RIGA TECHNICAL UNIVERSITY

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IMPROVEMENT OF METHODS FOR EVALUATION OF ANTHROPOMETRIC FIT AND ERGONOMICS OF CLOTHING

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Materials Science and Applied Chemistry
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science (Ph. D.), the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on 26 May 2022 at 14:00 at the Faculty of Materials Science and Applied Chemistry of Riga Technical University, 6 Ķīpsalas Street, Room 117.

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I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science (Ph. D.) is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Eva Lapkovska ……………………………. (signature)
Date: ………………………… 2022

The Doctoral Thesis has been written in Latvian. It consists of Introduction, 4 chapters, Conclusions, 74 figures, 14 tables, and 2 appendices; the total number of pages is 161, including appendices. The Bibliography contains 221 titles.

CONTENTS

INTRODUCTION

In the supply of special-purpose clothing (work wear, protective clothing, uniforms), a problem appears, namely, the product the user receives does not comply with his morphology, the task to be performed, and does not correspond to the level of scientific and technical development; the situation in Latvia and abroad shows the lack of an appropriate policy for the obtainment of ergonomic solutions. As a result, the supply of clothing that is not suitable for the user in principle leads to inefficient supply, financial loss, wasteful use of resources and environmental damage. It is due to several aspects, such as the lack of anthropometric data on the population or at least a sufficient sample dataset size and the fact that existing data (used in production) are most often out of date. Acquisition of new data requires resources that neither manufacturers nor customers have. Thus, the systematization of data lies to the manufacturers: the customer orders special-purpose clothing and equipment (for example, uniforms), giving only a rough insight into the anthropometric systematization, and the manufacturer tries to adapt the production to it at best. Even if we assume that the customer and the manufacturer agree on the anthropometric features of the sample dataset, the whole process from procurement to supply is not transparent – the manufacturer uses previously approbated patterns about which the input data is no longer available. Finally, the user receives clothing that is not compliant but also cannot justify the non-compliance (because of lack of expertise). Moreover, if the consumer of everyday clothing has the choice not to wear inappropriate clothing, then those working in special services do not have that choice – in order not to endanger their health and life, staff must wear the required special clothing and personal protective equipment (PPE) performing duties following labour protection norms. All the aspects mentioned above do not make it easier to solve the problem globally – certain parameters of clothing compliance can be assessed statistically, provided that the data (such as clothing control measurements and human body characteristics) are sufficient and reliable. At the same time, however, there is a lack of assessment approaches that consider specific situations and include the subjective assessment of clothing wearers. Promoting the synergy between the wearer, the customer and the supplier and basing evaluation procedures on the specifics of a particular sector is an approach to facilitating the supply of anthropometrically fit and ergonomic special-purpose clothing.

The developed method – algorithm for assessing the anthropometric fit and ergonomics of clothing is described in the Doctoral Thesis. The topicality of the research is substantiated, the aim and tasks of the work are formulated, novelty and practical significance are described, theoretical and practical results are explained, and the approbation of the method is described. The Thesis describes the aspects of clothing design intending to identify the problems at different stages of the process and analyze the causal relationships and consequences of placing anthropometrically ill-fit and non-ergonomic clothing on the market. It has been concluded that comprehensive methods for assessing the anthropometric fit and ergonomics of clothing are needed to test the effectiveness of a set of theoretical and practical techniques. The components of the concept of clothing conformity, the methods of assessing the anthropometric fit and ergonomics of clothing, and the recommendations introduced for such evaluation in the industry standards are considered in the Doctoral Thesis. As a result of the analysis, an understanding of the principles of determining clothing conformity has been developed, which allows defining the elements of the method – algorithm for assessing the anthropometric fit and ergonomics of apparel. The main problem in the existing approach is the separation of the descriptions of known practices and procedures – their interaction and flow are not shown; thus, there is a lack of synergy to achieve results. Therefore, there is a need for a set of practical principles for assessing the anthropometric fit and ergonomics of clothing, facilitating both the parties' understanding of the parameters of appropriate clothing and their evaluation and decision-making process.

Based on the performed research and the author's experience in the implementation of practical research on clothing sizing problems, a method for assessing the anthropometric fit and ergonomics of clothing has been developed with the aim to promote the efficiency of appropriate clothing selection processes. The concept of this method is outlined, its implementation and operation are described, specifying the structure and elements of the algorithm – parts of the process. The approbation of the method is described, and the results of validation experiments with evaluation are included.

Topicality of the Doctoral Thesis theme

The topicality of the Doctoral Thesis is related to the challenges of the clothing manufacturing industry in supplying various consumer populations with appropriate clothing. The ability to choose reasonable clothing design parameters to create corresponding clothing for a target group is affected by available data on anthropometric profiles of wearers, understanding of the structure of sizing systems, knowledge of fabric properties, design techniques used, understanding of clothing wearing condition specifics, and access to evaluation of consumers about product suitability.

The design of a wide and varied range of special-purpose clothing, including protective clothing, workwear, sportswear, and other special needs, as opposed to everyday fashion items, is purposefully based on the wearer's specific needs. Key conformity indicators for such clothing include functional adequacy, anthropometric fit, and ergonomics, ensuring the wearer's ability to perform daily duties or other activities.

The world's largest buyers of functional clothing are state-level institutions, whose officials may not be sufficiently informed about the real needs of staff and the challenges of the clothing aspect in the work environment on the one hand and technological advances on the other. The situation is becoming clear that those working in procurement systems at the interior and defence structures cannot supply and provide really up-to-date, ergonomic, and scientific solutions. Procurement of equipment not suitable for the target group can lead to economic losses at a national level and the creation of unusable and disposable products, thus contributing to significant resource consumption, and thus to environmental damage. The current practice and experience show that the representatives of various state structures turn to external experts to promote the improvement of uniform supply and improve the system of personal protective equipment (the Doctoral Thesis on the improvement of the soldier's personal protection system was defended in 2014 and includes recommendations for the long-term stabilization of equipment provision and NAF supply[1]). Therefore, a practical set of principles for assessing the anthropometric fit and ergonomics of clothing is needed, facilitating the understanding of the parties involved about the parameters of appropriate clothing, their evaluation, and the decision-making process.

Goal of the Doctoral Thesis:

The Doctoral Thesis aims to develop a method for the preventive evaluation of the anthropometric fit and ergonomics of clothing.

Research tasks

- To identify and analyze aspects of clothing design, their inter-relationship and importance in ensuring the anthropometric fit and ergonomics of clothing.
- To summarize and analyze the components of the clothing conformity concept and their evaluation methods.
- To study and comparatively analyze standardized methods for assessing the anthropometric fit and ergonomics of clothing.
- To develop an algorithm of the method for evaluating the anthropometric fit and ergonomics of clothing based on research-based practical principles.
- To examine and approbate the operation algorithm of the developed method – to evaluate the anthropometric fit and ergonomics of certain special-purpose clothing for further recommendations for improving the procurement procedure.

Object and subject of research

The **object** of the research of the Doctoral Thesis is the evaluation of anthropometric fit and ergonomics of clothing for effective selection of clothing to ensure its functionality. The research **subject** is a method – algorithm (system of principles), which allows directing the combination of objective and subjective evaluation methods of clothing and the convergent properties of the results of their application into practical principles for determining the anthropometric fit and ergonomics of clothing.

Research methods and tools

General theoretical research methods (analysis of scientific literature, documentation), bottom-up and top-down problem analysis methods, empirical research methods (observations and experiments), surveys, interviews, applied mathematics, laser scanning methods, data acquisition with optical triangulation, computer graphics methods.

Anthropometric data were obtained with the human body 3D scanning device VitusSmart XXL® (Human Solutions Group GmbH) with the AnthroScan data processing system and traditional anthropometric instruments – anthropometer, caliper, scales, goniometer, and tape measure.

[1] Šitvjenkins, Igors. Enhancement of the Combat Individual Protection System. Doctoral Thesis. Riga: [RTU], 2014. 265 p.

Scientific novelty of the Doctoral Thesis

- A new clothing conformity evaluation method has been developed and proposed – an algorithm demonstrating the application of a systematic combination of clothing assessment methods in developing real principles for determining the anthropometric fit and ergonomics of clothing.
- A study validating the operation of the developed algorithm (method) for the conformity evaluation of special-purpose clothing has been implemented. The structure of the developed algorithm provides an opportunity to develop various procedures on different clothing evaluation procedures based on its principles, supplementing the existing structure or combining other evaluation methods.

Practical significance of the research

- The developed and implemented method for evaluating anthropometric fit and ergonomics of clothing is a practical contribution both to the improvement of processes for supplying certain groups of clothing wearers with special-purpose clothing and to the development of a new (new problem-solving) special-purpose clothing or personal protective equipment development process.
- The structure of the method allows a systematic identification of the shortcomings of clothing compliance and make decisions for its improvements.
- The algorithm is repeatable and adaptable – its variations can be used to evaluate a different assortment of clothing.
- The developed principles by summary reproduction in informative posters promote the ability of users (wearers, supply services) to use the method of conformity assessment of clothing in everyday working conditions.

Thesis to be defended:

- The developed method – algorithm – allows to identify anthropometric fit and ergonomic shortcomings of clothing, analyze them and introduce improvements in the procurement procedure documentation.
- The developed algorithm promotes the understanding of consumers (wearers, supply services) about the regulation of industry standards, the adaption of procedures to a specific field and/or the level of ergonomics and the techniques of ergonomics required for the case, and thus the objectivity of decision-making in preventing anthropometric non-compliance and non-ergonomics of clothing.

Approbation of the Doctoral Thesis:

The research results carried out within the development framework of the Doctoral Thesis were presented in international scientific publications (a total of 22 publications, of which 13 are indexed in SCOPUS, are cited in 25 documents; the applicant's h-index = 3), and have been reported at local and international conferences.

During the development of the Doctoral Thesis, research was initiated for the Latvian National Armed Forces contingent within the framework of the EU European Regional Development Fund, Interreg BSR Programme project "Smart and Safe Work Wear" (SWW)

R#006. During this project, procedures of anthropometric fit evaluation of uniforms were developed based on measurements of 150 people[2].

The result of the work was approbated by assessing the anthropometric fit and ergonomics of the Latvian SFRS (State Fire and Rescue Service) daily wear duty-uniforms, attracting a staff's sample dataset, competent Service contact persons and procurement officials. Representatives of the institution have expressed interest in the applicability of the method for the improvement of clothing supply processes. They have expressed support for introducing the method in the work of the Service (see Letter of support in Appendix 1 of the Doctoral Thesis).

The specific result of the work (development of special-purpose clothing) is realized in the National Research Program "Covid-19 Mitigation" (No. PPP-COVID-2020/1-0004)" (01.07.2020.-31.12.2020.) project "Integration of Safe Technologies for Protection against Covid-19 in Healthcare and High-Risk Areas" by implementing the branch of the algorithm, where a suit for a special task is not available.

The findings of the anthropometric research conducted during the development of the Doctoral Thesis are included and have contributed to the preparation of the IEEE Standard Association (IEEE SA) White Paper "Landmarking for Product Development" with the aim to facilitate the definition of virtual anthropometric points in relation to the real human body by promoting the development of virtual tools and wearable products [1].

Author's reports at scientific conferences:

1. Clothing – Body Interaction 2021, Joint International Conference, Online conference, 2. – 3 June 2021, Session: Scanning and product development; report "Development of an ergonomic suit for physiotherapists" (Dabolina, I., Lapkovska, E., Silina, L.).
2. 61st International Conference "Materials Science & Applied Chemistry" (MSAC), Latvia, Riga, 23 October 2020; report "Method for evaluation anthropometric fit and ergonomics of clothing".
3. 7th Workshop on Advances in Information, Electronic and Electrical Engineering (AIEEE 2019), Latvia, Liepaja, 15–16 November 2019; poster "Effect of Active Performance on Skin – Sportswear Interface Pressure" (Silina, L., Lapkovska, E., Porins, R., Dabolina, I., Apse-Apsitis, P.).
4. 60th International Conference "Materials Science & Applied Chemistry" (MSAC), Latvia, Riga, 24 October 2019; report "Garment Fit and Sizing Development at Pattern-Making Stage".
5. 12th International Scientific and Practical Conference "Environment. Technology. Resources", Latvia, Rezekne, 20–22 June 2019; poster "Sizing for a Special Group of People: Best Practice of Human Body Scanning" (Lapkovska, E., Dabolina, I.).
6. 59th International Conference "Materials Science & Applied Chemistry" (MSAC), Latvia, Riga, 26 October 2018; poster "Method of Drape, Appearance and Comfort Measurements" (Lapkovska, E., Dabolina, I., Silina, L.).

[2] The author of the Doctoral Thesis was a participant in the implemented project (from 01.03.2016 to 28.02.2019). The inclusion of the results has been agreed upon with all participants involved in the development of the method.

