributing factors in designing a crane cabin of high quality in order to ensure the safety and comfort of the operator and his environment (Spasojević, Brkic, et al., 2014b).

While conducting a survey of tower cranes' cabins it was found that the working environment in a crane cabin was inconvenient and caused fatigue due to insufficient air conditioning. Only 21.2% of participants were satisfied with the working conditions. Cabin space was uncomfortable for 36.8% of the participants, and together with long working hours (9-10 hours/day) such factors lead to unsafe crane operations (Tam, and Fung, 2011).

Unpleasant body postures during the operation of heavy construction equipment, such as cranes, are due to the improper design of the cabin and to not enough adaptation to the prescribed work procedures. The poor visibility of the task that the operator of the cabin must do, the limited space in the cabin for carrying out work movements and other necessary activities, the need to use too much force to move levers, pedals, and other command instruments, as well as inadequate seat design, are some of the characteristics of poorly designed cabins. Unless controlled, the improper holding of any part of the body can lead to an increased risk of premature fatigue, pain, or injury. Exposure to discomfort, performance of repetitive movements in a noncompliant working position and overtime are factors that can lead to miscellaneous musculoskeletal disorders of the operator in the cabin.

Several very important factors depend on the compatibility of the anthropometric characteristics of the operator with the dimensions of the crane cabin, as well as the dimensions and position of the equipment in the cabin. These factors can be divided into three basic categories. The first category includes factors related to the effects that the anthropometric mismatch of the cabin (with the equipment in it) has on the operator. The second category includes factors related to the effects that the anthropometric mismatch of the cabin has on the performance and financial losses of the company. The third category includes factors related to the effects that the anthropometric mismatch of the cabin has on safety.

In relation to the first factor, it should be pointed out that from an anthropometric point of view the inadequately designed cabin has a great influence on the comfort, health and working ability of the operator. If the equipment is not adapted to the body dimensions of the operator, comfort will be reduced. As a result, an operator often takes up positions that are not suitable for long-term work. Unsuitable work positions that are incompatible with ergonomic and biomechanical recommendations and principles, in addition to the development of pain in certain parts of the body, can lead to the occurrence of occupational diseases over an extended period of time. Degenerative changes on the spinal column are one example of the anthropometric mismatch in the health of the operators, which is manifested through the reduction of their working ability.

In relation to the second factor, it should be noted that there are several ways in which the anthropometric mismatch of the cabin can lead to a reduction in performance. However, they are all related to extending the time needed to perform the task. If the equipment in the cabin is not adapted to the operator, the worker is forced to spend most of his working hours in a noncompliant working position, which often limits the unintentional performance of work movements. Due to the existence of such limiting factors, the worker works slower. In addition, as a result of the existence of an uncomfortable working position, the operator is forced to take more frequent breaks. Due to prolonged work in inadequate working conditions, workers experience health problems over time, which, according to a certain dynamic, lead to the absence of workers from work. In addition to the fact that employers allocate significant financial resources for the treatment of workers due to the occurrence of occupational diseases, employers are often unable to find an adequate replacement for the sick worker in time, which can affect the completion of the work on schedule. All this results in a slower process than planned, which further results in a decrease in profit due to reduced performance.

Regarding the third factor, it should be pointed out that the precision of execution of the work assignment is directly related to the anthropometric conformity of the cabin and the equipment in it. The inadequate formation of the command instruments, the inadequate dimensions of control devices, an inadequate cabin layout, and the incompatibility of the force required to activate command instruments with the anthropometric characteristics of the operator can have an impact on the accuracy of the execution of the task. The accuracy of work execution is also greatly influenced by visibility from the cabin. Inadequate construction of the cabin, which is not in line with the anthropometric characteristics of the operator, can lead to reduced visibility, which can be reflected in the precision of the execution of the work task. However, inaccurate execution of a work assignment can also jeopardize the safety of the cargo, as well as the people within the scope of the transported load. As a consequence of imprecise execution of a work assignment, the load may miss the target, hit another object, disconnect, or fall on other workers or passers-by. In the case of a high-risk load, such as hazardous substances, the consequences can be both far-reaching and long-lasting. Operator safety can also be compromised if the access to the cabin (stairs and other elements) is not designed in accordance with the anthropometric characteristics of the operator.

A possible explanation for the improper crane cabin adequacy for the operator may be found in the fact that today's available standards and manufacturers rely on the anthropometric data of the general population (Zunjic et al., 2015). Zunjic et al. (2015) tested the hypothesis of whether the dimensions of the cabin and the layout of equipment would rely on the data derived from the general population of Serbian citizens (using the largest known sample of the published data) instead of from the population of crane operators and confirmed that on the level of significance of 0.05, more than 50% anthropometric dimensions showed disagreement. Zunjic et al. (2015) provided qualitative advice to use transparent material in the design of the floor, ceiling and the lateral parts of the cabin and to remove all accompanying elements of construction from the visual field of the operator but did not define the interior space dimensions that enable anthropometric convenience.

Another reason probably lies in the inconvenience of the applied univariate percentiles method. Multivariate anthropometric models have not been used to design crane cabin interior space so far. It is expected that a contribution in this area could benefit the design of future crane cabins which, in turn, would help promote the safety and health of the crane operators. Hence, the first aim herein is to model the crane cabin interior space using up-to-date crane operator anthropometric data collected on two different nationalities and to compare the multivariate and univariate method for anthropometric models. The second aim is to define the dimensions of the interior space of the crane cabin that enable anthropometric convenience. Thus, in order to achieve these aims, the focus is on the following objectives:

1 – The application of multivariate and univariate (percentiles) statistics on the anthropometric dimensions of crane operators with data collected for both Serbian and Libyan crane operators.

2 - Crane operators' multivariate models accommodation in the interior crane cabin space on the basis of kinematics mechanism.

3 - The 5th and 95th percentile crane operators' models accommodation in the interior crane cabin space.

4 - Suggesting recommendations for improving performance and safety through the new crane cabin interior design. Accordingly, the ultimate goal herein is to solve the problems found in contemporary crane cabin designs and to practically eliminate the gap between the theoretical and actual productivity of the crane caused by the operator's stress and visibility problems, which often result in high injury and fatality rates.

4.2.2 Need for passenger vehicle interior modeling

Vehicle interior space modeling includes human interactions with the interior space, aspects of seat comfort, location of visual displays, pedal controls, reaches etc. All those aspects should be considered in the ergonomic design of vehicle interiors, in order to achieve satisfactory driving tasks in terms of safety, driver feedback, and driving tasks execution in a comfortable manner.

Numerous studies have researched those aspects in order to improve driving task performance through ergonomic design. In this context, Andreoni et al. (2002) has stated that ergonomic details and approach used in determining and evaluating the interface between the driver and the car is essential, in order to ensure high visibility with easy reach of all controls and displays, and it is evident that real progress could be achieved in interior vehicle modelling, resulting in enhanced safety, comfort and performance.

On the other hand, the updated anthropometric measurements usage is vital in design to overcome the variation in human anthropometrical characteristics that take place over time **(**Spasojević et al., 2014a; Fatollahzadeh, 2006; and Guan et al., 2012). Existing research that uses PCA presents a shortcoming in that they do not execute the calculation of extreme data (Epifanio et al., 2013)**.** There are also no available interior space designs offered in the available research. Chung and Park (2004) have noted that there are problems in current occupant vehicle interfaces which result in non-updated use of physical dimensions in SAE J826 (SAE 1995a), because they are based on the 1960-1962 human examination survey by the U.S. Public Health service (Stoudt et al.,1965). Thompson (1995) enhanced this concept and pointed to errors stemming from the adoption of the SAE standard models in designing interior drive space.

Multivariate anthropometric models have not been used to design passenger vehicle interior space so far, so it is expected that a contribution in this area could benefit the design of future passenger vehicles, which, in turn, would help promote safety and health in traffic, but will also help professional drivers enhance performances of the companies where they work. Hence, the first aim herein is to model the passenger vehicle interior space using up-to-date drivers' anthropometric data and to compare the methods of the multivariate and univariate anthropometric models. The second aim is to define the passenger vehicle interior space dimensions that enable drivers' anthropometric convenience. Thus, in order to achieve these aims, the focus is on the following objectives:

1 – The application of multivariate and univariate (percentiles) statistics on anthropometric dimensions of both Serbian and Libyan drivers.

2 - Drivers' multivariate models accommodation in the interior passenger vehicle space on the basis of a kinematics mechanism.

3 - The 5^{th} and 95^{th} percentile drivers' models accommodation in the interior space of the passenger vehicle interior.

4 - Suggesting recommendations for improving performance and safety through new passenger vehicle interior design. Accordingly, the ultimate goal herein is to solve the problems found in contemporary passenger vehicles and to lower traffic injuries and fatality rates.

4.3 Data collection procedures

4.3.1 Crane operators' data collection procedure

In the present survey, all Serbian operators were recruited and measured using standard anthropometric instruments. The Electric Power Industry of Serbia has 6 production companies, located throughout Serbia. All of them agreed to participate in the survey. The number of participants that agreed to participate at each power plant is shown in Table 4.1, and anthropometric measurements were taken through an iterative sampling procedure. Iterative sampling is recommended as a procedure by Manjrekar (2010) since it has been shown that when building the sample size through iterations, a smaller sample size is needed.

Table 4.1 Number of Serbian participants from each production plant

Power plant	1	2	3	4	5	6	Total
Number of Participants	15	12	14	10	13	19	83

Since anthropometric variables that are significantly related to fit or accommodate the particular environment should be evaluated (Bovenzi et al., 2002), foot length, standing height, sitting height, lower leg length, upper leg length, shoulder width, hip breadth and arm length were measured herein using standard anthropometric instruments and procedure. The static anthropometric method which implies measuring in the erect position during standing and sitting was used (so that the torso is at a 90° angle with the upper leg, and the upper leg at a 90° angle with the lower leg). The instruments used included a beam caliper, sliding calipers, a stool and a steel tape, similarly to the procedure used in previous studies (Zunjic et al., 2015;

Kushwaha and Kane, 2016; Ray and Tewari, 2012; Nordin and Olson 2008; da Silva, 2014; Spasojević et al., 2016; Hsiao, 2012; Klarin et al., 2011). All dimensions were determined with working clothes and footwear, similarly to previous studies (Zunjic et al., 2015; Klarin et al., 2011), with the aim to find an interior space for accommodation in which operators work with personal protective equipment. The summarized statistics for 83 Serbian crane operators' dimensions, together with the participants' demographics and the values of the mean, standard deviation, maximum and minimum are given in Table 4.2.

Table 4.2 Summarized statistics for 83 crane operators in Serbia (all measurements in mm)

Participant demographics	Gender: 83 male participants, Age: mean 48.48 years, Standard deviation 10.07 years				
Anthropometric Dimensions	*N*	*Min.*	*Max.*	*Mean*	*SD*
FOL	83	259	321	297.42	12.524
STH	83	1630	1937	1768.19	68.210
SIH	83	750	1020	907.31	56.749
LLL	83	490	770	587.17	40.176
ULL	83	520	710	618.23	36.350
SHW	83	380	580	478.35	48.520
HIB	83	300	590	401.31	58.629
ARL	83	495	800	704.55	50.892

The data given in Table 4.2 are comparable to the data available from previous studies. Our mean and standard deviation values for standing height are 1768.19 and 68.21 mm, while Burdorf et al. (2004) obtained 1765 and 74 mm on the data from the Netherlands, and Bovenzi et al. (2002) arrived at the values 1780 and 68 mm on the data from Italy. Ray and Tewari, (2012) did not provide mean values, but they did state that for the control position of the longitudinal travel, main hoist, and auxiliary hoist, the 50^{th} percentile Indian user had a 45 mm of misfit.

A sample of Libyan crane operators was taken in similar manner from a Libyan iron and steel company where a very large number of cranes operate. Crane lifting is a vital task in the production units of the company. Crane operators spent 8 hours of work in each shift in overhead cranes with high capacity, handling steel products and supporting maintenance work that require a high level of accuracy from the operator. Fifty crane operators agreed to participate in this survey. In order to study and model the crane cabin for the Libyan population, which has not yet been studied according to the surveyed literature, Table 4.3 shows the demographics and summarized statistics of the sample.

Table 4.3 Descriptive statistics of Libyan crane operator participants (all measurements in mm)

Participant demographics	Gender: 50 male participants, Age: mean 42.36 years, Standard deviation 7.91 years				
Anthropometric Dimensions	*N*	*Min.*	*Max.*	*Mean*	*SD*
FOL	50	255	295	273.7	9.25
STH	50	1830	1570	1701.4	58.55
SIH	50	700	900	829.4	47.83
LLL	50	460	600	534.6	36.55
ULL	50	500	630	559	32.78
SHW	50	410	620	489	53.92
HIB	50	300	490	382	49.65
ARL	50	450	800	642.4	82.05

4.3.2 Passenger vehicle drivers' data collection procedure

The data about passenger vehicle drivers are collected in a similar manner as previously. All participants, of both nationalities and genders, who had drivers licenses and were interested in participating, taking into account iterative sampling, are included , descriptive statistics of anthropometric measuesments as given in table 4.4, and 4.5. The average age of Serbian participants is 42.72 years with a standard deviation of 12.84. For Libyan participants, the average age is 34.68 with a standard deviation of 11.13.

Table 4.4 Descriptive statistics for 1197 Serbian participants (all measurements in mm)

Dimension	*N*	*Min.*	*Max.*	*Mean*	*SD*
FOL	1197	225	321	277.58	18.013
STH	1197	1520	1995	1789.43	84.078
SIH	1197	560	1020	908.29	50.969
LLL	1197	370	770	587.33	38.476
ULL	1197	384	800	627.95	48.519
SHW	1197	358	630	462.37	50.106
HIB	1197	290	590	388.41	45.522
ARL	1197	410	830	697.60	50.757

Table 4.5 Summarized statistics for 400 Libyan participants (all measurements in mm)

Dimension	*N*	*Min.*	*Max.*	*Mean*	*SD*
FOL	400	230	300	272.64	12.374
STH	400	1510	1900	1732.79	68.492
SIH	400	670	970	848.34	50.198
LLL	400	450	670	538.21	36.950
ULL	400	490	720	577.68	38.223
SHW	400	340	640	464.99	51.083
HIB	400	230	570	370.29	55.847
ARL	400	450	800	632.265	70.345

4.4 Multivariate Modeling Approach

The procedure of multivariate modeling includes the Principal Components Analysis (PCA) used as one of the phases to obtain representative body models. PCA is essentially a rotation of the coordinate axes, chosen in such a way that each successful axis captures as much variance as possible and can be thought of as fitting an n-dimensional ellipsoid to the data (Abdi et al., 2010). After determining the principal components of the collected anthropometric data, the component scores are calculated and later transformed to the anthropometric measurement dimensions of the representative body models on the boundaries or on the surface of the ellipsoid by a reverse process of calculating matrices of eigenvalues, eigenvectors and factor loadings. If each variable load on only one factor simultaneously and there is a clear difference in intensity between the relevant factors whose eigenvalues are clearly larger than one, while the noise represented by factors with eigenvalues is clearly smaller than one, then further rotation is likely to provide a solution that is more reliable than the initial solution. Otherwise, there is no need to implement PCA because the rotation would make the solution less replicable and potentially harder to interpret since the mathematical properties of PCA have been lost (Abdi et al., 2010, and Babamoradi, 2013). A few statistical software packages, such as SPSS-IBM, Statistica-StatSoft etc., offer the possibility for PCA procedure execution.

An analysis of the main components often reveals relationships that were not obvious and thus enables interpretation of data that would otherwise not have occurred (Johnson et al., 2002).