Author’s publications on the topic of the Doctoral Thesis (22):

1. **Lapkovska, E.**, Dabolina, I., Silina, L., Vilumsone, A. Development of an ergonomic protective suit for physiotherapists during the COVID-19. *Journal of Engineered Fibers and Fabrics* (scientific article in press, Scopus).
2. Dabolina, I., Fomina, J., **Lapkovska**, **E**., Silina, L. Selected Dynamic Anthropometrics and Body Characteristics for Posture Corrector Fit. *Communications in Development and Assembling of Textile Products*. 2020, Vol. 1, No. 2, pp. 96–103. ISSN 2701-939X. Available from: doi.org/10.25367/cdatp.2020.1. pp. 96–103 (scientific article).
3. Lage, A., Ancutiene, K., Pukiene, R., **Lapkovska**, **E**., Dabolina, I. Comparative Analysis of Real and Virtual Garments Distance Ease. *Materials Science – Medžiagotyra*. 2020, Vol. 26, No. 2, pp. 233–239. ISSN 1392-1320. e-ISSN 2029-7289. Available from: doi:10.5755/j01.ms.26.2.22162 (scientific article, Scopus).
4. Dabolina, I., **Lapkovska**, **E**. Sizing and Fit for Protective Clothing. Red. Zakaria, N., Gupta, D. *Anthropometry, Apparel Sizing and Design.* Cambridge: Woodhead Publishing, 2020, pp. 289–316. ISBN 978-0-08-102604-5. e-ISBN 9780081026052. Available from: doi:10.1016/B978-0-08-102604-5.00011-1 (book chapter, Scopus).
5. Traumann, A., Peets, T., Dabolina, I., **Lapkovska**, **E**. Analysis of 3-D Body Measurements to Determine Trousers Sizes of Military Combat Clothing. *Textile & Leather Review*. 2019, Vol. 2, No. 1, pp. 6–14. ISSN 2623-6257. e-ISSN 2623-6281. Available from: doi:10.31881/TLR.2019.2 (scientific article).
6. Silina, L., **Lapkovska, E**., Porins, R., Dabolina, I., Apse-Apsitis, P. Effect of active performance on skin – sportswear interface pressure. In: *Advances in Information, Electronic and Electrical Engineering, AIEEE 2019 - Proceedings of the 7th IEEE Workshop 2019-November, Latvia, Liepaja, 15–16 November 2019*. Latvia: IEEE, 2019, pp. 1–4. e-ISBN 978-1-7281-6730-5. Available from: doi:10.1109/AIEEE48629.2019.8977129 (publication in conference proceedings, Scopus).
7. Dabolina, I., **Lapkovska**, **E**., Vilumsone, A. Functional Textiles and Clothing/Dynamic Anthropometry for Investigation of Body Movement Comfort in Protective Jacket. In: Red. Mujumdar, A., Gupta, D., Gupta, S. *Functional Textiles and Clothing*. Singapore: Springer Nature Singapore Pte Ltd., 2019, pp. 241-259. ISBN 978-981-13-7720-4. e-ISBN 978-981-13-7721-1. Available from: doi:10.1007/978-981-13-7721-1 (book chapter).
8. **Lapkovska**, **E**., Dabolina, I., Silina, L. Method of Drape, Appearance and Comfort Measurements. In: *Key Engineering Materials, Latvia, Riga, 24–24 October 2018*. Key Engineering Materials: Trans Tech Publications Ltd., 2019, pp. 336–340. ISSN 1013-9826. e-ISSN 1662-9795. Available from: doi:10.4028/www.scientific.net/KEM.800.336 (publication in conference proceedings, Scopus, WoS).
9. **Lapkovska**, **E**., Dabolina, I. Sizing for a Special Group of People: Best Practice of Human Body Scanning. In: *Environment. Technology. Resources: Proceedings of the 12th International Scientific and Practical Conference, Latvia, Rezekne, 20–22 June 2019*. Vol.1. Rezekne: Rezekne Academy of Technologies, 2019, pp. 136–141. ISSN 1691-5402. e-ISSN 2256-070X. Available from: doi:10.17770/etr2019vol1.4137 (publication in conference proceedings, Scopus).

10. Dabolina, I., **Lapkovska**, **E**., Silina, L. Anthropometric Sizing and Lower Limb Movement Range during Climbing Position. In: *19th World Textile Conference on Textiles at the Crossroads (AUTEX2019), Proceedings, Belgium, Ghent, 11–15 June 2019*. Ghent: Open Journal System (OJS) of Ghent University, 2019, pp. 1B–245. (publication in the collection of conference abstracts, Scopus).
11. **Lapkovska**, **E**., Dabolina, I., Silina, L. Garment Fit: Where do We Stand? In: *Proceedings of 3DBODY.TECH 2019, Switzerland, Lugano, 22–23 October 2019*. Ascona: Hometrica Consulting – Dr. Nicola D'Apuzzo, 2019, pp. 196–203. ISBN 978-3-033-07528-3. Available from: doi:10.15221/19.196 (publication in the collection of conference abstracts, Scopus).
12. Silina, L., Dabolina, I., **Lapkovska**, **E**., Dabolins, J., Apse-Apsitis, P., Graudone, J. Sensor Matrix for Evaluation of Clothing Fit. In: *Proceedings of 2019 IEEE 60th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), Latvia, Riga, 7–9 October 2019*. Piscataway: IEEE, 2019, pp. 1–6. (publication in conference proceedings, Scopus).
13. Dabolina, I., **Lapkovska**, **E**., Vilumsone, A. The Influence of Human Body Posture on the Determination of Total Dimensions (Morphological Characteristics). In: *IOP Conference Series: Materials Science and Engineering, Greece, Lesvos, 5–7 September 2018.* Vol. 459, pp. 1–6. ISSN 1757-8981. e-ISSN 1757-899X. Available from: doi:10.1088/1757-899X/459/1/012076 (publication in conference proceedings, Scopus).
14. Dabolina, I., Vilumsone, A., Dabolins, J., Strazdiene, E., **Lapkovska**, **E**. Usability of 3D Anthropometrical Data in CAD/CAM Patterns. *International Journal of Fashion Design, Technology and Education.* 2018, Vol. 11, No. 1, pp. 41–52. ISSN 1754-3266. e-ISSN 1754-3274. Available from: doi:10.1080/17543266.2017.1298848 (scientific article, Scopus).
15. Abu-Rous, M., Dabolina, I., **Lapkovska**, **E**. Fabric Physical Properties and Clothing Comfort. In: *IOP Conference Series: Materials Science and Engineering, Greece, Lesvos, 5–7 September 2018*. Greece: IOP Publishing Ltd., 2018, pp. 1–6. ISSN 1757-8981. e-ISSN 1757-899X. Available from: doi:10.1088/1757-899X/459/1/012028 (publication in conference proceedings, Scopus, WoS).
16. **Lapkovska, E.**, Dabolina, I. An Investigation on the Virtual Prototyping Validity – Simulation of Garment Drape. In: *Proceedings of the International Scientific Conference Society. Integration. Education, Latvia, Rezekne, 25–26 May 2018*. Rezekne: Rezekne Academy of Technologies, 2018, pp. 448–458. ISSN 1691-5887 Available from: doi:10.17770/sie2018vol1.3187 (publication in conference proceedings, WoS).
17. Dabolina, I., **Lapkovska**, **E**. 3d Digital Anthropometry in Case of Fit and Ergonomics of Army Uniform. In: *Proceedings of 3DBODY.TECH 2018, Switzerland, Lugano, 16–17 October 2018*. Switzerland: 2018, pp. 106–112. ISBN 978-3-033-06970-1. Available from: doi:10.15221/18 (publication in the collection of conference abstracts).
18. Dabolina, I., **Lapkovska**, **E**., Zommere, G., Vilumsone, A. End-User Satisfaction with Army Uniforms – Case Study. In: *9th International Textile, Clothing & Design Conference "Magic World of Textiles": Book of Proceedings, Croatia, Dubrovnik, 7–10 October 2018*.

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19. Dabolina, I., Vilumsone, A., **Lapkovska**, **E**. Anthropometric Parametrization of Uniforms for Armed Forces. In: *Environment. Technology. Resources: Proceedings of the 11th International Scientific and Practical Conference. Vol. 3, Latvia, Rezekne, 15–17 June 2017*. Rezekne: Rezekne Academy of Technologies, 2017, pp. 41–46. ISSN 1691-5402. Available from: doi:10.17770/etr2017vol3.2519 (publication in conference proceedings, Scopus).
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Individual contribution of the author in publications:

In publications No. **1**, **8**, **9**, **11** and **16** the author conceived the study and was in charge of overall direction and planning, performed and supervised the part of the literature review, planned and carried out the experiments, performed the measurements, processed and analyzed the data, performed the interpretation of the results and their visualization. Publications were developed with a discussion and input from all co-authors – in different study stages and parts of the manuscript. As a result, the author consolidated the manuscript, designed the figures, provided style and grammatical editing, and gave final approval of the version to be published.

Publications No. **2**, **4**, **6**, **7**, **10**, **12**, **13**, **15**, **17**, **18**, **19** and **20** were developed with input from all co-authors. The author provided discussion and helped to shape the research design, made a substantial contribution to the literature review, performed experiments and measurements with co-authors, processed the data, and was involved in the analysis and interpretation of the results. Moreover, the author carried out a significant part of result visualizations and figure design, contributed to the final version of the manuscript – provided style editing and aided in grammatical revision.

In publications No. **3**, **5**, **14**, **21** and **22** the author provided the discussion on the study design, assisted with the performance of measurements and data analysis, helped to carry out result interpretations and contributed to the final version of the manuscript by critical revision and development of result visualizations.

1. CLOTHING DESIGN ASPECTS

The research is focused on the specifics of functional or special-purpose clothing. The literature review looks at a set of clothing design aspects that are important in creating anthropometrically fit and ergonomic clothing, including anthropometry in clothing branch, issues of sizing system development, specifics of clothing design (pattern making) and textile selection, as well as application of modern technologies in clothing design and research. The range of special-purpose clothing is wide and varied, applying it to different professions (construction, forestry, road workers, agricultural workers, chemical workers, medical staff, various interior and defence structures) and activities (motorcyclists, cyclists, skiers, swimmers, divers, climbers, and different types of athletes).

Special-purpose clothing is designed with its purpose, tactical function and, to a lesser extent, its appearance [2], so that, unlike fashion goods, the design of functional clothing is based on the specific needs of the consumer [3], [4], but without excluding aesthetics aspect in the case of uniforms. The basic requirements for such clothing are physiological (refers to physiology, anatomy, comfort), biomechanical (body mechanics, kinematics, dynamics), ergonomic (freedom of movement), as well as psychological factors (also related to aesthetics). In general, it is concluded that special-purpose clothing is purposeful, functional, and also aesthetic [5].

1.1. Anthropometry

As one of the fundamental methodologies of anthropological research, anthropometry is related to measurements of the human body and proportions. Traditionally, measurements of the human body are performed to determine physical development and growth trends and define their standards; to study changes in populations; to follow developmental factors at a certain age; to study sexual development; to detect growth-related diseases; to determine changes of biological characteristics within a century and constitutional body structure [6]–[8]. In terms of tailoring, a more comprehensive understanding of the need for anthropometric research and data systematization has been fostered by warfare at various times in history and in different regions of the world. It caused facing the need to supply a large number of soldiers with identical uniforms but individually suitable for each soldier (France's King Louis XIV or the Sun King wars in the 17th century, Napoleonic wars in Europe since the end of the 18th century, the American Civil War in the second half of the 19th century) [9,10].

The characteristics of the human body can be obtained using traditional anthropometric methods, known as manual measurement methods or contact methods with the use of traditional measuring instruments – anthropometer, tape measure, calipers, and scales, as well as additional tools for fixing anthropometric points/levels on the body (markers, stickers, elastic bands, etc.). However, because of global technological developments, anthropometric research has also introduced and developed so-called non-contact methods – light projection, photogrammetry, silhouette methods, laser scanning, electromagnetic wave and hybrid methods [11]. At the beginning of the 21st century, spatial (3D) scanning has begun to replace contact methods.

The use of anthropometric data through effective measurement of the human body is considered the most effective solution for developing anthropometrically fit clothing and adequate sizing systems. Posture characteristics (lateral and frontal position of the torso), proportions of body parts, and the types of body shapes (legs, chest, back, shoulders, neck, abdomen, buttocks, thighs, and arms), as well as the location of the soft tissues forming the shape of the figure are also considered to promote conformity. The possibilities of obtaining adequate body measurements, the analysis of data for the implementation of efficient sizing systems, and the further usability of the systems in marketing to promote wearer satisfaction are emerging as present problems in the anthropometry of clothing or tailoring [12]. Data on different populations worldwide vary in both quantity and quality, which has always been influenced by the time consumption and high costs of the process. Recommendations of various industry standards [13]–[17] are used to obtain anthropometric data and compile databases. The aim is to introduce general requirements or guidelines for promoting the reliability and usability of research and the data obtained in them. Industry standard ISO 8559-3: 2018 "Methodology for the creation of body measurement tables and intervals" (Fig. 1.1. in block diagram form) summarizes the industry's needs for anthropometric data and its systematization [18].

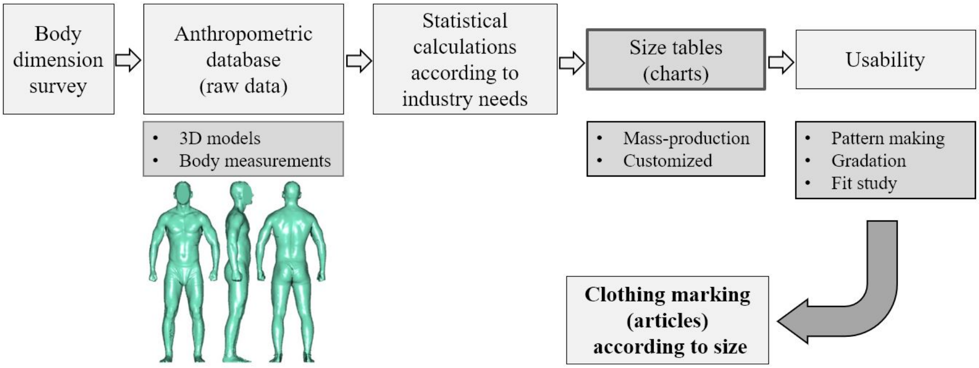


Fig. 1.1. Industry needs regarding anthropometric data [18].

Industry standard [13], [19] data on human body sizes, traditionally used in clothing design, are derived from measurements of people in a static position. However, in everyday life, the human body is in constant motion, which requires garment designers to understand and quantify changes in body size and shape during these movements to be able to "dress" a body subject to movement rather than static mannequin. Dynamic anthropometry studies body size and surface changes resulting from movements to introduce additional ease allowances or constructive solutions in the clothing design, promoting freedom of movement during daily, work and physical activities [2], [20]–[24]. Further, the findings of dynamic anthropometry studies in ease allowances, design solutions, textile selection and additional clothing elements can be used based on the specifics of a particular sector in order to apply a solution for the promotion of ergonomics that is already known and traditionally used, also concluded, and tested in additional research.

Up-to-date data on the anthropometric profiles of a particular target group is a prerequisite for the design and sizing of anthropometrically fit clothing. Still, problems with the reliability and systematic acquisition of body measurements from different departments (users of special-purpose clothing) are limiting factors in drawing of procurement and supply. The most optimal methods and procedures are needed as well as the resources for data acquisition, updating, and purposeful use. It is essential that the anthropometric characteristics of the population can be reasonably judged by observing only a representative part of the population – a sample set (this is since in the empirical distribution of population anthropometric data is characterized by the normal distribution differential function curve[3]). The sample set should follow the type of population, the empirical distribution, and its classification to select specific data clusters and/or layers. It can be concluded that the production and efficient supply of special-purpose equipment and clothing (PPE and uniforms) requires a clear distribution of the target audience sizes. An anthropometric survey provides it by, in ideal situation, by acquiring the anthropometric data of the entire target group through annual surveys for data updating. This is followed by the classification of body sizes and the distribution of typical figures according to the group of wearers, as well as a summary of ergonomic parameters, considering the specifics of work and special clothing.

1.2. Sizing systems

To provide anthropometrically appropriate clothing to the target audience, transparent body size variants based on anthropometric studies with statistical summaries should be distinguished from the diversity of bodies in the target population. The sizing system is, in principle, a table of numbers that summarizes and displays the body size values for each size group established in the system, which serves to classify the bodies within a population. The task of their development is to find the optimal number of sizes within the population that describe and include as many body shapes/sizes as possible, intending to provide as many individuals in the group as possible with conforming clothing. However, as far as possible, the number of sizes should be small enough to be cost-effective for the manufacturer and also not confuse the choice of size for wearers [2], [25]–[28]. It is vital to create such a set of sizes for quasi-commercial products, i.e., uniforms and special-purpose clothing, where the task of clothing is to achieve ergonomics for specific work and provide a similar appearance (uniform) for employees.

During the introduction and development of clothing sizing systems, the human body's key (primary) dimensions according to the type of clothing have been established and stabilised. They define the structure of the sizing system and serve as measures to know when choosing garments [2]. In the development of sizing systems, the key dimensions are those measurements of the human body that introduce classification scales for clothing sizes, as well as by which standardized values the sizes of the garments are marked directly or in coded form. The

[3] 19th-century anthropologists have noticed that in studies where the sample size is approaching a vast number of measurements, and the width of the equidistant intervals of the measurement variation range is close to zero, the frequency of occurrence of numerical values of anthropometric features can be described by the regularity of the normal distribution of random variables formulated in 1809 by German mathematician K. Gauss.

traditionally used key dimensions for garments for the upper body are chest circumference and body height, and, in some cases, the length of the arm. Waist circumference and body height are traditionally used for garments for the lower body; additionally, the inside length of the leg (inseam) and for women's clothing – hip circumference can be introduced.

However, one of the problems of clothing buyers is confusion about size designations and lack of explanations [12]. Industry challenges are initiating research into the adaptation or adjustment of sizing systems, with only a few trying to identify information and data, such as the amount of ease allowances that are hidden or not disclosed to consumers and are unlikely to be fully understood by manufacturers and researchers [29]. A crucial part of the effective operation of the sizing system is the labelling or size designation, which is a so-called coding system that allows users to identify the body sizes for which the garment is designed. However, not all manufacturers have a common approach, which may lead to confusion about whether the size on the label refers to the size of the body or the size of the clothing/its parts. There must be an understanding at the production level that this will result in the full range of sizes required and that the achievement of conformity across the whole range will require a series of decisions: how to design clothing according to the coding system known to the population, what body measurements to use for coding and the conditions under which they are gained [12].

Validation of sizing systems requires testing. A simple approach is to test a tight-fitting clothing sizing system, where a sample of test subjects (representing the population) perform all anthropometric fit tests on the whole size scale of the garment, assuming that the evaluation will allow predicting the conformity regarding the whole population. The purpose of such tests is to adjust the grading, i.e., to promote the anthropometric fit of clothing among a particular population when, in combination with the results of anthropometric fit tests, analysis of the deviations of the real and theoretical body-sizing system is performed [10].

1.3. Pattern design and selection of textiles

The tasks of ergonomic engineering methods are the solutions of the interaction between the size and design of clothing and the shape of the human body. When pattern-making a garment, the three-dimensional model (garment) is reproduced in a plane (pattern). This transformation must be reversible when the garment is acquired by joining parts of the pattern. The creation of a pattern drawing is a complex stage in the design of a garment, as the surface layout of a non-existent product with a complicated three-dimensional shape is created (drawn) [30]. In the practice of clothing pattern design, approximate surface spreading methods are used, known as pattern systems, when the intended garment is laid in a plane. The most advanced of these methods are based on knowledge of the human body (somatoscopy and somatometry) and the properties of textiles [27], [31]. The usefulness of clothing patterns is proved by how the constructed shape corresponds to the design intent of the object. The multifactor process of pattern-making can be viewed from the perspective of defining input variables (human body morphology and anthropometric parameters, materials, and design) [5], [32].

- Body measurement data:

    - anthropometric data from standard databases or data as a result of a special anthropometric survey;
    - a sizing system developed based on experience and knowledge of the target audience or using the aforementioned anthropometric data sources;
    - direct body measurements;
    - biomechanical parameters for pattern adaptation to body movements.
- Material parameters – the various properties of textiles (elasticity, drape, thickness, stiffness) that can be determined by testing or intuitive, experience-based evaluation.
- Pattern (construction) parameters: total volume and ease allowances; the needs of the wearers in terms of the total volume of clothing; production allowances.

The conformity of clothing is achieved not only by the appropriate quality of patterns but also by the ability to integrate the properties of the selected textile material into them, anticipating the influence of their various characteristics in the finished product. The functionality of uniforms, special-purpose clothing and PPE is primarily determined by the properties of the textile (protection, wearability, care, visibility/camouflage, etc.), and the properties of such specific materials affect the shape and ergonomics of clothing (e.g., fit, slip, elongation, etc.). Therefore, knowledge and practical understanding of fabric parameters [33] – geometrical/structural characteristics, mechanical and physical properties are required to ensure the clothing conformity. Scientific research, with access to test equipment and knowledge of standardized test methods, provides a wide range of information on fabric characteristics. However, in manufacturing and supply, the data on the characteristics included in the technical specifications may be limited. Consequently, a balance needs to be sought between customers and manufacturers to include justified, practical and verifiable textile properties in the documentation, facilitating the design, manufacture, and supply of functional clothing.

1.4. Computer-aided design and 3D technologies

At present, almost all stages of clothing design and production are performed with the help of various specialized computer technologies: the creation of collections (design sketches, technical drawings); computer-aided design (pattern making, modelling); cutting (pattern layouts, computerized cutting); automated/semi-automated sewing machine management; and product life cycle management (PML software). The use of CAD/CAM (computer-aided design/manufacturing) software in the production theoretically envisages reducing of the production time; increasing productivity, production flexibility, product quality; reducing the need for human resources; increasing product life cycle transparency; increasing humanization of labour and reduced stocks [34]. Nowadays, a wide range of computerised clothing design software is available [35]–[43]. Their implementation depends on the scale of the company's operation, the methods used in the design of clothing, the existing or future production technologies, human resource planning, and technical and financial capabilities.

3D scanning is a method of optical (non-contact) data acquisition used in reverse engineering, medicine, ergonomic research, and in clothing design [31]. The advantage of 3D scanning technology in the clothing industry is, firstly, the ability to rapidly obtain reliable anthropometric data for use in the analysis of human body structure, the development and revision of sizing systems, and the implementation of personalization solutions in manufacturing. Secondly, as a result of the scanning, a 3D model of the human body is obtained and stored, which can be used for additional research, if necessary, as well as for the development of scanatars and avatars for the implementation of virtual prototyping or fabrication of anthropometric mannequins. Also, significant advantages are the fact that there is no physical contact between the person to be measured and the meter as a result of touches, for example, by mitigating the acquisition of potentially confusing measurements such as the inside of the leg, the arc of the crotch, etc. measurements. In the clothing industry, 3D scanning results can be used for [10], [32], [44] sizing standardization; online shopping; virtual try-on; fabrication of anthropometric and personalized mannequins (3D printing, milling). It is also used to evaluate the conformity of clothing with various approaches, such as visual assessment by scanning images, as well as volume, surface area and cross-section measurements.

1.5. Conclusions of Chapter 1

Given that the garment design process involves a large number of different factors with inherent disadvantages and advantages, comprehensive methods for assessing the anthropometric fit and ergonomics of garments are needed to test the effectiveness of the whole set. That will systematise the existing approaches to both data collection and use, enabling users and product developers to identify all stages of the process and understand those requiring their involvement, such as the involvement of uniform wearers in the anthropometric survey of the whole service, an understanding of the systematisation of supply and other aspects.

Main **conclusions** of Chapter 1:

- There is a lack of anthropometric research and its data in the clothing branch – the data in use are mostly outdated. However, access to new anthropometric data sets is expensive or even closed.[4] Anthropometric research of particular sample dataset of clothing wearers is an expensive and time-consuming process, and it is not always possible to attract a sufficient number of test subjects, considering people's daily busyness, lack of understanding of research, and personal psychological dislike of the process (measurements).
- Not only the lack of anthropometric data can be identified in the industry, but also the inability and/or misunderstanding of their use in production, for example, using long ago developed, inherited patterns without understanding the use of anthropometric parameters. Derived patterns inherit the previous problems, and without clarity on the principles of the ease allowances, it is impossible to analyse the clothing pattern regarding its effect on clothing fit.
- Presently, there is confusion among clothing wearers on clothing marking labels, given their diversity and the lack of explanation of the content of the labels.
- Without knowledge of the composition of fabrics, their structural characteristics, their mechanical and physical properties and their effects on finished garments, the designers may lack the ability to make reasonable choices about the material for clothing with specific

[4] Author's note: for example, SizeGermany (measurements in Germany) measurement tables cost around € 15,000

functions and integrate these properties into patterns. As a result, clothing is created that is unsuitable for wearing conditions and work duties, that is functionally inappropriate, not anthropometrically fit, and non-ergonomic.

2. CONFORMITY ASPECTS OF CLOTHING

Terminologically, “fit” is defined as a phenomenon or condition in which a phenomenon corresponds to another phenomenon [45], including synonyms such as “appropriate”, “valid”, “decent”, and in an aspect of everyday clothing "fit" [46]. Attempts to define the concept of conformity of clothing and its components have proved to be a complex task, given the different perspectives as well as what and how many of the multifaceted characteristics of clothing are ultimately included in it. The concept of conformity of clothing has been used, for example, including the components of physical comfort, psychological comfort, and appearance, all of which play a role in the consumer's perception and evaluation of the conformity of clothing [27], [47]. When distinguishing general dimensions or components, it is the relationship of clothing to the body, combining aesthetic/visual conformity, physical comfort, and proper functioning of clothing on the body [48]–[51]. The conformity of clothing is a critical factor in product quality and end-user satisfaction [52], and the user makes the final decision on the conformity of clothing. Therefore, all the factors included in the concept will be relevant in the various interrelationships [53]. From the wearer's point of view, it is recognized that well-fitting clothing contributes to the wearer's confidence, comfort, performance and also safety [33]. In addition, if in the choice of everyday clothing the wearer may decide not to wear a product, then for special-task clothing and especially for protective clothing, wearers refusal of it (due to non-compliance) can lead to health and life-threatening conditions.

2.1.Components of the concept of conformity

The compilation of compliance components should be done in a hierarchical structure to determine the quality of clothing; this principle has also been used in studies and textbooks [25], [54]–[56]. A multilevel approach to quality assessment is needed when considering the specific characteristics of clothing, and clothing is both a consumer product and an object of production. The components of clothing compliance within the framework of the Thesis are divided into four groups: functional compliance, anthropometric fit, ergonomics, and aesthetic conformity.

2.1.1. Functional compliance

The first group – functional compliance, includes:

- safety, for example, by preventing injuries, protection against various environments and substances, and visibility (increased (high) visibility/camouflage);
- performance – service life (wearing-life) and care qualities;
- product technologicality, including conformity of structure and sewing technologies.

The provisions of the legislation of the Republic of Latvia [57], [58] prescribe labour protection requirements when using personal protective equipment (devices, equipment, systems, and products, including work clothing and footwear), which an employee wears or otherwise uses at work to protect his safety and health from exposure to one or more risk factors in the work environment. The development of safety-appropriate clothing and other means requires the identification of potential risks and environmental conditions before the requirements are set and the design of clothing is performed, and, where possible, safety testing should be performed on both textiles and finished garments [59].

As a result of procurement, staff in various branches are provided with special clothing with certain functionality, and it is theoretically expected that the products will retain their properties for the intended service life. When evaluating performance indicators, it is challenging to draw unambiguous conclusions, given that both the intensity of clothing wear and the frequency and methods of care may vary within the staff, especially in cases where clothing care is not organized centrally within a department. Regarding the technologicality of clothing, assessors need to be sure that the type of design meets the intended objectives: work conditions, work functions, body parts to be covered, the degree of adaptability, and the reasonableness and quality of the chosen sewing technology. It can be concluded that from the point of view of practical implementation of the assessment procedure on the clothing functional conformity, the set of measures should include analysis of the manufacturer's actual information (specification); research and practical testing of finished products; identification of functional deficiencies among the wearers themselves (interviews and/or surveys).