If there is a vector x that represents p random variables, the first step is to find the linear function $\boldsymbol{x}$-a: $\boldsymbol{\alpha'_1 x}$, which contains the maximum variance, where $\boldsymbol{\alpha_1}$ is the vector of p constant $\alpha_{11}, \alpha_{12}, \ldots \alpha_{1p}$, a 'denotes the transposition, so that:

$$\alpha'_1 x = \alpha_{11}x_1 + \alpha_{12}x_2 + \ldots + \alpha_{1p}x_p + \sum_{j=1}^{p} \alpha_{1j}x_j \qquad (1)$$

Furthermore, the linear function α'_2x is required, which is not correlated with $\alpha'_1 x$, and so on until $\alpha'_k x$ represents the *k*-th main component. There can be up to *p* major components, but the idea is that most of the total variance contained in *x* is explained by m main components, where $m \ll p$, and thus a large number of *p* variables can be replaced by one, two or three main components, without much information being lost (Jolliffe, 1986).

In practice, the main components are defined as:

$$z = A' x^* \qquad (2)$$

Where A, in this case, has columns consisting of the own correlation matrix *S* vectors, and x * consists of standardized values. The purpose of adopting this approach is to find the main components of the standardized version of *x*, where this standardized version, labeled with x * has the *j*-th element $x_j/\sigma_{jj}^{1/2}$, j=1, 2,….p, *xjj* is the *j*-th element of *x*, and σ_{jj} represents the variation of *x*. Then the covariance matrix for x^* is actually a correlation matrix for *x*, and the main components of x^* are given by the equation (2).

A significant reason for using the correlation matrix instead of the covariance to define the main components is that the results of the analysis for different random variables can be directly compared. This is a consequence of the fact that data standardization results in measurement results on different measuring scales, different measuring units to a common metric space that is independent of any measuring unit and any measuring scale. When using covariates, the used data is not standardized, and if there are large differences between their variations then the variables with the highest variance will dominate in the first few main components, leading to incorrect conclusions whenever the variables are measured in different measuring units, and yet this is the most common practice. There are several other important reasons why it is better to use the matrix of correlations, although there are also several cases in which the matrix of covariates yields better results, (for details see Jolliffe, 1986). In any case, in practice, the use of PCA with a correlation matrix is the most commonly encountered.

One important feature of the main components obtained from the correlation matrix is that if instead of normalization $\alpha'_k \alpha_k$=1, one uses:

$$\tilde{\alpha}'_k \tilde{\alpha}_k = \lambda_k^{1/2} \qquad (3)$$

Then $\tilde{\alpha}_{kj}$, the j-th element of $\tilde{\alpha}_k$, represents the correlation between the j-th standardized variable x^*_j and the k-th main component. This is valid considering that for k=1.2...p is valid:

$$\tilde{\alpha}_k = \lambda_k^{1/2} \alpha_k, \qquad var(z_k) = \lambda_k, \qquad (4)$$

And the p dimensional vector $\sum\alpha_k$ has a covariance between x^*_j and z_k for its j-th element. But since $\sum\alpha_k = \lambda_k\ \alpha_k$, the covariance between x^*_j and z_k is $\lambda_k\ \alpha_{kj}$. Also var(x^*_j) =1, and hence the correlation between x^*_j and z_k given by:

$$\frac{\lambda_k \alpha_{jk}}{[var(x^*_j)var(z_k)]^{1/2}} = \lambda_k^{1/2}\alpha_{kj} = \tilde{\alpha}_{kj} \qquad (5),$$

from where it started.

Due to this feature, normalization (4) is often used in practice.

There are three criteria on how to decide the number of the extracted factors (the main components), which are: the a priori criteria based on the researcher who already knows how many factors are to be retained, the percentage of variance criterion which is based on a certain cumulative percentage of variance (at least 60%), and the latent root criterion or scree test (Hair et al., 2006). The scree test is performed by plotting latent roots (own values) in relation to the number of factors in their order of extraction, and the form of the resulting curve is used to evaluate the breakpoint (limit value). The point at which the curve first begins to straighten is considered to indicate the maximum number of extraction factors (Gordon et al., 1997). So, the place where the line changes direction is changing and the components that will be included in the analysis are counted to that point.

In the case of retaining three or more PCs, an ellipsoid or hyper-ellipsoid is required. Moreover, for the purpose of accommodating the desired percentage of the population, a tolerance ellipsoid rather than prediction is required (Chew, 1966). In this study we used a tolerance factor as provided by Krishnamoorthy and Mondal (2006). The obtained ellipsoid contains critical models. There are 14 points on the surface of the ellipsoid, 6 of them on the intersection of the axes and ellipsoid, and the remaining 8 at the centers of the octants, as given in Figure 4.1 (Essdai et al., 2018)

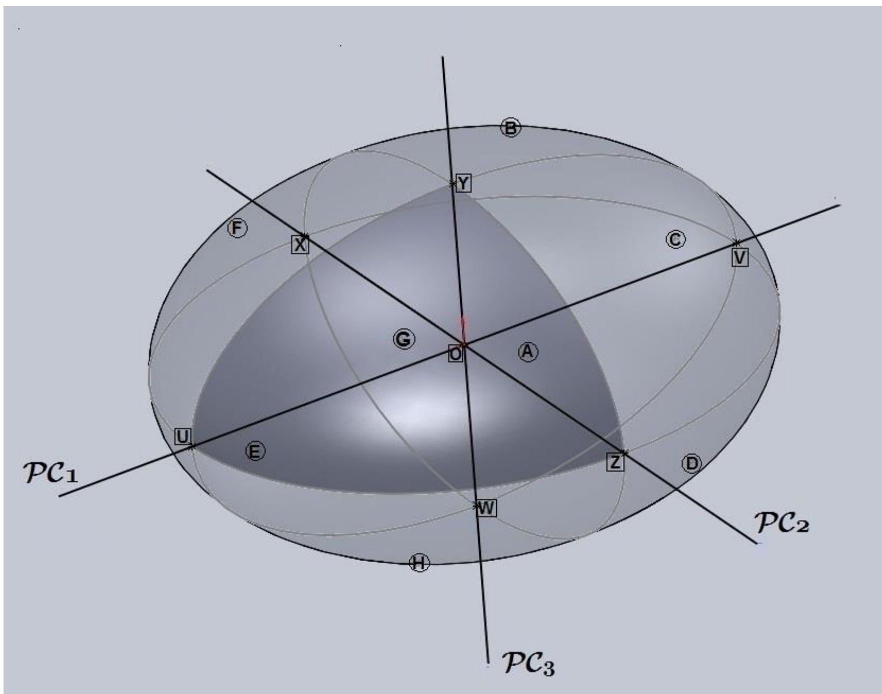

Figure 4.1 The points representing critical models of the 95% enclosure ellipsoid (Omic et al., 2017, Essdai et al., 2018)

The factor coordinates of the 14 critical models from the accommodation ellipse are transformed back into anthropometric dimensions by multiplying the matrix of factor scores with the inverse eigenvector matrix. Also, the anthropometric measures for those 14 models are obtained afterwards by multiplying the standardized values by the standard deviations and adding the total to the mean of the appropriate dimension, using the equation:

$$Z_{cm} = PC_{cm} \cdot U^{-1} \qquad (6)$$

Where Z_{cm} is the matrix of standardized anthropometric measures for 14 critical models, PC_{cm} is the matrix of factor scores for 14 critical models and U^{-1} is the inverse matrix of eigenvectors.

On the other hand, percentiles distribute the results to 100 parts, i.e. each part contains 1% distribution results. Univariate, 5th and 95th percentile models will also be obtained and compared to the multivariate results. In the end, both multivariate and univariate models will be used to determine the dimensions of the interior space necessary to accommodate all of them in an ergonomically designed interior space.

4.3.3 The multivariate anthropometric models of Serbian crane operators

The matrices of correlation, eigenvalues, eigenvectors and factor loadings obtained through the Principal Component Analysis are as follows in Tables 4.6, 4.7, 4.8 and 4.9 respectively, while Figure 4.2 illustrates the scree plot of active variables. The decision to use the first three principal components (PCs) to define body models is made on the basis of the scree test, PC1, PC2 and PC3, which are orthogonal to one another and were found to account for 77.75% of the total variance. Choosing a cut-off total variance somewhere between 70% and 90% and retaining *m* PCs provides a rule which in practice preserves most of the information in the first *m* PCs (Jolliffe, and Cadima, 2016).

Table 4.6 Correlation matrix of Serbian crane operators' anthropometric measurements

Dimension	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
FOL	1.0000	0.0489	-0.0051	0.0469	0.0788	-0.1219	-0.0208	-0.0838
STH	0.0489	1.0000	0.7524	0.4302	0.3395	0.1878	0.0254	0.6140
SIH	-0.0051	0.7524	1.0000	0.3135	0.2651	0.0865	-0.2072	0.6422
LLL	0.0469	0.4302	0.3135	1.0000	0.4874	0.4481	0.4235	0.5696
ULL	0.0788	0.3395	0.2651	0.4874	1.0000	0.4504	0.3856	0.4121
SHW	-0.1219	0.1878	0.0865	0.4481	0.4504	1.0000	0.7603	0.3407
HIB	-0.0208	0.0254	-0.2072	0.4235	0.3856	0.7603	1.0000	0.0446
ARL	-0.0838	0.6140	0.6422	0.5696	0.4121	0.3407	0.0446	1.0000

Table 4.7 Eigenvalues of the correlation matrix of Serbian crane operators

PCs	Eigenvalue	% Total	Cumulative eigenvalue	Cumulative variance
1	3.2849	41.0609	3.2849	41.0609
2	1.8826	23.5320	5.1674	64.5929
3	1.0525	13.1567	6.2200	77.7496
4	0.5496	6.8699	6.7696	84.6195
5	0.5155	6.4434	7.2850	91.0629
6	0.3622	4.5275	7.6472	95.5905
7	0.2159	2.6992	7.8632	98.2896
8	0.1368	1.7104	8.0000	100.0000

Table 4.8 Eigenvector of the correlation matrix of Serbian crane operators

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	0.00739	0.05001	0.95239	0.20136	0.02376	0.22189	0.00086	0.00747
STH	-0.40443	0.34635	0.03040	0.28688	0.28102	-0.49649	0.48441	0.27041
SIH	-0.35229	0.47659	-0.06165	0.13744	0.27933	0.02782	-0.66484	-0.32443
LLL	-0.43078	-0.10897	0.10270	-0.00057	-0.75994	-0.32486	-0.27869	0.17689
ULL	-0.38318	-0.15886	0.19704	-0.83232	0.30026	-0.07476	0.01109	0.02205
SHW	-0.35389	-0.44721	-0.13895	0.29044	0.27429	0.39837	-0.19510	0.54690
HIB	-0.24349	-0.59816	0.02690	0.28273	0.12718	-0.22130	0.11783	-0.65056
ARL	-0.44198	0.23558	-0.13723	-0.03486	-0.28872	0.62024	0.43999	-0.25974

Table 4.9 Factor loadings based on correlation for Serbian crane operators

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	0.01340	0.06862	*0.97709*	0.14928	0.01706	0.13354	0.00040	0.00276
STH	*-0.73301*	0.47522	0.03119	0.21268	0.20176	-0.29881	0.22510	0.10003
SIH	*-0.63849*	0.65391	-0.06325	0.10189	0.20055	0.01674	-0.30894	-0.12001
LLL	*-0.78075*	-0.14952	0.10536	-0.00042	-0.54561	-0.19551	-0.12950	0.06543
ULL	*-0.69448*	-0.21796	0.20215	-0.61704	0.21558	-0.04500	0.00515	0.00816
SHW	-0.61361	*-0.64140*	-0.14255	0.21532	0.19693	0.23975	-0.09066	0.20230
HIB	-0.44131	*-0.82071*	0.02760	0.20960	0.09131	-0.13318	0.05475	-0.24065
ARL	*-0.80106*	0.32323	-0.14079	-0.02584	-0.20729	0.37328	0.20446	-0.09608

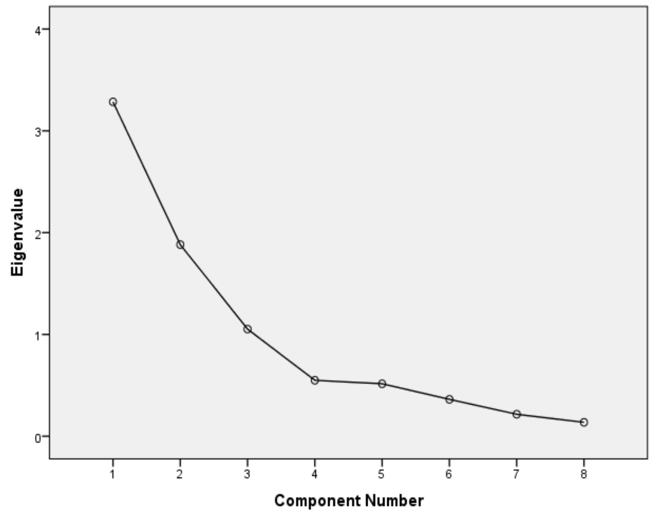

Figure 4.2 Scree plot of Serbian crane operators

The desired level of sample inclusion was set to 95% (95% tolerance ellipsoid) and was accomplished by fitting an ellipsoid in a three-dimensional space (Essdai et al., 2018; and Omic et al., 2017).

In many practical engineering cases, tolerances are needed to fit data or product specifications in intervals or regions (Krishnomoorthy and Mondal, 2006). Chew (1966) distinguished between formulas for confidence, prediction and tolerance regions for the multivariate normal distribution and pointed out that tolerance has to be used when there is an aim to contain a specified percentage of the population. In this study, the anthropometric data should accommodate 95% of target population. For such cases, Krishnomoorthy and Mondal, (2006) developed a way, 40 years later, to calculate the tolerance factor for multivariate normal distribution in terms of the sample size and tolerance level and enabled the execution of one of Chew's dissertation ideas (Chew, 1966). Through that, the semi axes of the ellipsoid could be derived in terms of the eigenvalues of the selected components. Whereas the semi axes of the ellipsoid are gained by multiplying the square root of the eigenvalues of the selected components by the square root of the c value, as in Table 4.10, the tolerance factor (c=9.92) for n=83 is calculated by interpolation (Krishnomoorthly and Mondal, 2006) for n between 80 and 90.

Table 4.10 Semi-axes of the ellipsoid for Serbian crane operators

Components	Eigenvalue (λ)	$\sqrt{\lambda}$	Tolerance factor (c)	$\sqrt{c}$	Semi-axes of ellipsoid ($\sqrt{\lambda}\sqrt{c}$)
PC1	3.284874	1.812422	9.92	3.149603	5.77778
PC2	1.882556	1.372063	9.92	3.149603	5.215558
PC3	1.052538	1.025933	9.92	3.149603	3.248198

The next step is to determine the critical models on the surface of the ellipsoid, where the 5th and 95th percentile are also included, to check if they within the boundary space. There were 14 points from PCA on the ellipsoid surface representing the diverse body size and shape combinations (Figure 4.1**)**. Six of them are intercepts on the ellipsoid surface by the three axes (points U, V, W, X, Y, and Z), while eight octant midpoints were obtained by cutoff of the ellipsoid into octants using CATIA software. The axes of the midpoint on the surface of the octant can be found by finding the inertia of the surface and extruded to the surface of the octant and then measure the axes (x, y, z), which are in this case 3.075, 2.46 and 1.996. There are eight sections (octants) divided by the three axes of this ellipsoid (points A, B, C, D, E, F, G, and H) (Spasojević Brkic et al., 2016, and Essdai et al., 2018). These 14 points, together with the centroid of the ellipsoid (point O), form the basis for the selection of the anthropometric models.

Table 4.11 addresses the PCA application output. It consists of three PCs that were preserved according to the criterion that their eigenvalues should be greater than 1 (Hsiao, 2012, Jolliffe and Cadima, 2016; and Bittner, 2000), which implies a minimum variance of 13.156. Such a result is in accordance with the variance criterion given by Jolliffe and Cadima, (2016), as can be seen in Table 3.11. PC1, which accounts for 41.061% of the total variation, looking at the factor loadings and sample size needed for significance (Jolliffe and Cadima, 2016). This mostly explains standing height, sitting height, lower leg length, upper leg length, and arm length (all refer to the overall height, and maximum reach, so PC1 can be interpreted as 'height'). PC2, accounting for 23.532% of the variation, counted mostly from hip breadth and shoulder width, is interpreted as ‘width’. PC3, accounting for 13.157% of the variation, mostly explains the variable foot length, and is hence interpreted as ‘depth’.

Table 4.11 The first three PCs and their correlations with variables for Serbian crane operators

Dimension (variables)	PC1	PC2	PC3
FOL	0.0134	0.069	*0.977*
STH	*0.733*	0.475	0.031
SIH	*0.654*	0.638	0.063
LLL	*0.781*	0.150	0.105
ULL	*0.694*	0.218	0.202
SHW	0.614	*0.641*	0.143
HIB	0.441	*0.821*	0.028
ARL	*0.801*	0.323	0.141
Eigenvalue	3.285	1.883	1.0525
Cumulative percentage of total variation	41.061	23.532	13.157

The first three selected components form the first three components coordinates of 14 points as in Table 4.12. The next step is to calculate the factor/PC scores (standardized values) for 14 body models as given in Table 4.13, by multiplying the factor coordinates matrix (Table 4.12) by the inverse matrix of the eigenvector matrix (Table 4.8). The results are shown in Table 4.13.

Table 4.12 Factor/PC coordinates for body models

Model	PC1	PC2	PC3
U	-5.71	0	0
V	5.71	0	0
X	0	4.32	0
Z	0	-4.32	0
Y	0	0	3.23
W	0	0	-3.23
A	3.075	2.46	-1.996
B	3.075	2.46	1.996
C	3.075	-2.46	1.996
D	3.075	-2.46	-1.996
E	-3.075	2.46	-1.996
F	-3.075	2.46	1.996
G	-3.075	-2.46	1.996
H	-3.075	-2.46	-1.996

Table 4.13 Standardized values of 8 anthropometric dimensions for representative body models of Serbian crane operators including univariate percentile of 95th, 5th values.

Model	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
P95	1.44347	1.69194	1.44826	0.81718	1.42424	2.07442	1.85379	1.67895
P5	-1.67848	-1.58617	-1.52097	-1.64695	-1.60189	-1.61479	-1.19928	-1.25862
U	-0.04222	2.30932	2.01157	2.45974	2.18795	2.02073	1.39034	2.52371
V	0.04222	-2.30932	-2.01157	-2.45974	-2.18795	-2.02073	-1.39034	-2.52371
X	0.21604	1.49625	2.05886	-0.47077	-0.68625	-1.93196	-2.58404	1.01772
Z	-0.21604	-1.49625	-2.05886	0.47077	0.68625	1.93196	2.58404	-1.01772
Y	3.07621	0.09818	-0.19914	0.33173	0.63643	-0.44880	0.08689	-0.44325
W	-3.07621	-0.09818	0.19914	-0.33173	-0.63643	0.44880	-0.08689	0.44325
A	-1.75520	-0.45228	0.21218	-1.79771	-1.96234	-1.91103	-2.27391	-0.50565
B	2.04673	-0.33093	-0.03394	-1.38773	-1.17577	-2.46570	-2.16651	-1.05347
C	1.80068	-2.03499	-2.37875	-0.85157	-0.39420	-0.26541	0.77643	-2.21253
D	-2.00125	-2.15634	-2.13263	-1.26156	-1.18078	0.28926	0.66903	-1.66472
E	-1.80068	2.03499	2.37875	0.85157	0.39420	0.26541	-0.77643	2.21253
F	2.00125	2.15634	2.13263	1.26156	1.18078	-0.28926	-0.66903	1.66472
G	1.75520	0.45228	-0.21218	1.79771	1.96234	1.91103	2.27391	0.50565
H	-2.04673	0.33093	0.03394	1.38773	1.17577	2.46570	2.16651	1.05347

Table 4.14 shows anthropometric dimensions for the representative models that are gained by reversing the standardized values to anthropometric measurements, both for PCA and the percentiles, which have been obtained as the sum of the mean value of the appropriate dimension and the value of product of its standardized value and the standard deviation. Representative multivariate body models (Table 4.14) of Serbian crane operators can be described in the following manner, where the center of the ellipsoid represents an average person in all body dimensions.

- Model U represents an individual with large overall height, width, arm length (maximum reach) and average foot length.
- Model V represents an individual with small overall height, small width, average foot length and small arm length (minimum reach).
- Model X represents an individual with large width, small height, average foot length and average arm length.

- Model Z represents an individual with small width, large height, average foot length and average arm length.
- Model Y represents an individual with large foot length, and average overall height, width and arm length.
- Model W is identical to Model Y, but represents an individual with small foot length.
- Model A represents an individual with relatively average width, but small overall height, small foot length and small arm length.
- Model B represents an individual with relatively small overall height, small arm length, but average width and large foot length.
- Model C represents an individual with average overall height, average arm length, and small width but relatively large foot length.
- Model D represents an overall small individual.
- Model E in contrast to Model B, represents an individual with large overall height and large width but relatively small foot length.
- Model F, in contrast to Model D, represents an overall large individual.
- Model G in contrast to Model A, represents an individual with relatively small width, but large overall height, large arm length and small foot length.
- Model H in contrast to Model A, represents an individual with relatively large overall height, large arm length, large foot length but relatively small width.

The univariate, percentiles approach is also applied in order to verify whether these models fall inside the multivariate models. The 95^{th} and 5^{th} percentiles were calculated, and it was found that the percentiles value as summarized in Table 4.15 (all measurements in mm), fall within the range of the multivariate for all the anthropometric dimensions. Such a fact leads to the conclusion that the multivariate approach provides better population inclusion and is more effective than the univariate approach in cases of multi-anthropometric dimensions issues.

Table 4.14 Anthropometric dimensions of representative body models for Serbian operators including univariate percentile 95th, 5th values (all measurements in mm)

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	316	1884	990	620	670	579	510	790
P5	276	1660	821	521	560	400	331	641
U	297	1926	1021	686	698	576	483	833
V	298	1611	793	488	539	380	320	576
X	295	1666	790	606	643	572	553	653
Z	300	1870	1024	568	593	385	250	756
Y	336	1775	896	600	641	457	406	682
W	259	1761	919	574	595	500	396	727
A	272	1621	786	536	575	492	441	620
B	320	1629	772	553	604	465	447	592
C	323	1746	905	531	575	359	274	651
D	275	1737	919	515	547	386	268	679
E	272	1791	909	643	661	598	528	758
F	319	1799	895	659	690	571	535	730
G	275	1907	1042	621	633	491	356	817
H	322	1915	1028	638	661	464	362	789
Min	259	1611	772	488	539	359	250	576
Max	336	1926	1042	686	698	598	553	833

Table 4.15 Summary of univariate percentiles models for Serbian crane operators (all measurements in mm)

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	316	1884	990	620	670	579	510	790
P5	276	1660	821	521	560	400	331	641

In that manner the hypothesis:

H1 - Using an integral multivariate model for anthropometric adaptation it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy.

Has been proved in the crane cabin interior space modeling problem, based on the Serbian crane operators' data. There are 3 PCs that form the mathematically described *three-dimensional, spatial model* with an accuracy of 95% instead of the 90% coverage that the univariate percentiles application provides.

4.3.4 The multivariate anthropometric models of Libyan crane operators

A similar procedure of modeling has been applied to the Libyan crane operators collected data. The tables below show the matrices of correlation (Table 4.16), the eigenvalues (Table 4.17), the eigenvectors (Table 4.18), factors loading (Table 4.19), and Figure 4.3 illustrates the scree plot.

Table 4.16 Correlation matrix of Libyan crane operators

Dimension	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
FOL	1.00000	0.51599	0.32812	0.32603	0.37264	-0.12954	0.13467	-0.02539
STH	0.51599	1.00000	0.31439	0.42228	0.39947	-0.00537	0.25944	0.13139
SIH	0.32812	0.31439	1.00000	0.18376	0.05168	-0.24083	-0.12840	0.24999
LLL	0.32603	0.42228	0.18376	1.00000	0.47752	0.30481	0.51556	-0.04595
ULL	0.37264	0.39947	0.05168	0.47752	1.00000	0.18417	0.29718	-0.19561
SHW	-0.12954	-0.00537	-0.24083	0.30481	0.18417	1.00000	0.64949	-0.03773
HIB	0.13467	0.25944	-0.12840	0.51556	0.29718	0.64949	1.00000	-0.04228
ARL	-0.02539	0.13139	0.24999	-0.04595	-0.19561	-0.03773	-0.04228	1.00000

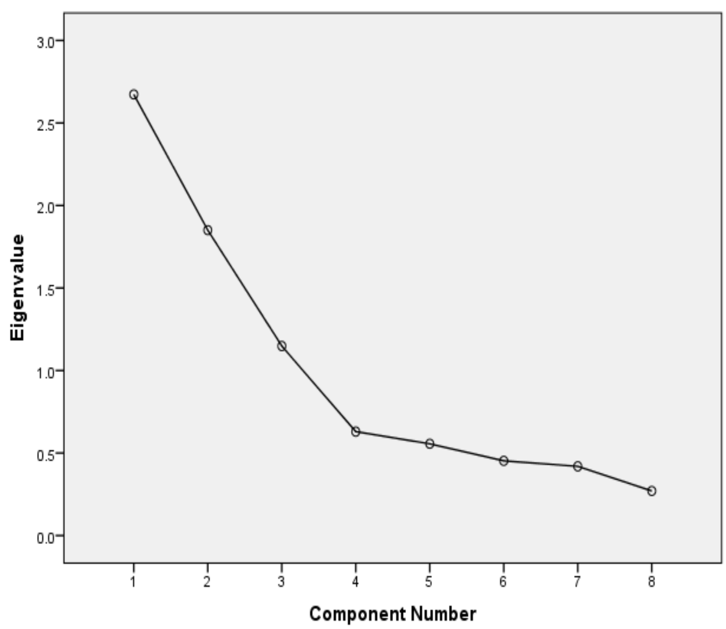

Figure 4.3 Scree plot of Libyan crane operators

Table 4.17 Eigenvalues of correlation matrix of Libyan crane operators

PCs	Eigenvalue	% Total	Cumulative	Cumulative
1	*2.672929*	*33.41161*	*2.672929*	*33.4116*
2	*1.850471*	*23.13089*	*4.523400*	*56.5425*
3	*1.148651*	*14.35814*	*5.672051*	*70.9006*
4	0.629653	7.87067	6.301705	78.7713
5	0.555987	6.94984	6.857692	85.7211
6	0.452521	5.65651	7.310213	91.3777
7	0.419502	5.24377	7.729714	96.6214
8	0.270286	3.37857	8.000000	100.0000

Table 4.18 Eigenvectors of correlation matrix of Libyan crane operators

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	-0.36833	-0.36294	-0.21518	-0.23781	0.52574	0.43545	0.37598	-0.14961
STH	-0.42946	-0.29503	0.05893	-0.39889	0.08257	-0.46812	-0.56084	-0.15950
SIH	-0.14918	-0.51892	0.23859	0.70340	0.02104	0.22198	-0.30435	0.12010
LLL	-0.49174	0.05851	0.04827	0.35749	-0.18939	-0.47671	0.54113	-0.26210
ULL	-0.43273	0.01463	-0.34849	-0.13410	-0.69573	0.38328	-0.09210	0.18351
SHW	-0.24541	0.54220	0.29487	0.10044	0.09435	0.37923	-0.28013	-0.56352
HIB	-0.40924	0.39734	0.23570	0.00183	0.31793	-0.03051	-0.00440	0.71907
ARL	0.02955	-0.23761	0.79185	-0.36563	-0.29403	0.15188	0.26772	0.02758

Table 4.19 Factor loadings based on correlation of Libyan crane operators

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	*-0.60219*	-0.49371	-0.23062	-0.18870	0.39201	0.29293	0.24352	-0.07778
STH	*-0.70212*	-0.40133	0.06316	-0.31652	0.06157	-0.31490	-0.36325	-0.08292
SIH	*-0.70590*	-0.24390	0.25571	0.55815	0.01569	0.14933	-0.19712	0.06244
LLL	*-0.80395*	0.07959	0.05173	0.28367	-0.14122	-0.32068	0.35048	-0.13626
ULL	*-0.70748*	0.01990	-0.37349	-0.10641	-0.51877	0.25783	-0.05965	0.09540
SHW	-0.40123	*0.73757*	0.31602	0.07970	0.07035	0.25511	-0.18144	-0.29297
HIB	0.54051	*-0.66907*	0.25261	0.00145	0.23706	-0.02053	-0.00285	0.37384
ARL	0.04831	-0.32323	*0.84867*	-0.29013	-0.21924	0.10217	0.17340	0.01434

The first three PCs as summarized in Table 4.20 are selected based on the eigenvalues and desired total explained variance amount to 70.90%. The first component loaded foot length, standing height, lower leg length, and upper leg length, with total explained variance 33.41%. This component represents body height and pedal reach. The second PC covers 23% of total variance containing shoulder width and hip breadth, which represent body width, and the third PC includes arm length with total explained variance 14% representing the maximum reach of 'depth'.

Table 4.20 First three PCs and their correlations with variables

Dimension (variables)	PC1	PC2	PC3
FOL	*-0.6022*	-0.49371	-0.23062
STH	*-0.7021*	-0.40133	0.063163
SIH	*-0.7059*	-0.2439	0.255712
LLL	*-0.8039*	0.07959	0.051729
ULL	*-0.7075*	0.0199	-0.37349
SHW	-0.40123	*0.73757*	0.316024
HIB	0.540505	*-0.6691*	0.252607
ARL	0.048314	-0.32323	*0.84867*
Eigenvalue	2.672929	1.850471	1.148651
Cumulative percentage of total variation	33.41161	23.13089	14.35814

The semi axes of the ellipsoid are calculated using the already proposed methodology for calculations (Table 4.21) wherein, in this case, the tolerance factor is 11.07 for *n*=50 (Krishnomoorthy and Mondel, 2006). By the same procedure, the midpoint on the surface of octants is obtained, and the axes are 3, 2.59, and 2.2. The factor coordinates of the representative body models developed are given in Table 4.22, and the score coordinates (*z* values) are shown in Table 4.23. Then from the *z*- values the body models are generated as in Table 4.24**.**

Table 4.21 Semi-axes of ellipsoid for Libyan crane operators

Components	Eigenvalue (λ)	$\sqrt{\lambda}$	Tolerance factor (c)	$\sqrt{c}$	Semi-axes of ellipsoid ($\sqrt{\lambda}\sqrt{c}$)
PC1	2.672929	1.634909	11.07	3.327161	5.439607
PC2	1.850471	1.36032	11.07	3.327161	4.526004
PC3	1.148651	1.071751	11.07	3.327161	3.565889

Table 4.22 Factor/PC coordinates for body models

Model	PC1	PC2	PC3
U	-5.44	0	0
V	5.44	0	0
X	0	4.53	0
Z	0	-4.53	0
Y	0	0	3.57
W	0	0	-3.57
A	3	2.59	-2.2
B	3	2.59	2.2
C	3	-2.59	2.2
D	3	-2.59	-2.2
E	-3	2.59	-2.2
F	-3	2.59	2.2
G	-3	-2.59	2.2
H	-3	-2.59	-2.2

Table 4.23 Standardized values of 8 anthropometric dimensions for representative body model of Libyan crane operators including percentile 95th, 5th values.