2.1.2. Anthropometric fit

Anthropometric fit is determined mainly by the air space or interlayer between the body and the material layer. The topology of these gaps depends on many factors, such as the type and design of the garment (including the number and type of elements), its size, the ease allowances and the drapeability [60]. Various explanations describe anthropometric fit, such as:

- "be in the right shape and size for someone/something" [61];
- conformance of the physical dimensions of clothing to the body [62];
- matching the size and shape of clothing to the size and shape of the human body [63];
- correspondence of the size and shape of the structural design of the garment to the dimensions of the wearer's body or the three-dimensional human body [28];
- fit is not about measurements but accordance to the shape of the human body [29];
- anthropometrically fit clothing appears to be part of the wearer himself [27].

Summarizing the definitions and considering the direct relationship of the indicator with the human body, it can be called anthropometric fit (fit to the human figure). Like the whole concept of clothing comfort, the anthropometric fit must be seen as a complex process with a holistic understanding [64]. The process of assessing the conformity of clothing for certain groups of wearers is based on actual data and analysis, based on an initial reliable anthropometric survey followed by an analysis of the conformity of the size system to the target group. The necessary results of these measures can also be achieved through a timely, regular, and comprehensible exchange of information between the parties involved (wearer, customer, manufacturer).

2.1.3. Ergonomics

When structuring the components of ergonomics, the third group of components of clothing conformity in this Doctoral Thesis includes:

- anthropometric fit in statics and dynamics;
- mobility or movement abilities, which also includes the convenience of doffing and donning of clothing, ease of use of fasteners, drawstrings, etc. elements, the effects of the weight of the clothing, the effects of the material properties, the freedom of movements in everyday life and specific to work;
- hygiene, which includes thermal insulation, air and water vapour permeability, and water absorption performance;
- psychophysiological indicators – fatigue, working capacity, metabolism and senses.

The ergonomics of clothing is linked to many research disciplines (anthropology, anatomy, physiology, biomechanics, materials science, including design and psychology), the findings of which focus on improving products and processes for human use [65]. Clothing is in constant contact with the surface of the human body, creating psychophysiological feelings – warmth, cold, comfort, pressure, muscle tension. The effects of PPE on wearer performance are usually quantified by measuring physiological or thermal effects (heart rate, temperature, blood pressure, respiration, and sweating); energy consumption (oxygen uptake); mobility (ability to perform tasks); task performance or work capacities [66]; and also various psychophysical reactions (comfort, wearability, load effects and preferences among analogues) [67]. The requirements for the clothing ergonomics also refer to freedom of movements; reduction, and prevention of various loads, including support of body shape. It should be provided that the mechanical properties of the garment are consistent with the movements of the body, the degree of movement freedom, the ROM (range of motion) and the force and moment of human joints.

Most of the components of clothing ergonomics cannot be evaluated without the subjective opinion of the wearers themselves; therefore, in the supply of clothing with ergonomic solutions to the target groups, it is necessary to provide a process for the evaluation of these indicators. Supply officials may not always be fully informed and aware of the real needs of wearers or, for example, the ergonomic shortcomings of clothing already in use. Accordingly, the manufacturer is only partially aware of the specifics of the work and the wearing habits, which are understandable due to the differences in the nature of the work in the various professions, as well as linked to the lack of information on the nuances known and accumulated over time only among the wearers themselves. To achieve the best results in supplying the target groups with ergonomically appropriate clothing, a rational set of measures is: obtaining initial information on work specifics (work movements, conditions, habits) from competent service contact-persons; identification of deficiencies and recommendations from real wearers (interviews, surveys); as well as real ergonomic testing with reasonable evaluation conditions and criteria.

2.1.4. Aesthetic conformity

The fourth group – components of aesthetic conformity of clothing, includes:

- good appearance/neatness, which can be divided into two groups: personal – human preferences regarding one's appearance; the appearance of the service – uniform does not depend on the wishes or tastes of the individual (service message, history, traditions, etc.);

- compliance with somato-characteristics.

The result of aesthetic conformity is the visual satisfaction of the appearance of clothing in relation to the body. Thus, serving the wearer's confidence and, in general, contributing to the wearer's psychological comfort. If part of the aesthetics depends on the properties of the fabrics (wrinkling, peeling, colour fastness), then compliance with somato-characteristics and the aesthetics of the manufacturing technology is based mainly on the manufacturer's experience and best practice in the design and manufacturing of clothing. Therefore, to achieve optimal results in this process: all parties involved need to achieve synergy, taking into account the opinions of wearers on the shortcomings of aesthetics of special-purpose clothing and its improvements (e.g., design elements and their location, silhouette and proportions), with a clear vision of supply services on requirements for the overall image of the staff and understanding of product quality, and when manufacturers can offer and ensure solutions that are in line with modern scientific and technological progress and fulfilled under the principles of best practice.

2.2. Methods for assessing anthropometric fit and ergonomics

The combination of subjective and objective methods of clothing evaluation (see Fig. 2.1) allows clarifying the interrelationships between subjective conformity assessment and objective physical indicators [4]. The subjective evaluation results are not reproducible and cannot be expressed in absolute terms – only in comparatively (relative terms) [68]. Recognizing that conformity assessment is related mainly to qualitative methods characterized by subjectivity and lack of precision and that quantitative methods are not always easily achievable [27], it is concluded that a combination of methods is valuable for evaluation processes [4].

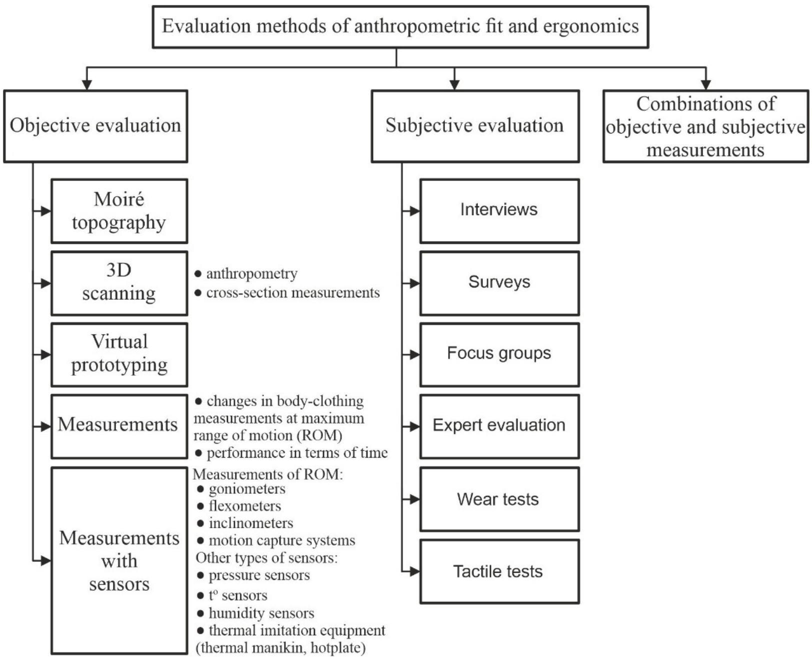


Fig. 2.1. Objective and subjective methods of assessing anthropometric fit and ergonomics.

Various objective methods are used to assess the conformity of clothing [4], [27], [68]–[71].

- **Range of motion measurements (ROM).** Measurements are used to assess the ergonomic factors of clothing and PPE in statics, dynamics (movements) and work tasks. In most cases, this means recording changes in joint angle or evaluating the level of performance in various tasks. Regarding clothing, particular parameters to be assessed can be set, such as comparing clothing size and weight effects on ROM [67], [72]. Such measurements help evaluate analogue product solutions for comparisons regarding the mobility of wearers.
- **Pressure measurements.** In solving clothing compliance problems, benefits in future are seen in the use of pressure and other sensors [70]. It is possible to observe the pressure of a clothing layer on different body parts [2] by using pressure sensors and their systems [73], thus assessing the effects and afterwards using the results to compare different product solutions and select the most appropriate ones.
- **Moiré topography.** Moiré optics (topography), which is in principle the topography of the black-and-white, is an effective method for studying clothing when contact measurements are not valid due to the soft and unstable structure of the fabrics. The nature of drapery, wrinkling and the overall shape of the body and clothing are studied. The method's task is to determine the closeness and conformity of the layer of clothing to the body [68].
- **3D scanning and cross-sections.** The changes in the body's volume (compression, tissue movements) and the space between the body and the layers of clothing are studied using 3D scanning, representing, and analysing it by linear (circumference and cross-section dimensions), area and volume measurements [27]. The principle involves scanning an unclothed (wearing underwear) and clothed body with the following superimposition of scans and acquisition of cross-sections to characterize the anthropometric fit. Recognition that the use of 3D scanning as a method of analysing clothing is proving to be effective includes conditions: it determines whether the clothing is loose, appropriate, or tight; it helps to assess the balance of clothing through a drape in different cross-sections; to understand the overall distribution and air gaps in different areas of clothing.
- **Virtual prototyping.** This method for profound conformity assessment of clothing is still in the stage of progression [2], but the existing solutions allow assessment of compliance, closeness, pressure, grain of the fabric, conformity to body shapes (cross-sections) before actual prototypes are made. Models created on realistic virtual human models have the potential to provide proper conformity; however, the full benefits of a live model are still not offered – both visual and tactile and physical (soft tissue, movements). Nevertheless, the method may be useful in individualising specific clothing (e.g., shaping and/or performance-enhancing sportswear, specific human body shape support/transformation equipment), where in-depth research is possible within small target groups.

Subjective methods include the involvement of users and experts in the conformity assessment of clothing, obtaining feedback, opinions and evaluation from the individuals involved in the process.

- **Wearing tests.**

The opinion of the users is needed to judge the indicators, which cannot be assessed directly because with the help of objective methods it is not possible to deal with the problems without knowing the specifics of work, tactics, and other aspects. During the tests, participants express the general perception of the clothing; the properties of the fabrics and tactile sensations; the effects of ease allowances; the convenience of donning and doffing clothing; and the ability to move in clothing [4]. People are used as "assessment tools", therefore these human variations are important for analysis [59]. Specifically, for protective clothing – wearer acceptance tests are essential to determine how the subject feels in clothing and how it affects the job responsibilities and moving abilities. Without this acceptance, a person may refuse to wear it and thus endanger himself/herself [60]. Wearing tests are mainly used to determine people's physiological reactions and psychological perceptions. Psychological responses are usually assessed using subjective assessment scales such as thermal sensations, perceptions of comfort and loads. Other indicators, such as the ease, freedom, severity, lightness, stiffness, moisture and heat exchange, pain, roughness, itching, etc. of the garment should also be used for a comprehensive assessment of sensory comfort [60]. There are four approaches involving wearers: simple movement tests [74]; time/motion research [75]; work/energy research [2]; obtaining a subjective assessment with different "acceptability" scales (e.g., Likert) [62], [68], [76].

- **Expert/valuator evaluations.**

The participants in the evaluation are designers, pattern makers and technologists, as well as manufacturers' representatives, distributors and, ultimately, professional customers and wearers. The evaluation categories depend on the type of assortment and the requirements set in advance for the final products [4], [10], [27], [62], [69], [76]. Ergonomic design is valued by freedom of movements; design adequacy (body coverage during movements); suitability of clothing part dimensions (sleeves, trouser legs, etc.); ergonomics of details (access to pockets, operation of fasteners), and compatibility with equipment [51], [59]. It is necessary to introduce reasonable and correctly performed subjective evaluation methods in the process of clothing assessment, which promotes the fullness of the evaluation because experts' decisions are corrected by the shortcomings identified in real wearing conditions and user recommendations. The content of the wearability tests used to assess the ergonomics of clothing and the resulting ergonomic requirements depends on the type of clothing, the assessment methods available and the ability to involve a sufficient number of target group representatives to obtain reliable statistics. Wearability tests, interviews, and user-friendly surveys are practically the easiest methods to get the opinion of target audience and use the evaluation results to promote compliance.

2.3. Anthropometric fit and ergonomics in industry standards

The recommendations of several industry standards on the conformity assessment of PPE have been revised for planning the structure concept of the method to be developed in the Doctoral Thesis. As far as possible, the content of the standards for transparency has been schematized, thus identifying evaluation stages and approaches, as well as analysing shortcomings. For example, by a schematizing the described process in ISO 13688:2013 "Protective clothing – General requirements" [77], the author has included stages/decisions in a different colour – purple (see Fig. 2.2 with an explanation of the symbols in Table 2.1). Thus, in this process, the theoretically missing stages are included – situations where as a result of a negative assessment, decisions shall be made not to accept protective clothing for wearing (emphasizing that the standard does not provide complete information on the actions to be taken).