Model	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
p95	2.30327	1.51312	1.26708	1.51593	1.72364	1.89176	1.77234	1.4332
p5	-0.94077	-1.73172	-1.66016	-1.76767	-1.49484	-1.27972	-1.47024	-1.93652
U	2.00372	2.33624	0.81154	2.67506	2.35407	1.33504	2.22628	-0.16076
V	-2.00372	-2.33624	-0.81154	-2.67506	-2.35407	-1.33504	-2.22628	0.16076
X	-1.64411	-1.33646	-2.35071	0.26504	0.06627	2.45619	1.79994	-1.07638
Z	1.64411	1.33646	2.35071	-0.26504	-0.06627	-2.45619	-1.79994	1.07638
Y	-0.76818	0.21039	0.85178	0.17231	-1.24409	1.05267	0.84143	2.82691
W	0.76818	-0.21039	-0.85178	-0.17231	1.24409	-1.05267	-0.84143	-2.82691
A	-1.57161	-2.18214	-2.31645	-1.42987	-0.49364	0.01937	-0.71716	-2.26883
B	-2.51839	-1.92283	-1.26664	-1.2175	-2.02698	1.31678	0.3199	1.21531
C	-0.63837	-0.3946	1.42137	-1.52057	-2.10276	-1.49184	-1.7383	2.44614
D	0.30841	-0.65391	0.37156	-1.73294	-0.56942	-2.78925	-2.77536	-1.03801
E	0.63837	0.3946	-1.42137	1.52057	2.10276	1.49184	1.7383	-2.44614
F	-0.30841	0.65391	-0.37156	1.73294	0.56942	2.78925	2.77536	1.03801
G	1.57161	2.18214	2.31645	1.42987	0.49364	-0.01937	0.71716	2.26883
H	2.51839	1.92283	1.26664	1.2175	2.02698	-1.31678	-0.3199	-1.21531

Table 4.24 Anthropometric dimensions of representative body models of Libyan crane operators including percentile 95th, 5th values (all measurements in mm)

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
p95	295	1790	890	590	616	591	470	760
p5	265	1600	750	470	510	420	309	484
U	292	1838	868	632	636	561	493	629
V	255	1565	791	437	482	417	271	656
X	258	1623	717	544	561	621	471	554
Z	289	1780	942	525	557	357	293	731
Y	267	1714	870	541	518	546	424	874
W	281	1689	789	528	600	432	340	410
A	259	1574	719	482	543	490	346	456
B	250	1589	769	490	493	560	398	742
C	268	1678	897	479	490	409	296	843
D	277	1663	847	471	540	339	244	557
E	280	1725	761	590	628	569	468	442
F	271	1740	812	598	578	639	520	728
G	288	1829	940	587	575	488	418	829
H	297	1814	890	579	625	418	366	543
Min.	250	1565	717	437	482	339	244	410
Max.	297	1838	942	632	636	639	520	874

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Representative models of Libyan crane operators and their characteristics are described below, where the center of the ellipsoid represents an average person in all body dimensions.

- Model U represents an individual with large overall height, large foot length, large width and average arm length.
- Model V represents an individual with small overall height, small width and, small foot length and average arm length.
- Model X represents an individual with large width, small height, small foot length and average arm length.
- Model Z represents an individual with small width, large height, large foot length and average arm length.
- Model Y represents an individual average in width, height, and foot length but large with large arm length.
- Model W is identical to Model Y, but represents an individual with small arm length.

- Model A represents an individual with relatively average width, but small overall height, small foot length and small arm length.
- Model B is identical to model A, but represents an individual with average arm length.
- Model C represents an individual with average overall height, large arm length, but small width and foot length.
- Model D represents an overall small individual.
- Model E represents an individual with large overall width, small arm length but average foot length and height.
- Model F in contrast to Model D, represents an overall large individual.
- Model G in contrast to Model A, represents an individual with relatively small width, but large overall height, large in arm length and foot length
- Model H in contrast to Model B, represents an individual with large overall height, large arm length, large foot length but with relatively small width.

95th and 5th percentiles values are as summarized in Table 4.25, and they fall within the range of multivariate models.

Table 4.25 Univariate - percentiles models for Libyan crane operators

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	295	1790	890	590	616	591	470	760
P5	265	1600	750	470	510	420	309	484

In that manner the hypothesis:

H1 - Using an integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy

has been proved in the crane cabin interior space modeling problem, based on Libyan crane operators' data. There are 3 PCs that form the mathematically described *three-dimensional, spatial model* and accuracy is 95% instead of the 90% coverage that the univariate, percentiles application provides.

4.3.5 The multivariate anthropometric models of Serbian drivers

A similar procedure of modeling has been applied to the Serbian drivers collected data (males and females). The PCA output gives the results shown in Table 4.26**,** Table 4.27, Table 4.28 and Table 4.29, the matrixes of correlation, the eigenvalues, the eigenvectors, and factor loadings, respectively. The scree plot is illustrated in Figure 4.4.

Table 4.26 Correlation matrix of Serbian drivers

Dimension	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
FOL	1.00000	0.64398	0.44191	0.46244	0.44998	0.41320	0.25136	0.48798
STH	0.64398	1.00000	0.73799	0.61774	0.57239	0.41486	0.15839	0.62120
SIH	0.44191	0.73799	1.00000	0.49480	0.41937	0.35303	-0.04289	0.61091
LLL	0.46244	0.61774	0.49480	1.00000	0.68061	0.38339	0.20867	0.56465
ULL	0.44998	0.57239	0.41937	0.68061	1.00000	0.45026	0.28139	0.54279
SHW	0.41320	0.41486	0.35303	0.38339	0.45026	1.00000	0.62970	0.45183
HIB	0.25136	0.15839	-0.04289	0.20867	0.28139	0.62970	1.00000	0.17096
ARL	0.48798	0.62120	0.61091	0.56465	0.54279	0.45183	0.17096	1.00000

Table 4.27 Eigenvalues of correlation matrix of Serbian drivers

PC	Eigenvalue	% Total	Cumulative	Cumulative
1	4.231026	52.88782	4.231026	52.8878
2	1.345680	16.82100	5.576706	69.7088
3	0.681135	8.51418	6.257841	78.2230
4	0.570965	7.13707	6.828806	85.3601
5	0.394681	4.93352	7.223487	90.2936
6	0.318888	3.98610	7.542375	94.2797
7	0.278387	3.47984	7.820762	97.7595
8	0.179238	2.24047	8.000000	100.0000

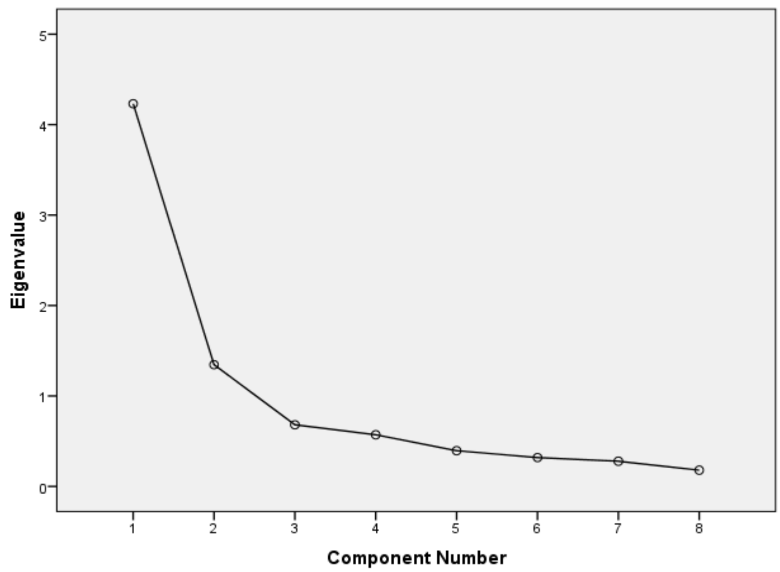

Figure 4.4 Scree plot of Serbian drivers

Table 4.28 Eigenvectors of correlation matrix of Serbian drivers

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	-0.35282	-0.00835	0.37051	-0.77052	0.21139	0.08368	-0.20672	-0.22373
STH	-0.41621	-0.21547	0.19206	-0.11771	-0.33280	-0.08337	0.40113	0.67156
SIH	-0.35653	-0.37433	0.33124	0.38208	-0.37142	0.02125	0.04953	-0.57984
LLL	-0.38168	-0.08422	-0.54453	-0.07602	-0.15394	-0.59721	-0.40457	-0.02994
ULL	-0.37568	0.04000	-0.59931	-0.07591	-0.02615	0.65223	0.22358	-0.12745
SHW	-0.32501	0.48574	0.23571	0.33374	-0.10566	0.28307	-0.57209	0.27001
HIB	-0.18424	0.74228	0.05166	-0.00999	-0.08207	-0.32474	0.48157	-0.26118
ARL	-0.38573	-0.13330	0.04695	0.35135	0.81506	-0.13394	0.14506	0.06696

Table 4.29 Factor loadings based on correlation of Serbian drivers

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	*-0.72573*	-0.00968	0.30578	-0.58222	0.13280	0.04725	-0.10907	-0.09472
STH	*-0.85611*	-0.24996	0.15851	-0.08894	-0.20908	-0.04708	0.21165	0.28431
SIH	*-0.73336*	-0.43423	0.27337	0.28871	-0.23334	0.01200	0.02613	-0.24548
LLL	-0.44941	-0.09770	*-0.78509*	-0.05744	-0.09671	-0.33725	-0.21346	-0.01267
ULL	-0.49462	0.04640	*-0.77276*	-0.05736	-0.01643	0.36832	0.11797	-0.05396
SHW	0.56347	*-0.66852*	0.19453	0.25218	-0.06638	0.15985	-0.30185	0.11431
HIB	-0.37896	*0.86107*	0.04263	-0.00755	-0.05156	-0.18338	0.25409	-0.11057
ARL	*-0.79343*	-0.15464	0.03875	0.26548	0.51205	-0.07563	0.07654	0.02835

The selected first three PCs are as summarized in Table 4.30. The criteria to select the first three PCs to define body models is made on the basis of enough factors to meet 60% or more of the explained variance (Hair et al., 2006). The retained first three PCs covered the total explained variance of 78%, where, PC1 accounts for 52.887% of total variation and explains and preserves most of the information (Jolliffe, and Cadima, 2016), including foot length, standing height, and sitting height, and which represent body height and pedal reach. PC2 accounts for 16.82% of total variation, including shoulder width and hip breadth, and represents body width. PC3 includes lower leg length and upper leg length, which accounts for 8.54% of total variation, and represents the length of the sitting segments.

Table 4.30 First three PCs and their correlations with variables for Serbian drivers

Dimension (variables)	PC1	PC2	PC3
FOL	*-0.72573*	-0.00968	0.30578
STH	*-0.85611*	-0.24996	0.15851
SIH	*-0.73336*	-0.43423	0.27337
LLL	-0.44941	-0.09770	*-0.78509*
ULL	-0.49462	0.04640	*-0.77276*
SHW	0.56347	*-0.66852*	0.19453
HIB	-0.37896	*0.86107*	0.04263
ARL	*-0.79343*	-0.15464	0.03875
Eigenvalue	4.231026	1.34568	0.681135
Cumulative percentage of total variation	52.887%	16.821%	8.514%

The already explained modelling approach comes to semi axes of ellipsoid as in Table 4.31, with captured at tolerance factor 6.25 for n>1000 (Krishnomoorthy and Mondal, 2006). The midpoints of surface octants of ellipsoid are gained through semi axes using CATIA or MATLAB, which are 2.66, 1.65, and 1.3. Factor coordinates of body models developed are as in Table 4.32, and score coordinates (z values) are as shown in Table 4.33.

Table 4.31 Semi-axes of ellipsoid for Serbian drivers

Components	Eigenvalue (λ)	$\sqrt{\lambda}$	Tolerance factor (c)	$\sqrt{c}$	Semi-axes of ellipsoid ($\sqrt{\lambda}\sqrt{c}$)
PC1	4.231026	2.056946	6.25	2.5	5.142364
PC2	1.34568	1.160034	6.25	2.5	2.900086
PC3	0.681135	0.825309	6.25	2.5	2.063272

Table 4.32 Factor coordinates for body models for Serbian drivers

Model	PC1	PC2	PC3
U	-5.14	0	0
V	5.14	0	0
X	0	2.9	0
Z	0	-2.9	0
Y	0	0	2.06
W	0	0	-2.06
A	2.66	1.65	-1.3
B	2.66	1.65	1.3
C	2.66	-1.65	1.3
D	2.66	-1.65	-1.3
E	-2.66	1.65	-1.3
F	-2.66	1.65	1.3
G	-2.66	-1.65	1.3
H	-2.66	-1.65	-1.3

Table 4.33 Standardized values of 8 anthropometric dimensions for representative body model including univariate percentile 95th, 5th values for Serbian drivers

Model	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
P95	1.52235	1.57678	1.60319	1.62883	1.69110	1.78887	1.79234	1.62341
P5	-1.80860	-1.65831	-1.73219	-1.74990	-1.60659	-1.44427	-1.28310	-1.72589
U	1.81349	2.13930	1.83257	1.96183	1.93101	1.67054	0.94698	1.98265
V	-1.81349	-2.13930	-1.83257	-1.96183	-1.93101	-1.67054	-0.94698	-1.98265
X	-0.02421	-0.62487	-1.08555	-0.24423	0.11600	1.40864	2.15260	-0.38658
Z	0.02421	0.62487	1.08555	0.24423	-0.11600	-1.40864	-2.15260	0.38658
Y	0.76324	0.39564	0.68235	-1.12174	-1.23458	0.48556	0.10642	0.09672
W	-0.76324	-0.39564	-0.68235	1.12174	1.23458	-0.48556	-0.10642	-0.09672
A	-1.43393	-1.71231	-1.99662	-0.44634	-0.15421	-0.36947	0.66753	-1.30703
B	-0.47062	-1.21296	-1.13540	-1.86212	-1.71242	0.24337	0.80185	-1.18496
C	-0.44307	-0.50190	0.09988	-1.58420	-1.84442	-1.35957	-1.64767	-0.74505
D	-1.40638	-1.00125	-0.76134	-0.16842	-0.28621	-1.97241	-1.78198	-0.86712
E	0.44307	0.50190	-0.09988	1.58420	1.84442	1.35957	1.64767	0.74505
F	1.40638	1.00125	0.76134	0.16842	0.28621	1.97241	1.78198	0.86712
G	1.43393	1.71231	1.99662	0.44634	0.15421	0.36947	-0.66753	1.30703
H	0.47062	1.21296	1.13540	1.86212	1.71242	-0.24337	-0.80185	1.18496

Table 4.34 shows the representative models and their characteristics for Serbian drivers, while the center of the ellipsoid represents an average person at all body dimensions. Moreover, the 95th and 5th percentiles (the univariate approach) are fitted within the models.

Table 4.34 Anthropometric dimensions of representative body models of Serbian drivers including univariate percentiles of 95th, 5th values.

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	305	1922	990	650	710	552	470	780
P5	245	1650	820	520	550	390	330	610
U	310	1969	1002	663	722	546	432	798
V	245	1610	815	512	534	379	345	597
X	277	1737	853	578	634	533	486	678
Z	278	1842	964	597	622	392	290	717
Y	291	1823	943	544	568	487	393	703
W	264	1756	874	630	688	438	384	693
A	252	1645	807	570	620	444	419	631
B	269	1687	850	516	545	475	425	637
C	270	1747	913	526	538	394	313	660
D	252	1705	869	581	614	364	307	654
E	286	1832	903	648	717	530	463	735
F	303	1874	947	594	642	561	470	742
G	303	1933	1010	605	635	481	358	764
H	286	1891	966	659	711	450	352	758
Min	245	1610	807	512	534	364	290	597
Max	310	1969	1010	663	722	561	486	798

Representative models of Serbian drivers and their characteristics are described below, where the center of the ellipsoid represents an average person at all body dimensions.

- Model U Represents an individual with large overall height, large foot length, large width and large arm length.
- Model V, in contrast to model U, represents an individual with small overall height, small width, small foot length and small arm length.
- Model X represents an individual with large width, overall average in height, foot length and arm length.
- Model Z has the same characteristics of model X, but represents an individual with small width
- Model Y represents an individual with overall average in height, foot length and arm length, but with relatively small width.

- Model W represents an overall average individual model.
- Model A represents an individual with relatively average width, but small overall height, small foot length and small arm length.
- Model B represents an individual with small overall height, small foot length, small arm length, but relatively large width.
- Model C represents an individual with average overall height, average arm length and average foot length, but who is small in width.
- Model D is identical to the C model, but who is small in foot length.
- Model E represents an individual with large overall width, average foot length and average height.
- Model F, in contrast to Model C, represents an individual with large foot length.
- Model G, in contrast to Model A, represents a relatively large individual.
- Model H is in contrast to Model B.