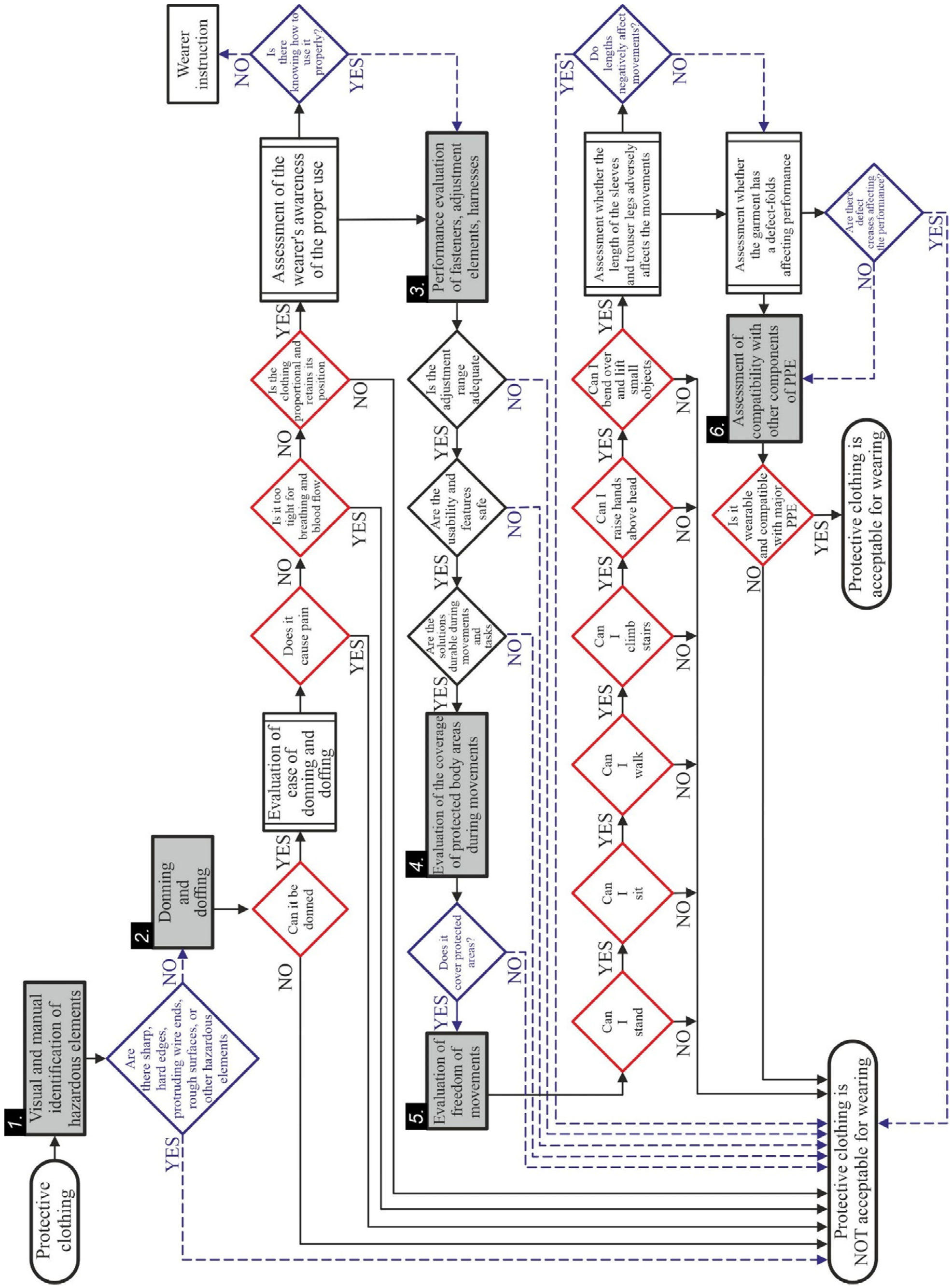
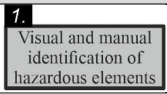
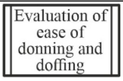


Fig. 2.2. Schematization of assessing ergonomics of protective clothing according to ISO 13688: 2013.

Table 2.1

Explanation of Symbols Used in the Scheme

No.	Designation in the scheme	Explanation
1.		Stages (components) of the evaluation process – six (6) in total.
2.		Evaluations to be carried out.
3.		Defective values of protective clothing specified in the standard, which result in a decision on its non-compliance (rhombuses with red outline).
4.		The author's additional defective values of protective clothing, from which the decision on its non-compliance must be derived (rhombuses with a purple outline).
5.	------------	Author's decision-making pathways (purple strikethrough lines).

This standard sets out general requirements for the ergonomics, safety, sizing, ageing and compatibility of protective clothing. Its annexe for examining the ergonomic properties of protective clothing employing practical performance tests contains a simple assessment description. It should be noted that most of the negative decisions implemented by the author may not be economically justified and, in the actual process, will rather require additional actions without disposal or refusing to use the products. Critical limits for decisive factors are not marked, allowing expert interpretation and reliance on the wearer's reactions to decide whether or not to wear the clothing. It can be explained by the generality of the content and purpose of the standard – without linking it to a specific protective clothing type but indicating the directions of a suitability assessment and emphasizing the need for assessment as such.

Also, EN 13921:2007 "Personal protective equipment. Ergonomic principles" in general and in the form of recommendations but with a broader vision, summarizes the factors to be considered, such as anthropometric characteristics, thermal interactions, and interactions with the biomechanics of the human body and effects on the wearer's senses. In assessing ergonomics, the approach remains the same, when a sufficient number of wearers don clothing, perform characteristic movements and doff them while in parallel obtaining the opinions and feedback of the wearers. In turn, ASTM F1154-99a, "Standard Practices for Qualitatively Evaluating the Comfort, Fit, Function, and Integrity of Chemical-Protective Suit Ensembles", aims to assess the suitability of protective clothing suits in the work environment based on comfort; anthropometric fit; functionality; and integrity. It includes a task scenario for determining the characteristics of human factors and assessing the ability to perform tasks in protective clothing [27], [79], [80]. The results that include measurements of objects (clothing) and subjects (people) and test subject evaluations (evaluation with a Likert scale) during the tests are indicated for further use in anthropometric fit and comfort evaluation procedures, as well as in the improvement of sizing systems [81]. Another standard, ASTM F3031-17, "Standard Practice for Range of Motion Evaluation of First Responder's Protective Ensembles" [82], is intended to determine the range of motion (ROM) of protective clothing under controlled conditions, thus, providing for the use of data analysis and interpretation for the comparison of both the same type and different classes of protective clothing in terms of ROM.

The development of the Thesis method considers the sets of instructions of different standards, their overlapping parts or their stages/elements, such as the movements/postures to be included in the ergonomics testing (standing, walking, climbing, squatting, bending, kneeling, hand movements). The variety of conformity assessment methods, approaches and scopes of clothing indicates their wide or, conversely, narrow and specific uses depending on the type of clothing assortment. The review of standards shows that they contain general recommendations, but no clearly structured decision-making system indicates separation from real supply and evaluation (testing) conditions. It, in turn, provides input data for the method developed in the Doctoral Thesis – intending to promote practical usefulness in the processes of conformity assessment and supply of clothing, and understanding the regulation of the industry.

2.4. Conclusions of Chapter 2

The components of the concept of clothing conformity described in the chapter, their evaluation approaches and methods allow defining the elements of the method – algorithm for the evaluation of clothing anthropometric fit and ergonomics. The theoretical review leads to the conclusion that the descriptions of known methods and procedures are disconnected and do not cooperate; therefore, it is necessary to link methods and processes that ensure the identification of clothing deficiencies, decision-making logic, and synergy promotion between stakeholders (wearers, suppliers, manufacturers).

The main **conclusions** of the Chapter 2:

- The concept of clothing conformity is broad and includes numerous components – the degree of mutual importance depends on the type of clothing assortment to be assessed and the requirements set for it.
- Clothing design processes involve designers and manufacturers, distributors and consumers, and researchers in the branch, and it is now accepted that objective methods are used, based on the content of knowledge about the object – clothing, regardless of subjective understandings; and subjective methods are linked with the perceptions of the wearer, considering the individual's psyche, personality, beliefs, and worldview.
- Industry standards include general, descriptive guidance and recommendations on the processes and sections in which clothing should be evaluated. Their content is often narrowed down to evaluating individual components, creating a lack of coherence and synergy when guidance is obtained on individual parts of the evaluation process, rarely revealing defective values and subsequent reactions.
- To improve the practical methods of assessing the anthropometric fit and ergonomics of clothing, the basic algorithm of the Doctoral Thesis should include the following steps: identification of users' anthropometric profile; evaluation of clothing

anthropometric fit and defects; movement tests; and subjective user evaluation; in addition, including the decision logic for systematizing the process.

3. METHOD FOR EVALUATION OF ANTHROPOMETRIC FIT AND ERGONOMICS OF CLOTHING

The analytical review of the research and literature in the first two chapters and the analysis of approaches and standards related to the conformity assessment of clothing, as well as the author's experience in researching the anthropometric fit issues of clothing, a method for assessing the anthropometric fit and ergonomics of clothing has been developed with the aim to promote the efficiency of appropriate clothing selection processes. The study is motivated by the need for a system of practical principles for the supply of special-purpose clothing to certain groups of clothing wearers and the development of new special-purpose clothing and PPE; at the same time promoting the understanding of the parties involved about the parameters of appropriate clothing, their evaluation, and the decision-making process.

Compared to the existing clothing evaluation approaches and research, the developed method includes not only general recommendations and instructions on the course of the evaluation process and its components but also develops and explains the graphical form of the logical structure of the method – algorithm that not only identifies deficiencies but also indicates further actions to analyze and prevent them. The logical structure of the method is based on the bottom-up and top-down approaches to information processing and analysis and knowledge structuring used in different branches. Bottom-up methods refer to an approach or procedure that focuses on the specific characteristics of individual components and moves towards generalization, serving as a form of initiating structuring and categorization in critical thinking. Thus, before reaching the highest level, decision-making first addresses the specifics of the problem, which in terms of the developed method is the identification of problems/shortcomings in supply processes (finding out the assessment of conformity) for their systematic analysis and solving. Top-down methods, on the other hand, refer to an approach or procedure in which decisions are based on the use of comprehensive factors to initially identify the "complete picture" and all its components to move towards the specifics of the problem, in critical thinking, serving as a form of initiating a hypothesis examination. To create a method that allows improving and/or developing a new assortment according to needs, the so-called top-down approach, the original algorithm[5] is supplemented with a system of modes required to generalize the method to all cases, as well as a set of principles analysing new issues.

3.1. Concept of the method

3.1.1. Initiation of the method

One of the initiating examples of the formulated method concept has been the developed algorithm [83], [84] for the improvement of uniform distribution processes and the development of new, improved prototypes as a result of the uniform/workwear (specifically the Latvian

[5] It is explained in more detail below that the algorithm developed by the European Union European Regional Development Fund, Interreg BSR Programme project "Smart and Safe Work Wear" (SWW) #R006 for solving a specific problem, serves as the initial data for the development of the method.

National Armed Forces combat uniform) anthropometric fit study.[6] The algorithm has been developed to solve the specific problem of the project, and its final stage envisages the anthropometric fit assessment of the newly developed prototypes, identifying whether its provision is affected by the size, materials, or accessibility discrepancies in the degree of ease. The development of the algorithm is a study based on a practical problem, where the scientific task was to find out the reasons for a real uniform object – trouser systematic burst in the crotch area (more than 80 % of a specific delivery). Such damage can result from a lack of anthropometric surveys, design flaws, the choice of inappropriate materials and inadequate sewing technology. As the cause of the problem can be a combination of such problems (or even interdisciplinary), there must be a definite system of solving it and looking for its cause. The research results in an algorithm: step by step revealing and structuring the processes, sub-processes and documentation required to implement the intended improvements.

An informative poster was created as an additional result in the project study (according to the recommendations of standard 13688:2013 "Protective clothing. General requirements" - see partly in Fig. 3.1. [83]) ensuring the awareness of the users of special-purpose clothing. It includes visual and textual information on uniform anthropometric fit inspection (see full original size poster at https://failiem.lv/f/k7u5yvz5r or contact the author: eva.lapkovska@rtu.lv). It consists of four sections: 1 – size determination; 2 – visual and tactile assessment of clothing; 3 – assessment of anthropometric fit features; 4 – evaluation of freedom of movement (ergonomics) in clothing.

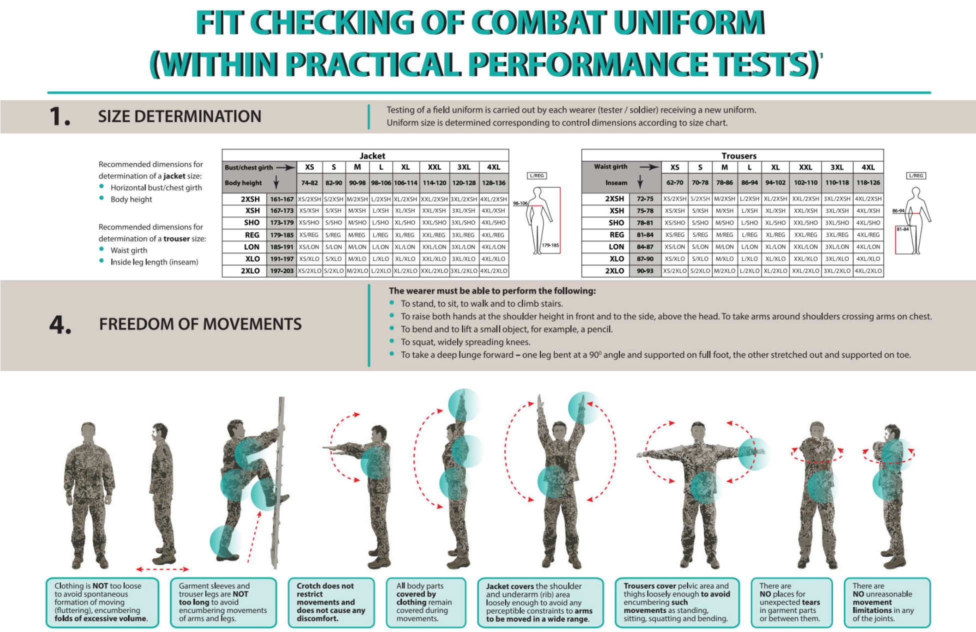


Fig. 3.1. Informative poster for checking the fit of the combat uniform (stages 1, 4) [83].

[6] European Union European Regional Development Fund, Interreg BSR Programme project "Smart and Safe Work Wear" (SWW) #R006

The information poster is a part of the final stage of the method when the user justifiably chooses ready-made special-purpose clothing suitable for a specific sample set. The approach (method step) is adaptable to check the anthropometric fit of any uniform or specialized PPE. In the case of specific products, an analysis should be performed at each evaluation stage to provide a user-friendly and appropriate examination procedure to the branch.

3.1.2. Elements of the method-algorithm

Various elements and components with specific requirements and conditions are involved in the implementation of the evaluation process of the proposed method at certain stages.