In that manner, hypothesis:

H1 - Using an integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy

has been proved in the crane cabin interior space modelling problem, based on Serbian drivers' data. There are 3 PCs that form the mathematically described *three-dimensional, spatial model*, and accuracy is 95% instead of the 90% coverage that the univariate, percentiles application provides.

4.3.6 The multivariate anthropometric models of Libyan drivers

The result of PCA application on Libyan drivers' data (males and females) is represented in these matrices: the correlation matrix (Table 4.35), the eigenvalues (Table 4.36), the eigenvectors (Table 4.37), the factor loadings (Table 4.38), and the scree plot as depicted in Figure 4.5.

Table 4.35 Correlation matrix for Libyan drivers

Dimension	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
FOL	1.00000	0.50985	0.27136	0.42023	0.29438	0.35492	-0.00086	0.02024
STH	0.50985	1.00000	0.56263	0.58439	0.55129	0.24767	0.04017	0.14574
SIH	0.27136	0.56263	1.00000	0.32032	0.30239	0.12976	0.03915	0.17466
LLL	0.42023	0.58439	0.32032	1.00000	0.69215	0.34798	0.17873	0.16534
ULL	0.29438	0.55129	0.30239	0.69215	1.00000	0.24085	0.18439	0.13844
SHW	0.35492	0.24767	0.12976	0.34798	0.24085	1.00000	0.48301	0.17840
HIB	-0.00086	0.04017	0.03915	0.17873	0.18439	0.48301	1.00000	0.24304
ARL	0.02024	0.14574	0.17466	0.16534	0.13844	0.17840	0.24304	1.00000

Table 4.36 Eigenvalues of correlation matrix of Libyan drivers

PC	Eigenvalue	% Total	Cumulative	Cumulative
1	3.136093	39.20116	3.136093	39.2012
2	1.399456	17.49320	4.535549	56.6944
3	0.979155	12.23944	5.514704	68.9338
4	0.820132	10.25165	6.334835	79.1854
5	0.674868	8.43585	7.009703	87.6213
6	0.397001	4.96251	7.406704	92.5838
7	0.308575	3.85718	7.715279	96.4410
8	0.284721	3.55901	8.000000	100.0000

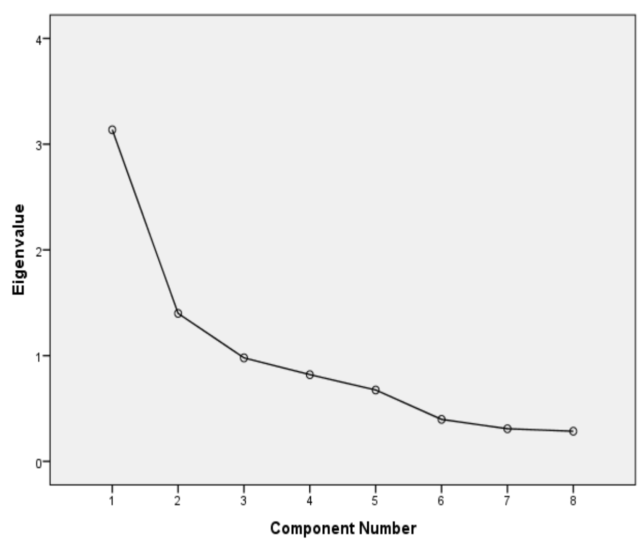

Figure 4.5 Scree plot of Libyan drivers

Table 4.37 Eigenvectors for correlation matrix of Libyan drivers

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	0.35457	-0.19124	0.39734	0.47376	0.39889	0.44770	0.26275	-0.16366
STH	0.45945	-0.27472	-0.08769	0.09127	-0.08516	0.12051	-0.79284	0.21690
SIH	0.33183	-0.24015	-0.41924	0.37657	-0.58534	-0.12856	0.38384	-0.09034
LLL	0.46210	-0.05722	0.08300	-0.39352	0.15077	-0.15997	0.37287	0.65885
ULL	0.42580	-0.07478	-0.00602	-0.59884	0.00712	0.00543	0.02013	-0.67377
SHW	0.31061	0.47378	0.37081	0.29545	-0.01256	-0.64915	-0.12441	-0.13128
HIB	0.17976	0.68243	0.05686	-0.07494	-0.40072	0.56700	0.01064	0.10461
ARL	0.17160	0.36228	-0.71485	0.13794	0.55451	-0.00078	-0.00237	-0.04219

Table 4.38 Factor loadings based on correlation of Libyan drivers

Dimension	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7	Factor 8
FOL	0.62790	-0.22623	0.39318	0.42905	0.32769	0.28209	0.14596	-0.08733
STH	0.81363	-0.32499	-0.08677	0.08265	-0.06996	0.07593	-0.44042	0.11574
SIH	0.58763	-0.28410	-0.41485	0.34103	-0.48086	-0.08100	0.21322	-0.04821
LLL	0.81833	-0.06769	0.08213	-0.35638	0.12386	-0.10079	0.20713	0.35156
ULL	0.75406	-0.08847	-0.00596	-0.54232	0.00585	0.00342	0.01118	-0.35952
SHW	0.55006	0.56047	0.36692	0.26757	-0.01031	-0.40902	-0.06911	-0.07005
HIB	0.31834	0.80730	0.05627	-0.06787	-0.32919	0.35726	0.00591	0.05582
ARL	0.30388	0.42857	-0.70736	0.12492	0.45554	-0.00049	-0.00131	-0.02251

The criteria to select the first three PCs to define body models is made on the basis of the three predetermined components for the purpose of study and to capture 60% or more of the explained variance (Hair et al., 2006**)**. The first three PCs cover a total explained variance of 68.9% as shown in Table 4.39. PC1 accounts for 39% of the total variation and preserves most of the information, including foot length, standing height, sitting height, lower leg length, and upper leg length, which represents the body height. PC2 accounts for 17% of the explained variance, including shoulder width and hip breadth, which represents the body width. PC3 accounts for 12% of the explained variance, which includes the arm length and represents the body depth (range of reach).

Table 4.39 First three PCs and their correlations with variables for Libyan drivers

Dimension (variables)	PC1	PC2	PC3
FOL	*0.627904*	-0.226231	0.393179
STH	*0.813632*	-0.324987	-0.086774
SIH	*0.587633*	-0.284098	-0.414849
LLL	*0.818334*	-0.067693	0.082132
ULL	*0.754059*	-0.088466	-0.005961
SHW	0.550056	*0.560474*	0.366923
HIB	0.318336	*0.807302*	0.056268
ARL	0.303883	0.428570	*-0.707359*
Eigenvalue	3.136093	1.399456	0.979155
Cumulative percentage of total variation	39.201%	17.493%	12.239%

The semi axes of the ellipsoid are calculated as in Table 4.40 at tolerance factor 8.52 for *n*=400, which is found by interpolation for *n* between 300 and 500 (Krishnomoorthy and Mondal, 2006). The same procedure is followed as for Serbian drivers and the midpoint of the surface of octants is given by the values 2.76, 2 and 1.76. The factor coordinates of the body models are as in Table 4.41 and the score coordinates (*z* values) are as shown in Table 4.42, which is reversed to real values in millimeters (the value multiplied by its standard deviation, plus its mean). Then the final model is generated as shown in Table 4.43.

Table 4.40 Semi-axes of ellipsoid for Libyan crane operators

Components	Eigenvalue (λ)	$\sqrt{\lambda}$	Tolerance factor (*c*)	$\sqrt{c}$	Semi-axes of ellipsoid ($\sqrt{\lambda}\sqrt{c}$)
PC1	3.136093	1.770902	8.52	2.918904	5.169092
PC2	1.399456	1.182986	8.52	2.918904	3.453023
PC3	0.979155	0.989523	8.52	2.918904	2.888321

Table 4.41 Factor coordinates for body models for Libyan drivers

Model	PC1	PC2	PC3
U	-5.17	0	0
V	5.17	0	0
X	0	3.45	0
Z	0	-3.45	0
Y	0	0	2.89
W	0	0	-2.89
A	2.76	2	-1.76
B	2.76	2	1.76
C	2.76	-2	1.76
D	2.76	-2	-1.76
E	-2.76	2	-1.76
F	-2.76	2	1.76
G	-2.76	-2	1.76
H	-2.76	-2	-1.76

Table 4.42 Standardized values of 8 anthropometric dimensions for representative body model for Libyan drivers including univariate percentile of 95th, 5th values.

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	1.80723	1.56536	1.42759	1.67221	1.89219	1.66421	1.78542	2.24230
P5	-2.23353	-1.64668	-1.75978	-1.57545	-1.52199	-1.46796	-1.43768	-1.16945
U	-1.83311	-2.37533	-1.71555	-2.38906	-2.20141	-1.60584	-0.92936	-0.88716
V	1.83311	2.37533	1.71555	2.38906	2.20141	1.60584	0.92936	0.88716
X	-0.65977	-0.94777	-0.82853	-0.19742	-0.25800	1.63454	2.35437	1.24986
Z	0.65977	0.94777	0.82853	0.19742	0.25800	-1.63454	-2.35437	-1.24986
Y	1.14832	-0.25343	-1.21161	0.23987	-0.01741	1.07163	0.16434	-2.06591
W	-1.14832	0.25343	1.21161	-0.23987	0.01741	-1.07163	-0.16434	2.06591
A	-0.10319	0.87297	1.17340	1.01487	1.03626	1.15221	1.76091	2.45630
B	1.29545	0.56429	-0.30233	1.30703	1.01506	2.45746	1.96107	-0.05997
C	2.06040	1.66316	0.65829	1.53592	1.31418	0.56234	-0.76864	-1.50908
D	0.66176	1.97184	2.13401	1.24376	1.33539	-0.74290	-0.96880	1.00719
E	-2.06040	-1.66316	-0.65829	-1.53592	-1.31418	-0.56234	0.76864	1.50908
F	-0.66176	-1.97184	-2.13401	-1.24376	-1.33539	0.74290	0.96880	-1.00719
G	0.10319	-0.87297	-1.17340	-1.01487	-1.03626	-1.15221	-1.76091	-2.45630
H	-1.29545	-0.56429	0.30233	-1.30703	-1.01506	-2.45746	-1.96107	0.05997

Table 4.43 Anthropometric dimensions of representative body models of Libyan drivers including univariate percentile 95th, 5th values.

Model	*FOL*	*STH*	*SIH*	*LLL*	*ULL*	*SHW*	*HIB*	*ARL*
P95	295	1840	920	600	650	550	470	790
P5	245	1620	760	480	520	390	290	550
U	295	1895	934	626	662	547	422	695
V	250	1570	762	450	494	383	318	570
X	264	1668	807	531	568	548	502	720
Z	281	1798	890	546	588	381	239	544
Y	287	1715	788	547	577	520	379	487
W	258	1750	909	529	578	410	361	777
A	264	1598	741	492	527	503	424	561
B	247	1619	815	481	527	436	413	738
C	257	1694	864	490	539	339	261	636
D	274	1673	789	501	538	406	272	459
E	271	1793	907	576	617	524	469	805
F	289	1771	833	587	616	591	480	628
G	281	1868	955	584	629	427	316	703
H	298	1847	881	595	628	494	327	526
Min	247	1570	741	450	494	339	239	459
Max	298	1895	955	626	662	591	502	805

The generated models of Libyan drivers and their characteristics can be described as follows, where the center of the ellipsoid represents an average person at all body dimensions, and the univariate approach (percentiles) fall within the extracted models.

- Model U represents an individual with large overall height, large foot length, large width and average arm length.
- Model V, in contrast to model U, represents an individual with small overall height, small width, small foot length and average arm length.
- Model X represents an individual with large width, overall average in height, foot length and arm length.
- Model Z is identical to model X, except that it represents an individual with small width.
- Model Y represents an individual with overall average height, relatively small arm length and who is large in width.
- Model W represents an individual with small foot length, relatively average in height and width, with large arm length.

- Model A represents an individual with relatively average width, but small overall height, small foot length and small arm length.
- Model B represents an individual with relatively small overall height, small foot length, small arm length, but average width.
- Model C represents an overall average individual, but small in width.
- Model D is identical with C model but represents an individual small in foot length.
- Model E in contrast with model C, represents an individual large in width and arm length, with average foot length, and average height.
- Model F is in contrast to Model C, but with larger foot length.
- Model G, in contrast to Model A, represents an individual with relatively small width, but large overall height, while relatively large in arm length and foot length.
- Model H is in contrast to Model B, and is represented by small body width and arm length, and large measures in body height.

In that manner, hypothesis:

H1 - Using an integral multivariate model for anthropometric adaptation, it is possible to reduce the multi-dimensional problem to a three-dimensional, spatial model of adequate accuracy

has been proved in the crane cabin interior space modeling problem, based on Libyan drivers' data. There are 3 PCs that form the mathematically described *three-dimensional, spatial model*, and accuracy is 95% instead of the 90% coverage that the univariate, percentiles application provides.

4.4 Multivariate Models Accommodation in Vehicles` and Machines` Interior Space

In workplaces design, multiple measurements must be considered. When each dimension is arranged sequentially to cover a certain percentile population, the design would include a certain percent of the user population for each specific function but will suffer from a compounded decrease in the level of overall accommodation, which would result in design inefficiency. Instead of focusing on each of the 8 individual dimensions, multivariate models rely on three PCs that are linear combinations of the 8 original variables. The models generated in this study therefore include not only overall large and small persons but also individuals of different body configurations and provide a wider coverage then the percentiles approach.

The representative models that are now described by mathematical functions have to be accommodated in interior space in a manner to take the smallest possible space. In that manner it is also evident that the hypothesis:

H2 - Anthropometric measurements have mechanical and mathematical functions that determine all three dimensions of the space, taking into account over 90% of the population,

Is partially proved. The missing part about mechanical functions is to be proved in text that follows.

4.4.1 Crane Operators Multivariate Models Accommodation in Crane Cabin Interior Space

The modeling of the cabin interior, for representative operators derived through multivariate statistics application, according to kinematics mechanism behavior, starts by adjusting the elements of the human-cabin system to comfort posture, along with fixing the origin of the coordinate system. Vogt et al. (2005) suggest fixing the joint visual angle or operator's hip for the heel, hip or hand, while Klarin et al. (2011) use the heel for vehicle design. After fixing the origin of the coordinate system, there is a need to minimize potential energy in each operator's joint, for which an angle of posture between anthropometric dimensions is also very important. Namely, fatigue is proportional to consumption of energy and each deviation from a physiological position is followed by energy consumption. Accordingly, it is logical that minimal potential energy enables the best comfort and the minimal fatigue, and that will be the guiding idea in multivariate models accommodation in crane cabin interior space.

The crane cabin, similarly to vehicles, requires the construction measured by the coordinate system with the fixed point in the operator's heel, which is in front of the foot pedal. Fixing the zero-coordinate point is enabled by the kinematics of heel movement, which for large legs and feet, due to seat movement backwards and downwards, moves the heel relatively towards the front along with an increase in the foot's angle with the floor. In the opposite case, this is achieved by moving the heel, e.g. in small anthropometric dimensions, towards the back and reducing the angle between the foot and the floor, along with an increase in the angle between the lower and the upper leg, as well as between the upper leg and the seat height, all aimed at the maximum overlapping of visual angles. Hence, our interior dimensioning methodology has three basic postulates:

1. The designing and dimensioning of the cabin begins from the starting point of the coordinate system located in the fixed contact point of the operator's heel and cabin floor, in front of the foot command next to the operator's right foot.

2. The visual angle, for the whole range of operators, is dimensioned to the minimum of 60º.

3. The dimensioning of the remaining space is accomplished according to the large anthropometric dimension of representative models, corresponding to the movement of a mechanical mechanism, i.e. complying with the kinematics of movement.