1. **Special-purpose clothing (research objects) –** special-purpose clothing such as workwear, protective clothing, sportswear, and other types of so-called functional clothing for which anthropometric fit and ergonomics are critical. The ability of professionals to thoroughly evaluate clothing requires access to its samples and/or prototypes. Depending on the study purpose, clothing in use/wear or a set of sizes of the new prototype should be examined.
2. **Users/consumers (subjects) –** wearers of special-purpose clothing – the sample dataset of a target group for the implementation of the study. When engaging clothing wearers to perform real tests and/or obtain measurements, these processes should not be prolonged and tiresome for the test persons. Also, the involvement of test subjects should be based on the principles of voluntariness. Before the procedures, they should be informed about the research aims and benefits, the course of procedure, and the tasks to be performed. Such approaches can be considered as contributing factors to the reliability of the study – test subjects participate without an order/ordinance/coercion, are informed and are not tired. Information and data on subjects shall be obtained, stored, processed, analysed, and the results approbated following the GDPR (General Data Protection Regulation [85]).
3. **Competent contact-persons –** persons with information on the real situation, specifics and needs of a particular sector. They can be daily wearers of special-purpose clothing and representatives of the particular target group, including officials in charge of the supply service. The method assumes that these individuals point to existing deficiencies in the feasibility study and, with knowledge of the wearer's daily habits and characteristic movements, help define the parameters to be included in the assessment (including the preparation of surveys).
4. **Experts/specialists** – specialists with knowledge and experience in the specifics of special-purpose clothing, anthropometry, commodity science, clothing pattern design, and material selection. They have the ability to assess the anthropometric fit and ergonomics of clothing visually and are informed/trained in the evaluation framework about the specifics of the type of clothing under study and the requirements set for it. The task of the representatives and experts of the structural units involved in the supply is to identify the assessment's input data and select the most appropriate procedures for the evaluation following the specifics of special clothing, existing issues, and available resources.
5. **Anthropometric research –** anthropometric studies of the target audience that are performed to obtain information about the wearer anthropometric profiles and analyze the conformity of the clothing sizing system. For the study's purposes, the wearers' demographic

data (gender, age, in the case of uniform studies, also the position and length of service) must be obtained and compiled.

6. **Interviews** – wearer and contact-person assessments of the clothing's shortcomings, issues; anthropometric fit and movement abilities during work or other activities are obtainable in the form of interviews. The information acquired may correct or supplement the findings of the feasibility study to be used in compiling the evaluation surveys.

7. **Surveys** –written (possibly also online) surveys with previously clarified evaluable clothing indicators to obtain the subjective opinion of the wearers (scheme of the questionnaire offered in the Thesis in Fig. 3.2.).

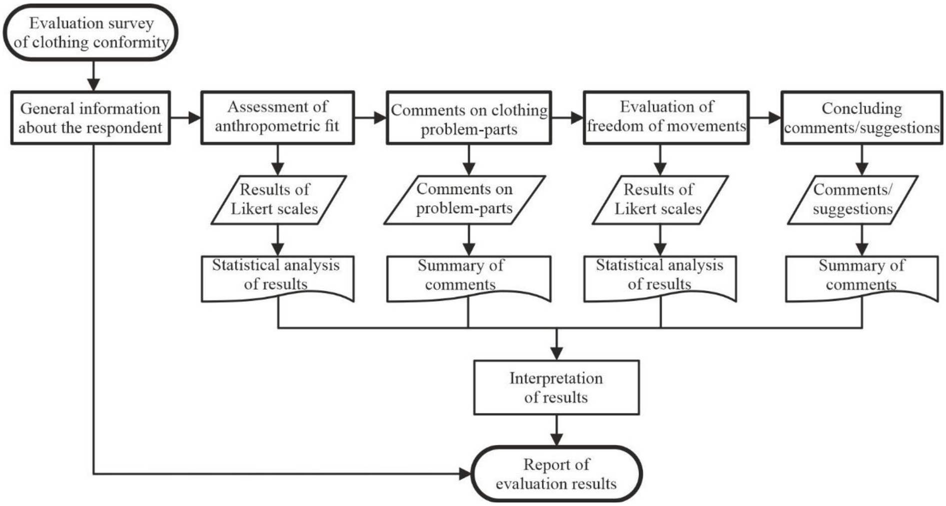


Fig. 3.2. Example of the scheme of operation of the subjective evaluation questionnaire.

8. **Tests of ergonomics** – performance of a series of movements in clothing with a consequent assessment of the wearers' ability to perform them (in the form of a Likert scale). The type and number of movements are included according to the wearer's daily/work/task activities. In the case of confirmation of the effectiveness of the evaluation method, ergonomic tests (motion pictures and explanations) may be included in visual information posters (example in Fig. 3.1).

3.2. Operation and implementation of the method

The proposed concept envisages the creation of a method – algorithm, which is a unifying system of interdependent elements, where combinations of objective and subjective clothing evaluation methods, convergent properties of results and decision-making principles on defective values are guided into practical principles of determination of clothing anthropometric fit and ergonomics. The method is based on top-down analysis, where comprehensive factors for decision-making are known and summarized. The general structure of the algorithm is shown in Fig. 3.3 (the full original size image at https://failiem.lv/f/h9m4fqnvy or contact the author: eva.lapkovska@rtu.lv).

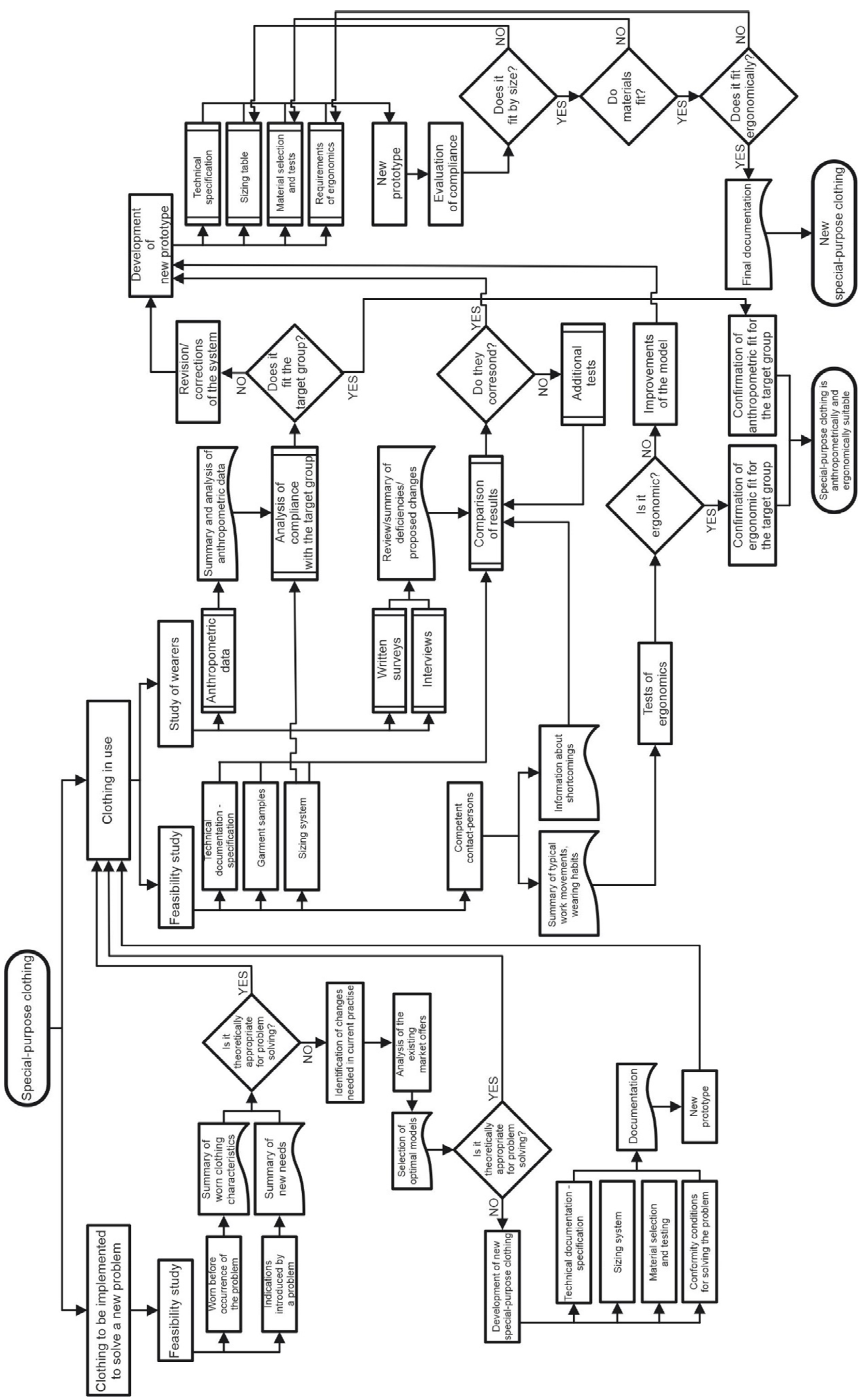


Fig. 3.3. Algorithm for evaluation of the anthropometric fit and ergonomics of clothing.

The developed method realizes the evaluation of the special-purpose clothing sectors and their anthropometric fit and ergonomics. Furthermore, it includes the use of this process in two cases (clothing in use and new clothing to be implemented), when in both cases, the final decision on conformity is determined by the approval of anthropometric fit and ergonomics. However, the algorithm's structure allows narrowing or widening the proposed assessment depending on the specifics of the clothing being evaluated, the problems identified with other compliance indicators, and the requirements of the wearers.

As mentioned above, the algorithm includes two branches (see Fig.3.3):

1. Improvement of clothing in use/wear by identifying deficiencies in anthropometric fit and ergonomics.
2. Implementation of special-purpose clothing to solve a new problem where new hazards, environmental/working conditions necessitate a review of existing practices and the search for solutions in an existing supply or the creation of new clothing for which anthropometric fit and ergonomics also is significant.

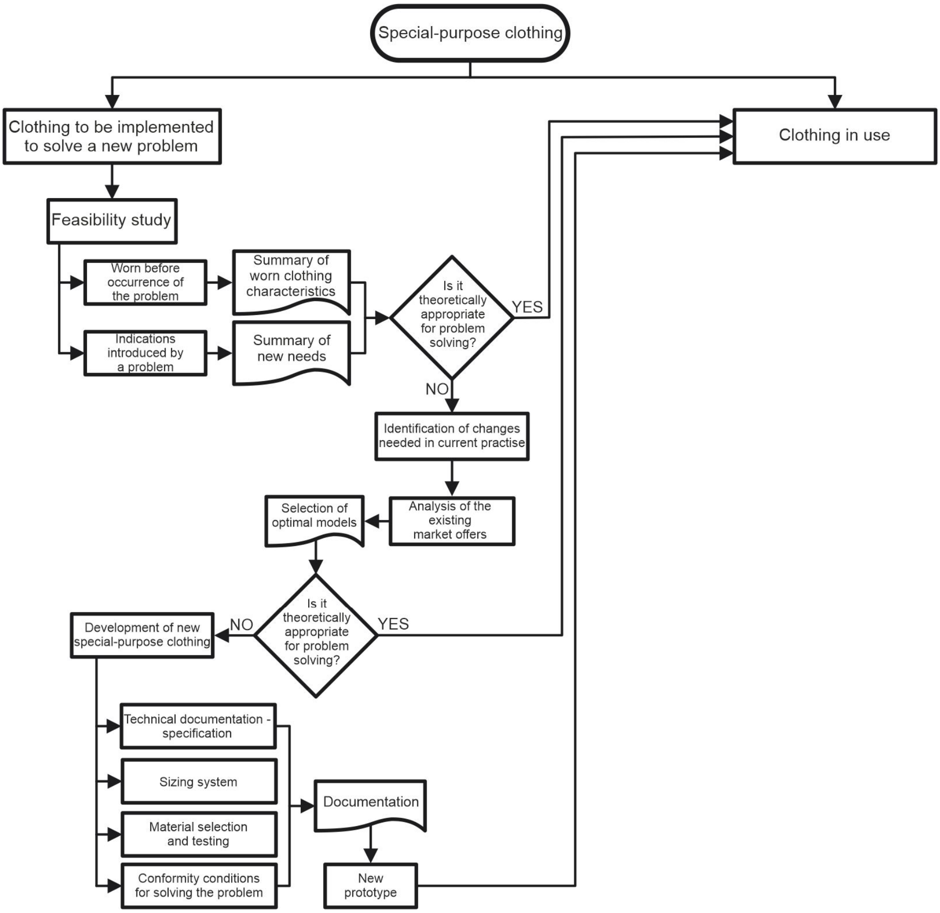


Fig. 3.4. Part of the algorithm – evaluation process of clothing to be implemented to solve a new problem.

The branch of the algorithm (Fig. 3.4) with the stages of the evaluation process of newly introduced clothing is described in Table 3.1. It involves actions for the development of a new prototype, which must be tested in succession. Then the practical use and approbation of the new prototype serves as a guarantee for the commodity evaluation of an existing prototype.

Table 3.1

Evaluation Process of Clothing to be Implemented to Solve a New Problem

No.	Description of the process stages
1.	The **feasibility study** includes: ▪ Research and summary of the characteristics of the worn clothing before the problem occurred. ▪ An explanation of the indications introduced by the problem and a summary of new needs.
2.	**Decisions resulting from a feasibility study on the theoretical suitability of clothing for problem-solving.** After gathering information about the clothing worn before a new problem occurrence and the new needs, a decision is made as to whether it is theoretically appropriate to solve the problem. ▪ In the case of a negative answer (**NO**), it is necessary to identify what needs to be changed in practice to solve the problem, followed by the traditional approach – analysis of the existing market offer (study of the existing solutions), resulting in the selection of theoretically optimal models. ▪ In the case of affirmative answer (**YES**), further evaluation is performed with the branch of the algorithm for the evaluation of the clothing in use/wear.
3.	The selection of optimal models from the current market offer is followed by a decision on actions in cases of their theoretical suitability or unsuitability: ▪ In the case of a negative answer (**NO**), when the current offer is not suitable for solving the problem, a decision is made to create a new special-purpose garment. The process that results in the documentation includes the development of technical documentation – specifications, the development or selection of a sizing system, the selection and testing of materials (if necessary), and the definition of compliance conditions to address the problem. As a result, new prototypes can be developed and further evaluated with a branch of the algorithm for the evaluation of clothing in use/wear to determine compliance with anthropometric fit and ergonomics requirements. ▪ In the case of affirmative answer (**YES**), further evaluation is performed with the branch of the algorithm for the evaluation of the clothing in use/wear.

The branch of the algorithm (Fig. 3.5) with the stages of the evaluation process of clothing in use/wear is described in Table 3.2. This branch of the algorithm describes the analysis of existing clothing and also the method of anthropometric fit assessment of new special-purpose clothing for solving a new problem – sequentially after the prototype approbation. The advantage of the process of improving the existing special-purpose clothing is in the commodity-scientific approach when most of the shortcomings can be identified from the objects already in use.

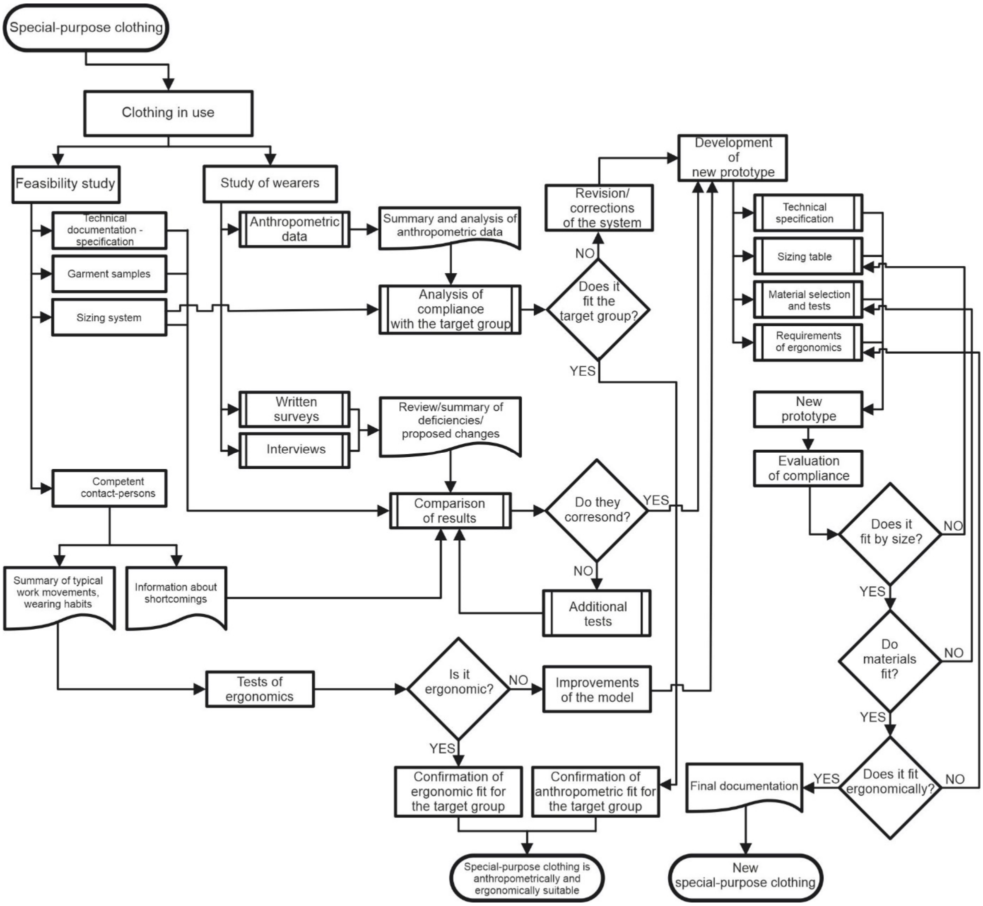


Fig. 3.5. Part of the algorithm – the process of evaluating the clothing in use/wear.

Table 3.2

The Process of Evaluating Clothing in Use/Wear

No.	Description of the process stages
1.	The **feasibility study** includes: ▪ research of technical documentation (specifications); ▪ examination of clothing samples; ▪ analysis of sizing system; ▪ interviews with competent contact persons to gain information on worn clothing deficiencies, wearing habits, and wearers' typical daily/work movements.
2.	**Study of wearers/consumers** includes: ▪ anthropometric research with data collection and analysis;

Table 3.3 continued

No.	Description of the process stages
	▪ written surveys and interviews to review and summarize the clothing shortages and proposed changes.
	Information and data on subjects should be obtained, processed, analysed, and the results approbated following the GDPR [85]. Test participants are informed and instructed about the study's objectives, the content of the tests and the course of action. Before their commencement, information on the age of the participants, the size of the uniforms to be worn, as well as confirmation of consent to anonymous participation in the study is obtained in the form of a signature.
3.	**Analysis of compliance with the target group** Based on the sizing system analysis and the results of anthropometric research, an analysis of the suitability of the clothing for the target group and decision-making can be made after having an answer to the question "Does the clothing fit the target group?": ▪ In the case of a negative answer (**NO**), the sizing system must be reviewed and corrected, thus the creation of a new prototype. ▪ In the case of affirmative answer (**YES**), a confirmation of the anthropometric fit of the clothing for the target group follows.
4.	The following results of the evaluation stages are comparable: ▪ deficiencies and recommendations identified in user surveys and interviews; ▪ a set of analysis of technical specifications, clothing samples and sizing system; ▪ information from competent contact-persons on clothing defects. **For decision making on the need for a new prototype or additional tests:** ▪ in the case of a negative answer (**NO**), when discrepancies or uncertainties are observed in the compilation and analysis of the results, additional tests or studies shall be performed; ▪ in the case of affirmative answer (**YES**), when stable correlations are found and consequent findings on clothing deficiencies are made, the decision is made to develop a new prototype with the previously identified deficiencies eliminated.
5.	**Assessment of ergonomics** As a result of the competent contact persons' information in the feasibility study on wearing habits and movements, ergonomics evaluation tests shall be performed. Following the evaluation, decisions are made: ▪ in the case of a negative answer (**NO**), when the garment is assessed as non-ergonomic, improvements to the model and development of a new prototype should be made; ▪ in the case of an affirmative answer (**YES**), when the garment is assessed as ergonomic, confirmation of the ergonomic suitability of the garment for the target group follows.

Table 3.4 continued

No.	Description of the process stages
6.	The final decision is made on the special-purpose clothing being appropriate when the anthropometric fit and ergonomics of the clothing have been confirmed.
7.	When deciding on the development of a new, improved prototype, the following tasks should be performed: ▪ development (or improvement) of technical specifications; ▪ development of a size chart (or revision and correction of the existing one); ▪ material selection and testing; ▪ definition of ergonomic requirements. It is followed by the production of a new prototype and the assessment of its conformity and decisions on the following characteristics: ▪ compliance of the newly developed prototype size – in case of non-compliance, returning to the revision of size systems/tables; ▪ conformity of the newly developed prototype materials – in case of non-conformity, returning to the selection of materials and/or additional testing; ▪ ergonomic compliance of the newly developed prototype – returning to the imposition of requirements in case of non-compliance. The final documentation and the production of new special-purpose clothing are approved, recognizing the compliance of the newly developed prototype with all three of the above indicators.

A summary of the theoretically achievable practical benefits and decisions resulting from the use of the method is shown in Table 3.3.

Table 3.5

Summary of Practical Benefits of Using the Method

No.	Process and results	Benefits
1.	**The feasibility study:** ▪ Technical documentation ▪ Sizing systems ▪ Clothing samples ▪ Interviews of contact-persons	▪ Information on the current situation has been collected, and problems have been identified ▪ Initial insight into the needs/specifics of the sector.
2.	**Study of wearers/consumers**: ▪ Anthropometric data ▪ Surveys ▪ Interviews	▪ Collection and statistical analysis of anthropometric data of sample dataset ▪ Summary of user opinions ▪ Ideally, an entire population's anthropometric screening within medical commissions/ examinations ▪ Potential improvements in measurement methodology (definitions, procedure recommendations)
3.	**Analysis of anthropometric fit**: ▪ Overview of sizing systems ▪ Anthropometric data statistics	▪ Analysis of the sample dataset with conclusions about the adequacy of the sizing system and procurement size distributions ▪ Decision making for revision/correction of the sizing system

Table 3.6 continued

No.	Process and results	Benefits
4.	**Analysis of deficiencies**: ▪ Feasibility study conclusions ▪ Disadvantages/suggestions from contact-persons ▪ Disadvantages/suggestions from wearers	▪ Comprehensive conclusions on deficiencies and recommendations for improvement following the feasibility study, the opinions of wearers and competent contact-persons ▪ Decision making on additional testing or the need to develop a new prototype
5.	**Assessment of ergonomics**: ▪ Typical work movements, wearing habits from contact-persons ▪ Ergonomic tests	▪ Clear and adaptable parameters for assessing ergonomics ▪ Results of ergonomic tests identifying clothing deficiencies ▪ Decision making for model improvement needs

The responsibilities of the procurement department of one institution mainly include the purchase of a wide range of items (from equipment, furniture and cars to clothing, stationery, etc.), and not all professionals can be equally knowledgeable and, even more so, experts, in all items. Compared to other products that are easily adaptable to humans, the multitude of clothing parameters (materials, functional solutions, anthropometric fit and ergonomics) is challenging to define and evaluate precisely, considering individual interactions with each consumer, different individual preferences, and comfort perceptions. In practice, complaints from tenderers for special-purpose clothing, indications of shortcomings or inaccuracies, and questions with consequent requests for clarification of specifications are the main reasons for discontinuing procurement. The problems are due to inadequate specifications from the outset and a lack of understanding among the services of the appropriate clothing, up-to-date materials, technological progress, and solutions meeting the scientific level. It is followed by the inability in providing answers to tenderers, resulting in the procurement termination without a result. Risks of not purchasing products of the desired quality permeate all stages of the procurement process, where appropriate knowledge, experience, or the involvement of an expert (material science specialist, procurement specialist, lawyer) is required for evaluation and decision-making. The critical cases are when the conformity of a product is only formal and the responsible official cannot identify the defects due to a lack of competence, thus putting a low-quality product at the disposal of the consumer. A rational decision to prevent such inefficient procurement is the timely involvement of experts. Because of knowledge and experience, they can reasonably assess product deficiencies and non-conformities or, on the contrary, see better solutions and even consider them in further improvements of specifications.

The practical application of the method principles introduces a new operational policy for the organization of special-purpose clothing and PPE supply processes, basing decisions on the regularities that the various aspects of conformity assessment cannot be considered separately and require a systematic approach. Moreover, the complexity of the assessment method – algorithm (scope and linkage of elements, processes, and methods), indicate the need for the supply services assess their ability to use it with/without the involvement of experts, considering their own competencies. The structure of the improved policy (Fig. 3.6), compared to the traditional one, includes sub-processes for the improvement of the procurement procedure and promotion of the objectivity of decisions, which envisages the involvement of experts with knowledge and experience in the practical application of the evaluation processes.

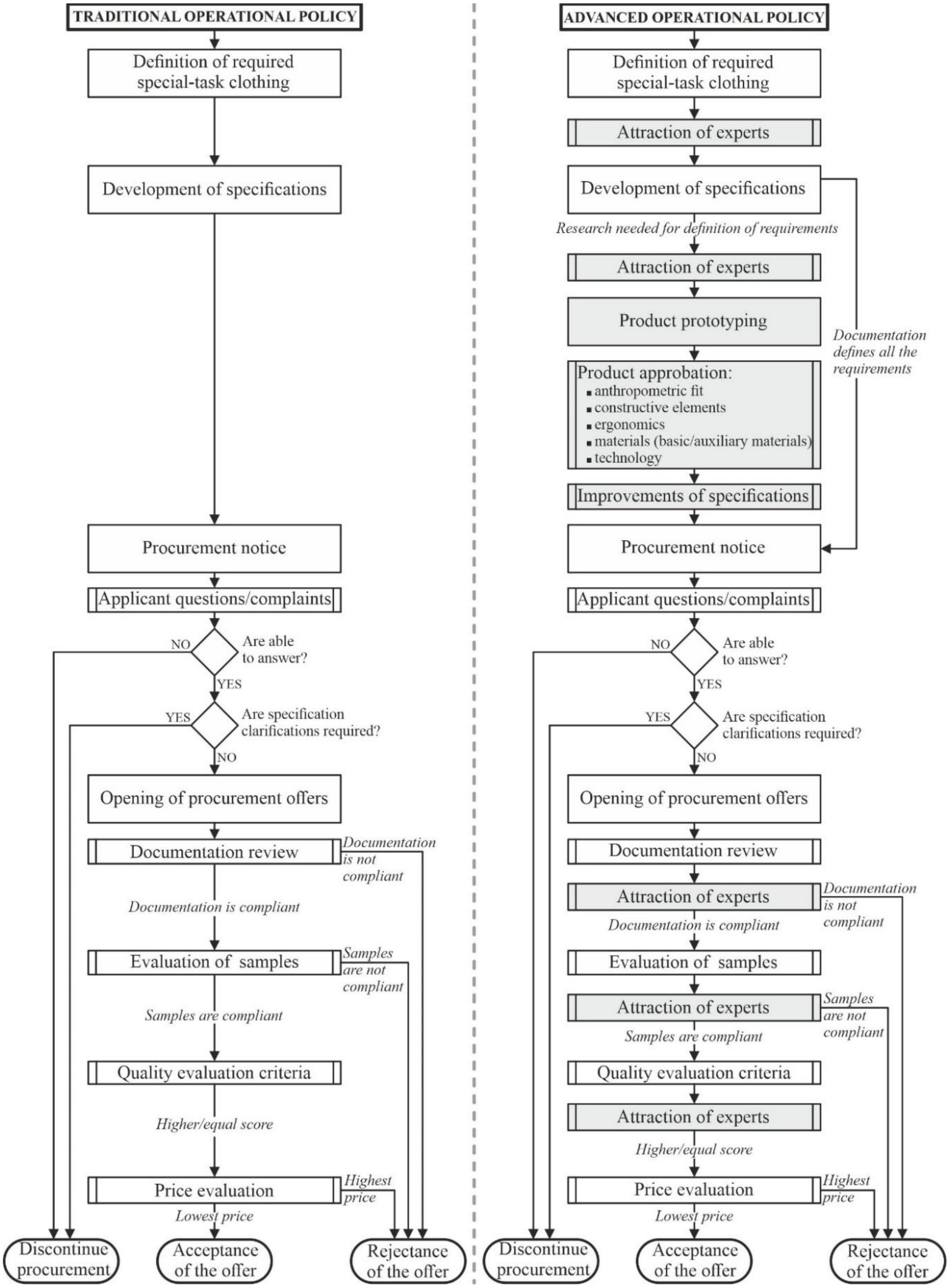


Fig. 3.6. Traditional and advanced operation policy for special-purpose clothing procurement.