4.4.1.1 Multivariate Models Accommodation in Crane Cabin Interior Space for Serbian operators

The vertical projection of the space required for the operator's accommodation in the cabin shows how the representative models U, V, Z, B, and Y determine cabin interior dimensions towards the *x* and *z* axes. Figure 4.6 shows that, for operators corresponding to models U and V, the angle of 60º is enabled when looking downwards, which overlap in two extreme positions, where the angle between the torso and the upper leg is optimal at 109º for both models. Further, the optimal angle of the seat surface has been enabled in all positions, so that the femur is horizontal, and the hip and the seat surface form an angle of 7º. The arm span for using manual commands for those two models amounts to 576 mm (model V) and 833 mm (model U). All of the above is in accordance to head position and movement, horizontal and vertical seat adjustment and other dimensions and angles, from the shoulder joint (the semi-center of rotation) to the hand with folded fingers. The arm span of model H, with maximum of 783mm, as well as of model B, with minimum of 596mm, should also be considered. The arm flexibility of the user with the smallest arms enables, within a reduced field, normal work and commands usage. Therefore, the chair should be adjustable horizontally close to 260mm according to the maximum and minimum arm lengths in models U and V (833-576=257), which enables controls reach, and 170 mm vertically. The adjustability of 170 mm enables minimizing of the space that is required for operator U, so operator U is moved to position U'. The seat length of 400 mm and back rest height of 550mm are determined by the anthropometric dimension of models U and V, wherein ergonomically, seat length constrained by upper leg length and lower leg segment (Reed,1994), considering enough space between knee and seat edge in order to avoid muscle stress. Model Y with the largest shoe length (shoe size) determines the length on the negative side on the *x*-axis. The minimal cabin dimension in the x-axes is 1327mm calculated by max. Lengths of the lower body segments (upper leg, lower leg, and foot length) and the sitting height which is reduced by 152.4mm (the distance between the back rest of the seat and the center of the hip, Spasojević-Brkić, 2014a). The z-axes should be 1926mm, representing the overall height of the cabin (model U), so that comfortable entrance of model U into the cabin is enabled.

In the *x-y* plane (Figure 4.7), the y-axis dimensions are determined by hip breadth. The hip breadth for model Z is 250mm, and for model X it is 553mm, which determines the seat width. Therefore, the total length required in the *y*-axes should 1123mm considering the controllers' dimensions (Figure 4.7) as close to 550mm. The horizontal adjustability of the seat by 50mm provides the comfortable accommodation of the operator in the *x-z* plane.

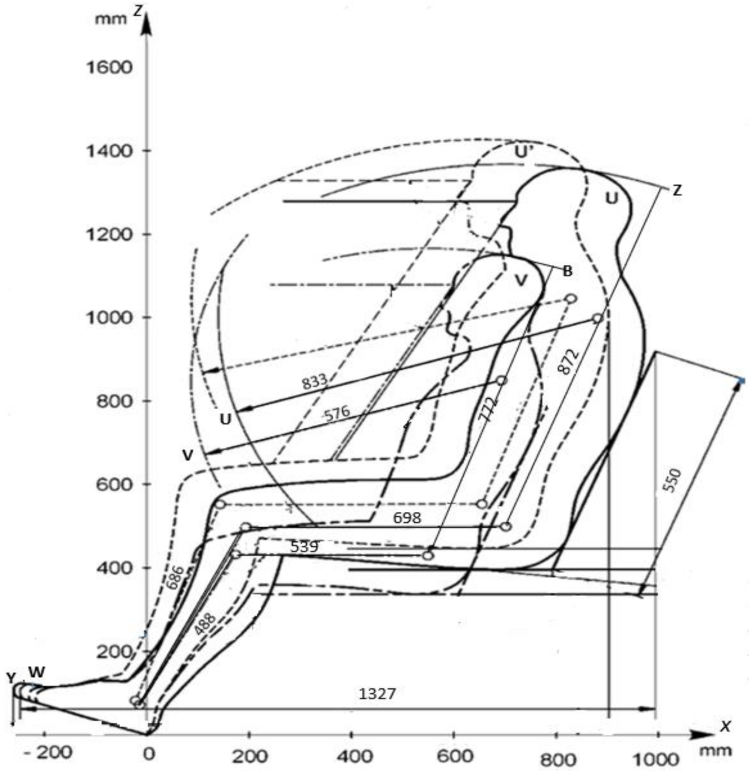

Figure 4.6 Space required for accommodation of the crane operator in the cabin, in the *x*-*z* plane for Serbian crane operators

The problem of the armrest height is reduced to a compromise between the requirements of standard ergonomics and the need to use both hands simultaneously. The ergonomics of arm movements during work requires the placement of the work object in the optimal haptic field, which means the field at elbow height with the upper arms hanging loosely next to the body, while the angle between the lower arm and the upper leg is 90º while forming arches in the horizontal plane of the left and right arm. The intersection of the fields of both arches directed towards the body is the optimal haptic field. Since in this case the position of the commands would obstruct the visual angle, they need to be separated into consoles, which also serve as armrests. The armrest and the seat should be adjustable, both in terms of height (*z*-axis) and length (*x*-axis). The position of the backrest with the commands is restricted by the maximum arm span, bearing in mind that the field within the optimal visible visual angle of 60° should be discarded. The next restriction refers to the depth of the chest, and hence the command should have a vertical axis on the straight-line *x*=500mm. The backrest provides support, which allows a seated person to transfer part of their upper-body load (even the gravity forces due to the head, arms and upper trunk) onto the lower part of the body (even to the backrest support itself), which reduces the intradiscal pressure and enhances the relaxation of the supporting back muscles (Karuppiah et al. 2012). The backrest position in relation to the seat surface is the result of two movements: movement due to differences in seating height and owing to the difference in the height of the bent elbow. In the same manner, utilizing critical models, the basic dimensions of the operator's seat are derived, in the *x-y* plane (Figure 4.7, all dimensions in mm), the dimensions of controller panels innfigureb 4.7 as given by Brkic et al., 2015.

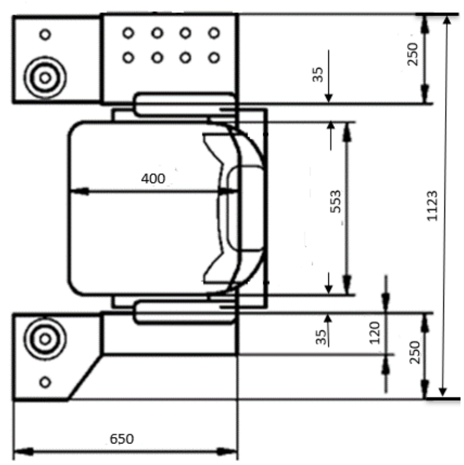

Figure 4.7 Space required for accommodation of the crane operator in the cabin, in the x-y plane for Serbian crane operators (Brkic et al., 2015)

The final minimal dimensions of the crane cabin, based on working requirements and appropriate comfort and safety, according to the proposed multivariate modeling procedure for Serbian crane operators, are 1327×1123×1926mm.

4.4.1.2 Multivariate Models Accommodation in Crane Cabin Interior Space for Libyan operators

With the same context as in section 4.4.1.1, the accommodation in the crane cabin interior space for Libyan operators is as illustrated in Figure 4.8, in which the minimal length of the *x*-axes amounts to 1203mm and the *y*-axes amounts to 1090mm (Figure 4.9), and the models U, V, Y, H, and W determine the cabin interior dimensions in the *x*-*z* plane. The arm span (horizontally) close to 465mm to overcome controllers reach, is determined from models Y and W (874-410=464), the vertical adjustment should be 125mm to minimizing the space required by operator U to move to position U'. The *z*-axes is 1838mm as given by model U and it represents the overall height of the cabin. The seat length and backrest, following the same criteria as Serbian operators, were determined at 400mm and 550mm respectively for models U and V. Model H determines the feet length on the negative side by 297mm on the *x*-axis.

The *y*-axis, as shown in Figure 4.9 (all dimensions in mm) is determined by hip breadth - the smallest breadth given by model D is 244mm and the largest breadth is model F (520mm). Therefore, the seat width is equal to 520mm. Also, the space required in the *y*-axis amounted to 1090mm. The final minimal model for Libyan crane operators that enhance safety and comfort is given at 1203mm×1090mm×1838mm.

In that manner, hypotheses:

H2 - Anthropometric measurements have mechanical and mathematical functions that determine all three dimensions of the space taking into account over 90% of the population and

H3 - On the basis of a multivariate model for anthropometric adaptation, it is possible to provide recommendations for dimensioning the interior of the crane cabin in such a way that comfortable and safe accommodation of the users is ensured

have been proved in the crane cabin interior space modeling problem.

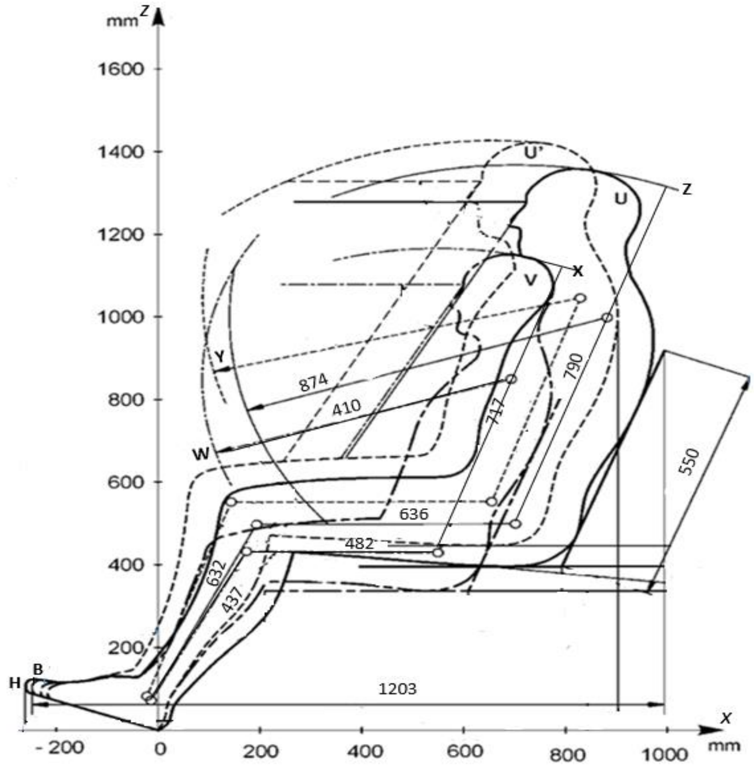

Figure 4.8 Space required for accommodation of the crane operator in the cabin, in the *x-z* plane for Libyan crane operators

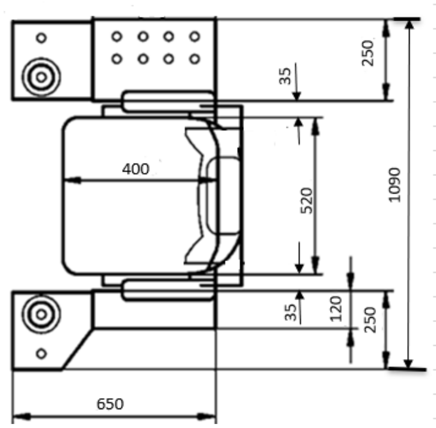

Figure 4.9 Space required for accommodation of the crane operator in the cabin, in the *x-y* plane for Libyan crane operators (Brkic et al., 2015)

4.4.2 Passenger Vehicles Drivers' Multivariate Models Accommodation in Interior Space

The interior space of lower and middle-class vehicles, which are the most popular on the market and the most complicated for driver accommodation, is determined by the end positions of the trajectories along which the end points of the anthropometric measurements move: the feet top, knees top and head apex of the driver under driving conditions. It is therefore logical to assume that the space needed for passenger accommodation is easily obtained by mapping the optimal space for the driver (Klarin et al., 2014). The mechanism of human anthropometric measurements can be viewed as analogous to a mechanical mechanism, similarly to crane cabin operators. Hence, the geometry and kinematics of movements are designed from the "*O*" point which is positioned in front of the accelerator pedal and is approximately fixed and is the origin of the coordinate system with three axes: *z*, *x*, *y*. The heel point, both for male and female drivers is shown in Figure 4.10.

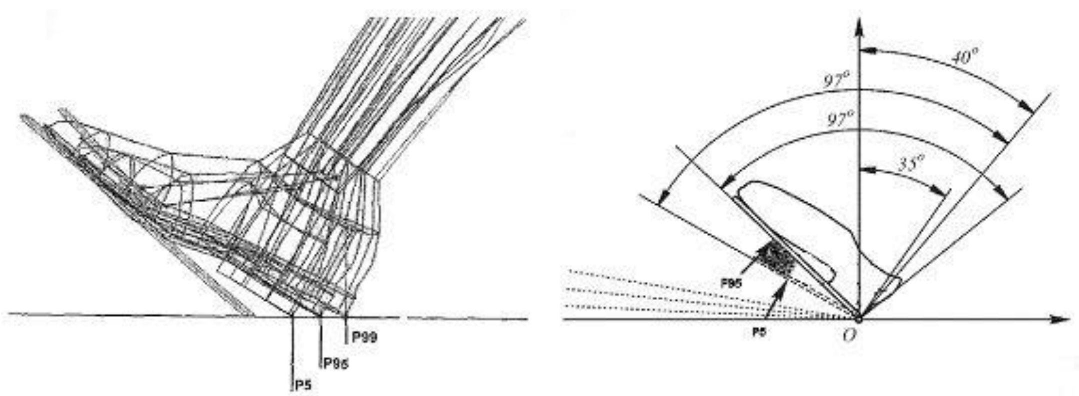

Figure 4.10 Heel point, both for male and female drivers (Brkić et al., 2015)

The position of the driver's anthropometric measurements under driving conditions is limited not only by the anthropometric measurements of dimensions, but also by the angles of movements. These angles are also subjected to the various effects of some lengths of individual anthropometric measurements. The passenger vehicle driver's posture defining joints are as shown in Figure 4.11.

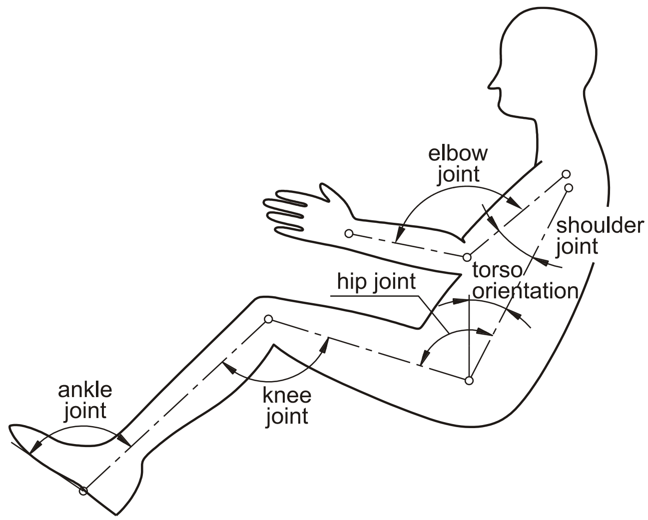

Figure 4.11 Posture defining joints 9 (Vogt et al., 2005)

Figure 4.12 shows additional limitations for angles not presented in Table 2.5, the angle between the feet and the car floor $\psi = 13^0 – 60^0$, the angle between the lower part of the upper leg and the horizontal $\beta = 5^0 – 12^0$ and the angle between the axis passing through the ankle and the knee joints and the vertical $\gamma + \beta = 15^0 – 37^0$. In our passenger car interior space design, the angle between the seat backrest and the vertical is considered to be the most approximate to the angle between the axis passing through the hip and the rotating shoulder joints.

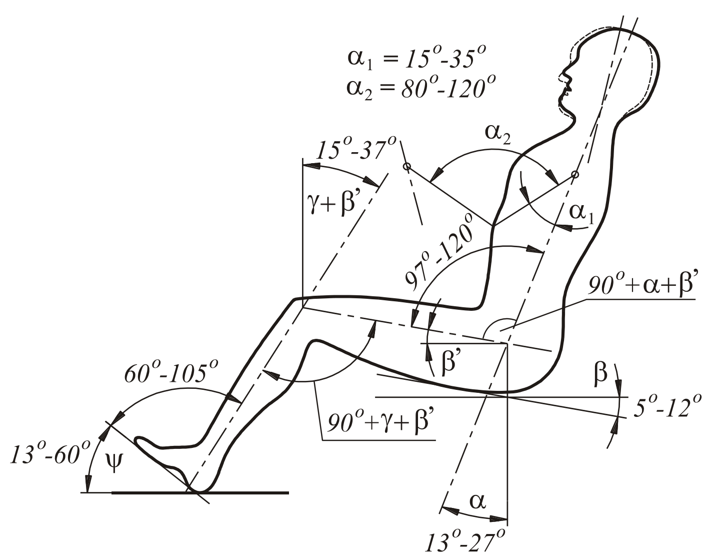

Figure 4.12 Optimal angles of the human body in a car (Klarin et al., 2008)

The most significant anthropometric measurements in the passenger car interior space design whose different individual measurements amount to the same total sum are sitting height, upper leg length and lower leg length (Klarin et al., 2008), while in the construction of space for feet accommodation the lower leg length differs from the upper leg length for their equal total (Klarin et al., 2009). Klarin et al., (2009) studied the latter issue in detail and demonstrated that very long legs can be accommodated in a comparatively limited space, and the impact of this fact on the width of the space for accommodating the driver was also shown.

The longer the legs and the higher the sitting height, the farther the hands are from the steering wheel. In this way, in addition to the limitations of optimal angles for the mechanism of anthropometric measurements accommodation, the limitation for moving the seat backwards along the *x*-axis is also obtained. The horizontal and vertical movement for the caricatured relations between the different upper and lower leg lengths, an example with a total of 800 mm, is presented in Figure 4.13.

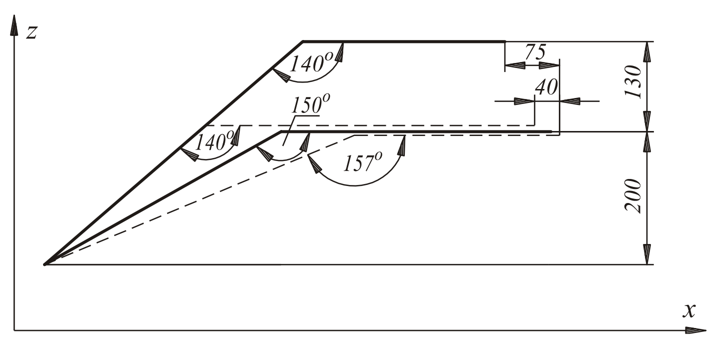

Figure 4.13 Horizontal and vertical driver seat movement in the example of upper and lower leg measurements

If the seat height is 200 mm and the lower leg lengths are 300 mm, 400 mm and 500 mm, the angle of the knee joint is 1400, 1500 and 1570, respectively, and the overall horizontal movement is approximately 40 mm. However, if the lower leg lengths are replaced, so that the lower leg length is 500 mm and the upper leg length 300 mm at the same angle of 1400, the seat height has to be raised by as much as 130 mm. That is why the lower leg length is a critical anthropometric measurement in the passenger car interior space height limitation. In that sense other variables and angles are not ignored but are not critical.

The key anthropometric measurements for the determination of the passenger car interior space height are the lower leg length and the sitting height of extremely large drivers and they are functionally interrelated as parts of the mechanism. Since the determination of the passenger car interior space height is equally influenced by the anthropometric measurements of the sitting height and lower leg length, the groups of the highest totals for these two anthropometric measurements will be observed for males.

The second limit for the range of vehicle adjustment will be obtained by means of methodology similar to that for determining the anthropometric measurements of the smallest female driver (Figure 4.10).

4.4.2.1 Serbian drivers' multivariate models accommodation in interior vehicle space

According to our original methodology, the minimal passenger car interior space for driver accommodation from the fixed point of the driver's heel in front of the accelerator pedal along the *x*-axis backwards should amount to 1500mm. The sitting driver posture horizontally represented by the largest value of models of lower leg, upper leg, foot length, and sitting height reduced by 152.4mm the distance between the back rest and center of the hip (Spasojević-Brkić, 2014a). The car floor-roof height along the *z*-axis should be 1230mm (200mm added to model G for sitting height as tolerance between the driver's head and ceiling, Klarin et al., 2009). The distance for feet accommodation along the x-axis from the zero point to the shoe toe is 310mm, on the *x-z* planes as illustrated in Figures 4.14. The *y*-axis illustrated in Figure 4.15, represented by model F (with the largest shoulder width), provides the minimal width, which is 561mm (*x-y* plane). The required minimal space for the Serbian drivers amounts to 1500×561×1230mm.

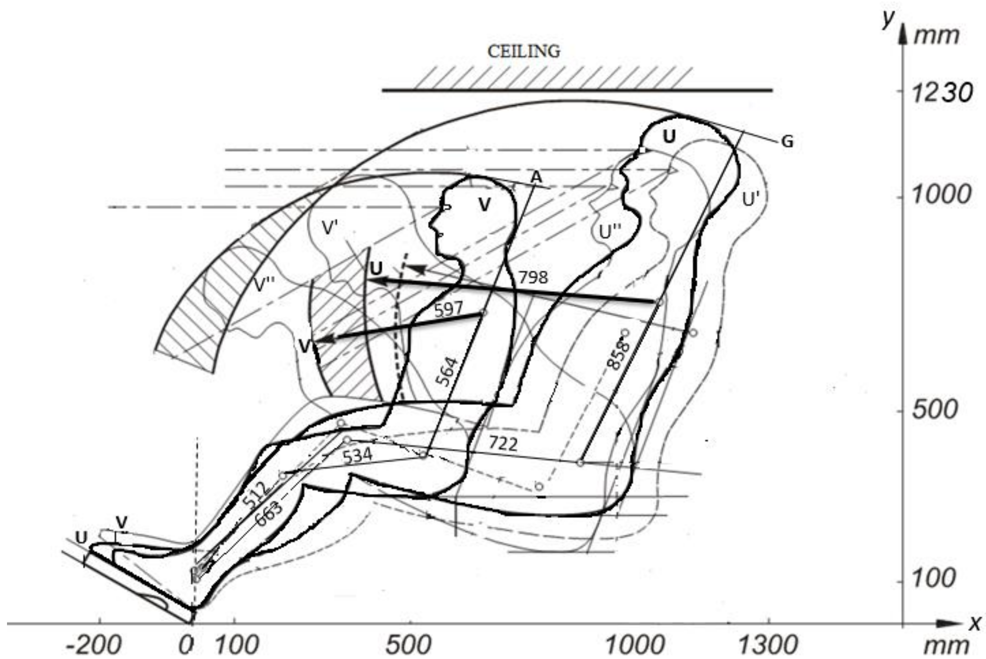

Figure 4.14 Space required for accommodation of Serbian car drivers – *x-z* plane

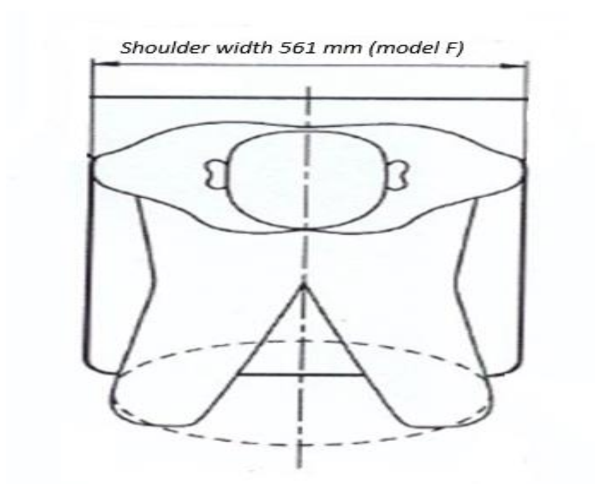

Figure 4.15 Space required for accommodation of Serbian car drivers – *x-y* plane

4.4.2.2 Libyan drivers' multivariate models accommodation in interior vehicle space

As a result of anthropometric multivariate modeling, the space of vehicle modeling for Libyan drivers can be defined by models U, V, D, E, F and H. Figure 4.16 illustrates the *x-z* plane, the minimal dimension on the *x*-axes is 1400mm, and the *z*-axes is 1155mm (just as in section 4.5.2.1). The arm reach is determined by model E and amounts 805mm, while foot accommodation is given by model H (298mm) along *x*-axes. The *y*- axis determined by model F is 591mm and represents the largest width as illustrated in Figure 4.17 (*x*-*y* plane). The minimal space required for Libyan drivers amounts to 1400×591×1155mm.

In that manner, hypotheses:

H2 - Anthropometric measurements have mechanical and mathematical functions that determine all three dimensions of the space taking into account over 90% of the population and

H3 - On the basis of a multivariate model for anthropometric adaptation, it is possible to provide recommendations for dimensioning the interior of the passenger car in such a way that comfortable and safe accommodation of the drivers is ensured

have been proved in the passenger car interior space modeling problem.

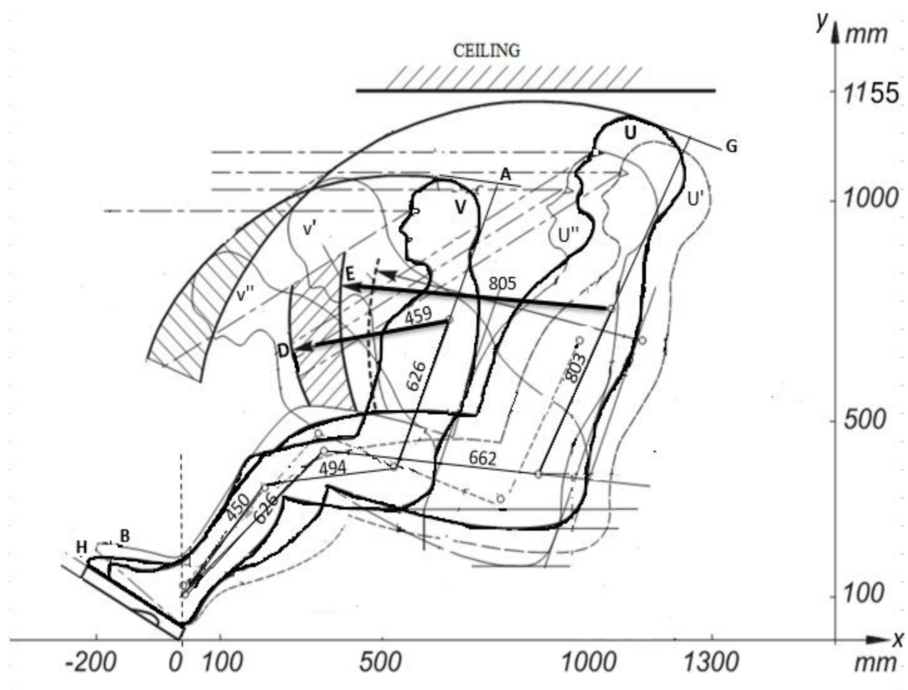

Figure 4.16 Space required for accommodation of Libyan car drivers – *x*-*z* plane

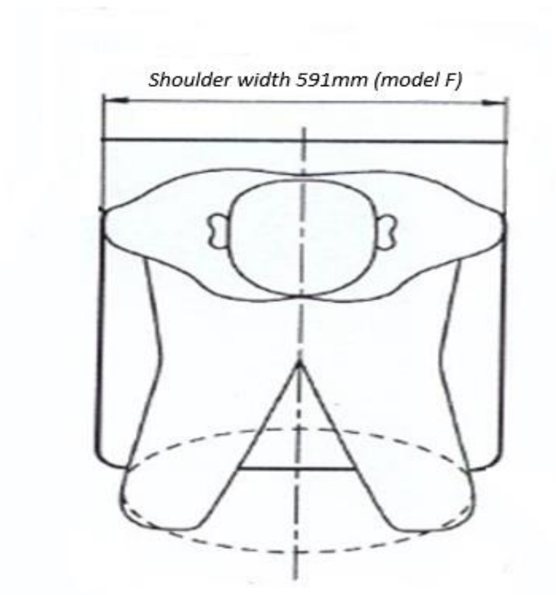

Figure 4.17 Space required for accommodation of Libyan car drivers – *x*-*y* plane

5 Discussion and conclusion

5.1 Discussion

One of the main issues of ergonomics in design is how to control the anthropometric variation, in order to set proper product design for multi users, to ensure safety, comfort, and enhance individual performance.

Therefore, this study has focused on the root of such issues (anthropometric variations), generated from nationality, occupation, and gender. The multivariate modeling approach is adopted in order to accommodate such variations, developing a convenient design for users, which is the main aim of this research along with enhancing the safety and comfort for operators and drivers of machines and vehicles.

This research sought to optimize the interior space of vehicles and driven machines (crane cabin), through the multivariate approach which is not widely applied as compared to the other anthropometric approaches such as the univariate (percentile) approach. Only a few authors (Bittner, 1987; Gorden et al., 1997; Kolich et al., 2004; Nadadur and Parkinson, 2012; Guan et al., 2012; Brkic et al., 2015) have used the multivariate approach under various concepts. Percentiles have revealed shortcomings in cases of multi dimensions and can be criticized when there is more than one dimension in design (Guan et al., 2012), since a large percentage of population is not covered – on average this amounts to 30% depending on the number of dimensions involved (Porter et al., 1993).

The interior space of vehicles has not been researched enough (Klarin et al., 2011) and there are problems in the current vehicle interfaces often as result of non-updated measurements in standards (Chung and Park, 2004). The driven cabins (i.e. crane cabin) have deficiencies in interior cabin design too, since the current design results in discomfort followed by the fatigue, backpain, neck pain of operators (Zunjic et al., 2015; Cote et al., 2009; Burdorf and Zondervan, 1990; Bonvezi et al., 2002), poor visibility, limited cabin space and poorly designed cabins (Kittusamy and Buchholz, 2004).

Moreover, the anthropometric measurements play a vital role in design and should be continually updated (Parkison and Reed, 2006; Essdai et al., 2017), since these measurements change over time (Klarin, 2011), and are affected by gender, nationality, and occupation (Spasojevic et al., 2014a; Fatollahzadeh, 2006; and Guan et al., 2012). This study seeks to overcome and solve these issues that have not been not solved in previous research. The root causes of the shortcomings in interior vehicles and crane cabins design as surveyed in the literature, can be summarized in the following three points, which are addressed in this research by multivariate models:

1- The effect of nationality, gender, and occupation is not considered enough, in the current anthropometric design.
2- The conventional approach (percentile) in modeling did not accommodate the entire targeted population when the design included multi-dimensions (more than one).
3- The working standards show deficiencies in the current anthropometric design as compared to the updated anthropometric measurement models.

The effect of gender, nationality, and occupation has been statistically studied and analyzed herein, and the regression and correlation analysis show different patterns with different correlation strength between measurements, exploring the relationships between them for the tested samples. Such different patterns of relationships, are revealed and quantified through a comparison between means (*z*-test). The samples are tested on the bases of nationality (Serbian male vs. Libyan male drivers, Serbian crane operators vs. Libyan crane operators, Serbian males vs. Libyan males, Serbian female drivers vs. Libyan female drivers, and all Serbian participants vs. all Libyan participants) and results show absolute significant differences between the examined mean values (Table 3.37) and reveal that Serbian participants are larger than Libyan participants in dimensions other than shoulder width, while Libyan female drivers are larger in body weight and hip breadth than Serbian female drivers. Such differences and relationships between the anthropometric measurements are beneficial to designers.

The effect of occupation (Serbian male drivers vs. Serbian crane operators, and Libyan male drivers vs. Libyan crane operators) and gender (Serbian female drivers vs. Serbian male drivers, and Libyan male drivers vs. Libyan female drivers), shows that gender has more effect than occupation (Table 3.38). The results are in line with those given in Spasojević-Brkić et al. (2014a) and Fatollahzadeh (2006).

This survey is based on the Serbian sample of 83 crane cabin operators and the Libyan sample of 50, that means 133 in total. Table 5.1 shows cabin interior space dimensions, those samples were considerably larger than all of the samples used so far and were composed of two different nationalities. Brkic et al. (2015) used a sample of 64, Burdorf and Zondervan (1990) used a sample of 33, Bonvenzi et al. (2002), used 46, Ray and Tewari, (2012) used 21 participants. The aim was to assess the operators not only according to the extreme measurements, as when using percentiles, but also according to extreme combinations of different measurements.

This was achieved through representative models obtained through use of both PCA and the 5th and 95th percentile models. Those models were later used to design the interior of a crane cabin on the basis of kinematic mechanism behavior and the dimensions of interior space. The percentiles models were obtained inside the interior space using the multivariate approach. It was confirmed that both the use of updated anthropometric data of crane operators and vehicle drivers and the use of the multivariate modeling approach have a great effect on improving the workplace design, resulting in comfortable accommodation and enhanced safety. In accordance with the results of this study, the most commonly used directives derived from the available standards should be partially corrected in order to solve today’s crane operators’ problems.

These survey results show that different model dimensions are obtained from Serbian and Libyan data, and such differences related to the different nationality of the participants.

A comparison of these results and the results of a survey conducted by NASA (2001), shows that the multivariate approach model applied here provides more comfort to users and shows the importance of updating anthropometric measurements together with the necessity of conducting a survey based on crane operators’ data, not on the general population.

Table 5.1 Crane cabin interior space dimensions (all dimensions in mm)

Dimension	Serbian sample	Libyan sample
Seat vertical adjustability	170	125
Seat width	553	520
Seat depth	400	400
Backrest height	550	550
Seat horizontal adjustability	260	465
Overall cabin dimensions	1327×1123×1926	1203×1090×1838

Both the interior cabin space dimensions (Serbian and Libyan, table 5.2) are significantly different from contemporary cabins with respect to the standard ISO 8566-5 (1992) that identifies a space of 1300×900×1600mm and those in Brkic et al. (2015) as shown in Table 5.2. It can be seen that the largest height (the z-axes) of operators for the Serbian population is 1926mm and for the Libyan operators is 1838mm, while ISO 8566-5 (1992) gives1600mm. Also, the cabin width (the y-axes) is 900mm according to ISO 8566-5 (1992), while according to this study the required width for Serbian operators amounted to 1123mm and for Libyan operators to 1090mm. In the same manner for cabin length (the x-axes), the dimensions are 1327 and 1203mm for Serbian and Libyan operators respectively, whereas ISO 8566-5 (1992) gives 1300mm. Table 5.3 shows the seat dimensions of the crane cabin as compared to the standards and to previous findings (Brkic et al., 2015).

Table 5.2 Comparison between study results of crane cabin interior space dimensions and ISO 8566-5 (1992) (all dimensions in mm)

Study results		ISO 8566-5 (1992) crane cabin dimensions	Brkic et al., 2015 (Serbian operators *n*=64)
Serbian crane operators	Libyan crane operators		
1327×1123×1926	1203×1090×1838	1300×900×1600	1150×1095×1865

Table 5.3 Summarized results of this survey results versus NASA (2001) and ISO 8566-5 (1992) specifications of crane seat dimensions (all dimensions in mm)

Seat dimensions	(Center–NASA, 2001)	ISO 8566-5 (1992)	Brkic et al. (2015)	*Multivariate modeling approach*	
				Serbian sample	*Libyan sample*
1-Backrest height	381-508	381-508	550	*550*	*550*
2-Backrest width (F)	300 -360	300-360	380	*400*	*400*
3-Seat height adjustment	152.4	-	-	*170*	*125*
4-Seat width (B)	450-510	450-510	490	*553*	*520*
5-Seat depth (C)	-	-	400	*400*	*400*

The passenger vehicle interior space was surveyed using a Serbian sample of 1197 and a Libyan sample of 400 male and female drivers. The interior space dimensions of the vehicle for Serbian drivers amounted to 1500×561×1230mm, and for Libyan drivers 1400×591×1155mm. The multivariate modeling approach reveals more accurate convergent values of hip breadth as compared to previous studies as shown in Table 5.4. The multivariate modeling approach results in greater comfort compared to all previous studies other than the Maertens (1993) study.

Table 5.4 Comparison between percentile and multivariate approach for hip breadth

Reference	Hip breadth(mm)	Clarification	*Multivariate Modeling approach (current study 2018)*	
			Serbian sample	Libyan sample
Chaffin and Anderson (1991)	457	*n*= 143 women aged 50-64 years 95th percentile.	*n*=1197 drivers (193 women and 1004 men) 486mm (model X)	*n*=400 drivers (50 women and 350 men) 502mm (model X)
Schneider et al., (1985)	439	*n*= 25 males of driver anthropometry 95th percentile by stature and weight.		
Grandjien (1980)	480	Recommended as minimum clearance at the hips to accommodate large females with clothing and an allowance for leg splay		

Table 5.4 Continued.

Maertens (1993)	500	Authors do not specify the position at which this dimension is measured, nor the sample size		
Gorden et all., 1989	432	95th percentile-female		

5.2 Conclusions and recommendations

This dissertation described research that studied the anthropometric human variations and how to model it, which is one of main issues in ergonomic design that is important to ensure user comfort, safety, and enhance individuals' performance, in light of producing products that better fit multi-users. The aim was to develop a multivariate model that includes a greater number of anthropometric variations than the percentile model does in order to resolve the anthropometric measurements variations in vehicles and crane cabins with better accommodation.

In addition to this main aim, the research included Libyan anthropometric data, not yet surveyed in the literature, to compare it to the Serbian nationality, which has been researched before using the univariate percentile modeling approach. The research hypothesis based on these two main ideas (affect of nationality, gender, and occupation, and fact that there is a significant difference in anthropometric measurements) has been proved. Also, it has been shown that the anthropometric measurements of the two different nationalities (Libyan and Serbian) present significant differences depending on gender, occupation and nationality and that the multivariate approach for modeling enables the construction of a precise model that covers a larger part of population and consequetivly enables better accommodation of drivers and crane operators.

Chapter two has provided reflective insights into the evolution of approaches that are still used today to address ergonomic issues in interior vehicle and crane cabin space. A large number of previous studies have shown that anthropometric data are essential when designing for target users (drivers or operators). These authors have used various methods to model with the percentile approach, as it is the most widely applied, and approaches such as the anthropometry range metric (ARM) and the multivariate modeling techniques - stepwise, linear regression and artificial neural network, etc. are much less frequently applied. The surveyed literature shows that up until now there has been no optimal methodology found and recommended for modeling. Due to that fact, in order to optimize the interior space of vehicles or crane cabins, there are factors / considerations effecting the anthropometric design, concluded from the surveyed literature that were not surveyed enough nor analyzed and quantified, and such factors are in this survey considered as starting point:

1-Nationality, gender, and occupation have an effect on anthropometric measurements.

2-The use of general population measurements is not convenient to a specific user's design, i.e. the use of anthropometric data of the general population for crane operator cabin design.

3-Available standards in the field are partially not compatible to up-to-date measurements.

Chapter three shows statistical analysis of the differences between the anthropometric measurements that relate to the gender, nationality, and occupation of the drivers and crane operators. In order to verify the stated hypothesis H, data was collected from the target population, Serbian drivers (male and female), Libyan drivers (male and female), Serbian crane operators (male), and Libyan crane operators (male). The regression and correlation analyses were performed to define the interrelationships between anthropometric measurements. Also, using hypothesis testing in the differences between sample mean values enabled exploring the relations and quantifying the differences. Most of the samples (male drivers, female drivers, males, crane operators, and all participants) show that there are significant differences between them. Only the shoulder width has no significant difference between Serbian and Libyan drivers, and the Libyan female drivers have a larger body weight than the Serbian female drivers. All other measurements in the Serbian participants are larger than the Libyan participants. In that manner, the results prove the posted hypothesis together with the significance and influence of gender, occupation and nationality.

Chapter four presented in detail the new, original modeling approach, which is based on PCA and accomplishes a 95% ellipsoid inclusion of the population. The original model is presented through 14 points that represent human models and are extracted from three main components by determining the ellipsoid axes in terms of 95% inclusion, the number of PCs, and the sample size. It is important to note that the percentile models (5^{th} and 95^{th}) fall inside the boundaries of the proposed multivariate model, which leads to the conclusion that the followed multivariate methodology has a wider inclusion/accommodation than the percentile method in the case of multidimensions.

The extracted models of crane operators as compared to recommendations in available standards and the literature in the field (Chaffin and Anderson, 1991, Schneider et al., 1985, NASA, 2001 and ISO 8566-5, 1992) show that the updated anthropometric measurements modeled by the multivariate approach define more comfort space. The conclusion is that the proposed methodology is recommended in cases of multidimensions and in cases of multi characteristics of users that vary in gender, occupation, and nationality, which is most frequently the case in today's products and markets. The continual improvements in terms of the anthropometric measurements update and remodeling use, and the approach proposed here, is recommended in order to efficiently enhance safety, comfort, and the individual performance of users.

5.3 Limitations of the study

By reviewing the available literature in this field of research as well as by analyzing the results of the research obtained using the selected methodology in the framework of this dissertation, it can be noticed that the obtained results relate to the previous researches, but also significantly complement the existing results, specifically the need for better ergonomic adaptation of vehicles and machines for operators.

In addition to undoubtedly significant contributions, this research has certain limitations which do not diminish the significance of it. The survey included populations from Serbia and Libya, whose differences are statistically proven. It is expected that other nationalities are to be included in the future research. Also, the newly established model can be applied to all other three-dimensional technical means. Although this dissertation represents not a small step forward in the field, the sample size could be larger and include additional nationalities. Accordingly, this is recommended in future research, although it is understood that this is not easy to accomplish. The lack of available or at least updated information of anthropometric data on national levels is a constraint in general in this field of research. These limitations are recommendation for further research in the field.

5.4 Proposal for further research

Future research should go beyond this topic into the same field to cover issues of noise, vibration, temperature, luminance, as well as on vehicle/machine displays and on the controllers with respect to human interface, posture, and user feedback. This research could also be extended to consider the nutrition effect on anthropometric design, which is not surveyed enough in literature.

5.5 Achieved scientific contribution

This dissertation undoubtedly expands the existing knowledge and represents scientific contribution in the field. The achieved scientific contribution of the doctoral dissertation "Multivariate model for anthropometric design of the interior space of vehicles and machines" ("Multivariate Model for Vehicles" and "Interior Space" Anthropometric Design) reflects in the following:

- Establishment of a modern database of anthropometry of certain populations based on the principles of static anthropometry and statistical confirmation of the present demographic differences.
- Defining an original integral research approach based on extreme sizes of pairs/arrays of anthropometry to form an integral model of anthropometric space optimization.

- Development of an integral multivariate model for the anthropometric adaptation of the operator in the cabin of the vehicle/machine of adequate coverage and accuracy and its experimental confirmation.
- Establishment and implementation of the design procedure for the minimum space required for the driver/operator.
- Creating a platform for wider application of research models in other contexts, as well as the possibility of further development and improvement of the model.

Part of the doctoral dissertation contributions is verified in works published in international journal on the JCR/SCI lists, in chapters in monographs and at international conferences.

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BIOGRAPHY – AHMED ALI ESSDAI

Ahmed Ali Essdai, was born on April 21, 1964. in Zliten, Libya, where he has finished elementary and high school. The University of Benghazi, Libya, he has enrolled in the 1982/1983 school year at the study program of Industrial Engineering, and completed the school year 1987/88. During school year 2003/2004, he enrolled in Master Studies at Lybian academy, Tripoli, in the study program Engineering Project Management. He completed his master's degree in 2006 by defending master's thesis entitled "Improving the Quality System of Materials Procurement in the Iron and Steel Company". Doctoral studies he has entered during school year 2013/2014. at the Faculty of Mechanical Engineering, University of Belgrade, after the diploma recognition. He works at the Department of Industrial Engineering, Misurata University, Libya, and is engaged in Ergonomics, Production Systems, System Simulations, Project Management, Statistics and as a Mentor for Final Studies in Basic Studies. In the period 2009-2011. During proffesional carreer, he worked as the director of the procurement department at INCOMA, Misurata, Libya. In the period 2007-2008. He was employed for research development in the Industrial Engineering Service of LISCO, Misurata, Libya, and from 1989-2006. He worked in the same company in inspections department. He uses MS Office, CATIA and SPSS software packages and speaks Arabian and English.

List of publications:

1. Essdai, A., Spasojević Brkić, V. K., Golubović, T., Brkić, A., & Popović, V. (2018). Crane cabins' interior space multivariate anthropometric modeling. Work, 59(4), 557-570.
2. Essdai, A., Brkic, V. S., & Veljkovic, Z. (2018). Serbian and Libyan Female Drivers' Anthropometric Measurements in Light of Third Autonomy Level Vehicles. In International Conference on Applied Human Factors and Ergonomics (pp. 56-68). Springer, Cham.
3. Essdai A., SpasojevićBrkić V. &Brkić A. (2017). Ergonomic multivariate modelling of Libyan drivers accommodation in passenger cars. Technical faculty of Bor, University of Belgrade. XIII INTERNATIONAL MAY CONFERENCE ON STRATEGIC MANAGEMENT, 51-59.
4. Brkic, V. S., Putnik, G., Veljković, Z. A., Shah, V., & Essdai, A. (2017). Interfaces for Distributed Remote User Controlled Manufacturing as Collaborative

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Прилог 1.

Изјава о ауторству

Потписани- Ахмед Али Ессдаи

број индекса _Д47/2013

Изјављујем

да је докторска дисертација под насловом

“МУЛТИВАРИЈАНТНИ МОДЕЛ ЗА АНТРОПОМЕТРИЈСКО ПРОЈЕКТОВАЊЕ УНУТРАШЊЕГ ПРОСТОРА ВОЗИЛА И МАШИНА“

“MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESI

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- резултат сопственог истраживачког рада,
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- да су резултати коректно наведени и
- да нисам кршио/ла ауторска права и користио интелектуалну својину других лица.

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У Београду, 23.09.2018

Прилог 2.

Изјава о истоветности штампане и електронске верзије докторског рада

Име и презиме аутора Ахмед Али Ессдаи.

Број индекса Д47/2013

Студијски програм Докторске студије

Наслов рада “МУЛТИВАРИЈАНТНИ МОДЕЛ ЗА АНТРОПОМЕТРИЈСКО ПРОЈЕКТОВАЊЕ УНУТРАШЊЕГ ПРОСТОРА ВОЗИЛА И МАШИНА“ - “MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESIGN“

Ментор Весна Спасојевић Бркић

Потписани/а

Изјављујем да је штампана верзија мог докторског рада истоветна електронској верзији коју сам предао/ла за објављивање на порталу **Дигиталног репозиторијума Универзитета у Београду.**

Дозвољавам да се објаве моји лични подаци везани за добијање академског звања доктора наука, као што су име и презиме, година и место рођења и датум одбране рада.

Ови лични подаци могу се објавити на мрежним страницама дигиталне библиотеке, у електронском каталогу и у публикацијама Универзитета у Београду.

Потпис докторанда

У Београду, 23.09.2018

Прилог 3.

Изјава о коришћењу

Овлашћујем Универзитетску библиотеку „Светозар Марковић“ да у Дигитални репозиторијум Универзитета у Београду унесе моју докторску дисертацију под насловом:

“МУЛТИВАРИЈАНТНИ МОДЕЛ ЗА АНТРОПОМЕТРИЈСКО ПРОЈЕКТОВАЊЕ УНУТРАШЊЕГ ПРОСТОРА ВОЗИЛА И МАШИНА“

“MULTIVARIATE MODEL FOR VEHICLES` AND MACHINES` INTERIOR SPACE ANTHROPOMETRIC DESIGN“

која је моје ауторско дело.

Дисертацију са свим прилозима предао/ла сам у електронском формату погодном за трајно архивирање.

Моју докторску дисертацију похрањену у Дигитални репозиторијум Универзитета у Београду могу да користе сви који поштују одредбе садржане у одабраном типу лиценце Креативне заједнице (Creative Commons) за коју сам се одлучио/ла.

1. Ауторство

2. Ауторство - некомерцијално

3. Ауторство – некомерцијално – без прераде

4. Ауторство – некомерцијално – делити под истим условима

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(Молимо да заокружите само једну од шест понуђених лиценци, кратак опис лиценци дат је на полеђини листа).

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