Procurement efficiency is based on the involvement of experts in the initial stages – specification development, product prototyping and approbation (innovation to improve specifications), as well as during tender evaluation – documentation review (technical specifications, sizing, materials), sample evaluation and assessment of compliance with quality criteria evaluation (evaluation of eligible tenders). Furthermore, the involvement of experts can mean both extensive studies included in the special-purpose clothing evaluation algorithm developed in the Doctoral Thesis and narrowed parts of it. It depends on the specificity and complexity of the procurement subject, the stage of existing developments, as well as on the previously identified problems and their extent in the evaluation and procurement processes of particular or similar items. As a result of operational policy changes and expert-level assessments and decisions, procurement is less frequently interrupted, the competencies of the supply services increase, and thus the synergy between the wearers (demands), the clothing designer/manufacturer/supplier and the supply services are systematically stabilized.

3.3. Conclusions of Chapter 3

The realization of the described method is based on conclusions about the lack of practical and systematic principle sets of conformity assessment and the decisiveness of special-purpose clothing characteristics, such as anthropometric fit and ergonomics, in meeting the needs of wearers – their ability to perform their daily duties. Systematic detection of non-conformity of clothing with such a method allows justified decisions to be made for its improvement. The method is already in the development process based on applied research to solve a specific problem. Theoretical findings have introduced additions to the generalization of the method.

Main **conclusions** of Chapter 3:

- The developed method is based on a system summarizing practical principles for clothing assessment and decision-making, facilitating the supply of appropriate special-purpose clothing to groups of wearers. Unlike similar methods, it is not generalized but includes a systematic approach and algorithmic elements for reviewing individual cases in the search for causality of existing problems.
- The principles of the method improve the existing approaches to assessing the anthropometric fit and ergonomics of clothing – the developed algorithm includes and links both processes and methods and decision ontologies for assessing the conformity of clothing to ensure the supply of wearers with clothing that meets the requirements.
- The logic of the decisions of the clothing supply process and the resulting synergy between the parties involved is facilitated by the element set involved in the evaluation process. The assessment is based not only on statistical data and technical information but also on the subjective evaluation of the wearers themselves.
- The basis for improvements in the operational policy of organizing the procurement of special-purpose clothing and, consequently, in the effective procurement process and the purchase of a higher quality item is the involvement of respective experts, ensuring objective decision-making following state of the art and best practices.

- The real application of both the left branch of the method – algorithm (clothing to be implemented to solve a new problem) and the right branch (clothing in use) will be influenced by the possibilities to obtain the necessary data and information, as well as their quality and interpretation skills.

4. APPROBATION OF THE DEVELOPED METHOD

The initial algorithm of the method was developed in the study of the Latvian National Armed Forces contingent within the framework of the European Union European Regional Development Fund, Interreg BSR Programme project "Smart and Safe Work Wear" (SWW) #R006; and its improvement and generalization need to be approbated for another sample set.

The approbation of the right branch of the algorithm has taken place by evaluating the duty-uniforms of the State Fire and Rescue Service (hereinafter – SFRS). During the development of the experimental part of the Doctoral Thesis, SFRS reviewed the technical specifications of clothing procurement for the preparation of procurement documentation; and the results of the research have allowed identifying the shortcomings of the duty-uniforms. Thus, it served as a practical guide for the responsible department to promote the conformity of the clothing to be delivered (SFRS support letter in Appendix 1 of the Doctoral Thesis).

The branch of the algorithm, when protective clothing is introduced as a result of a new problem, has been implemented in the project of the National Research Program "Covid-19 Mitigation" (No. VPP-COVID-2020/1-0004) "Integration of Safe Technologies for Protection against Covid-19 in Healthcare and High-Risk Areas". Based on the method, a survey of functional specialists was conducted to find out the opinion on the criteria for developing of specific personal protective clothing.

4.1. Method validation experiment

The approbation was performed to evaluate the SFRS duty-uniforms (jackets and trousers) operated in the supply, confirming the practical significance of the developed concept. Prior to the practical application of the method, validation experiments were planned – the components were identified and summarized (Table 4.1).

Table 4.1

Summary of Process Components

No.	Element	Description	Set in the study
1.	**Objects**	Uniforms (duty-uniforms) are worn during daily work. A uniform consists of a jacket (shirt type) and trousers. It is planned to wear a layer of fireproof protective clothing ("battle" suit) over them during rescue operations.	Uniform size set and list. A total of 84 items (42 jackets, 42 trousers). The samples received represent the total size scale of one clothing purchase (one manufacturer).[7]
2.	**Documentation**	Technical specification of duty-uniforms.	Descriptions of jackets and trousers.
3.	**Subjects**	SFRS employees performing active work on a daily basis.	59 people[8]: 9 women; 50 men

[7] The approbation of the method was performed in a real situation with the selection of the specific uniforms actually available.

[8] Volunteer participants – active service staff; the number of participants is close to the number of clothing sets delivered.

Table 4.2 continued

No.	Element	Description	Set in the study
4.	**Contact-persons**	Competent contact-persons to find out typical work movements and wearing habits.	Two competent contact-persons performing active work on a daily basis.
5.	**Experts**	Industry specialists with knowledge and experience in the specifics of special-purpose clothing, anthropometry, and clothing pattern design.	3 specialists

4.1.1. Feasibility study and target group research

According to the method, the feasibility study phase in which industry experts are involved in the specific case includes the examination of technical documentation, the evaluation of clothing samples, the analysis of the sizing system, and communication with the competent contact persons of the institution. Subjects are involved in the wearer/user research phase to identify available research sample set.

Uniform size sets and lists were issued for study purposes. Based on the list and the labelling of the uniforms, size tables were compiled for analysis, and it was concluded:

- After filling in the tables, it is concluded that the size distribution of received samples is not uniform and does not correspond to the normal distribution. Therefore, it is not substantiated and indicates unawareness about the anthropometric profile of the target audience.
- It has been concluded that, contrary to the traditional practice of introducing waist circumference as the key dimension for lower body garments, chest circumference serves as the key dimension in the trouser size system. It does not describe the structure of the trousers and the supporting surfaces, contributing to the difficulty in choosing appropriate clothing. The responsible officials were informed about the discrepancy, and it is recommended to control that the waist circumference is used as a key dimension. Thus, the first stage of the feasibility study has allowed identifying the shortcomings of the existing sizing system and increasing the competencies of the supply service on the basic principles of the structure of sizing systems.
- During interviews, it was found that most of the wearers are ot aware that they do not understand the content of the labelling – the meaning of the symbols in relation to body measurements. When summarizing the sizes indicated by the test persons (for jackets Fig. 4.1), various size labelling types were observed (9 types for jackets and 7 types for trousers).

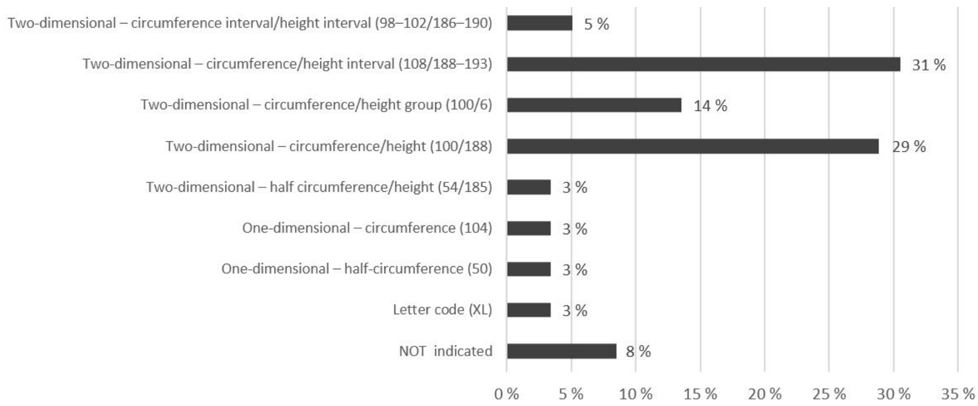


Fig. 4.1. Size labelling types of duty-uniform jacket indicated by wearers.

It shows that the uniforms have been delivered at different times, without labelling requirements, and that the decipherment has been left to the manufacturers' discretion. Thus, in the continuation of the feasibility study, the supply service acquires knowledge about the variations of the clothing size labelling, assuming that to increase the efficiency of further supply processes, they should define the desired type of labelling. However, the manufacturer should provide an explanation, and the staff should be informed about the implemented solution.

The following stages of the algorithm implementation include obtaining information about clothing deficiencies from both the contact-persons (interviews) and the wearer group (interviews, surveys, registration protocols), in parallel obtaining anthropometric data of the sample set and characteristic work movements from the contact persons.

Other deficiencies identified:

- Discrepancies observed by the wearers were identified, such as the proportions of garments for the upper body (jacket, T-shirt) and trousers in total and individual parts of clothing and functionality (belt, pockets). Various defects were mentioned – bursts in the crotch area, defects in the belt loops and buttons. The findings indicate the need for additional measures to prevent the entry into service of non-compliant clothing. The method involves reviewing the shortcomings/recommendations reported by users and specialists as a systematic step in improving future order specifications regarding quality criteria.
- Various objections were also raised to sensory and thermal comfort, which are affected by the properties of textiles. The systematic nature of the method implies the logical approach – to continue the shortage analysis by a comprehensive assessment (including textiles). Then, if necessary, the type of fabric or the requirements of parameters may be changed.

For the next evaluation process (tests of ergonomics), the characteristic work movements were clarified for inclusion in the subjective evaluation questionnaires (Fig. 4.2). A total of 11 body movements (fixed postures) are included.

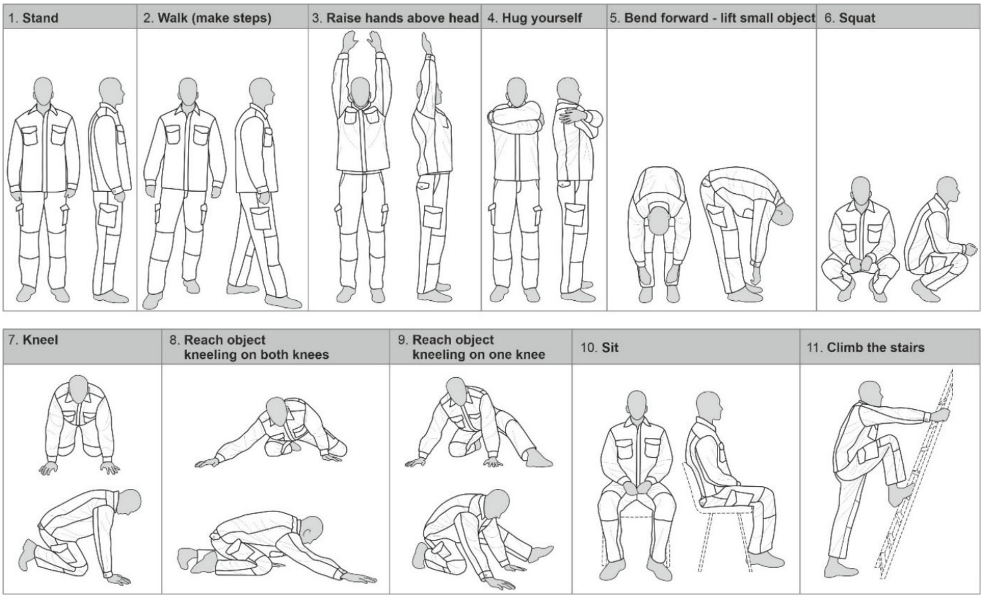
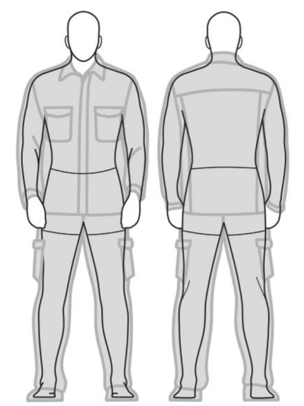


Fig. 4.2. Body postures/movements for assessment of duty-uniform ergonomics.

The evaluation questionnaires include a section on general suitability features of the garment, such as ease of donning and doffing, personal sense of anthropometric fit, the weight of the garment, ease of use of fasteners/adjusters, opinion on overall looseness and length of individual parts (sleeves, trouser legs) and joint restraint (Fig. 4.3).

EVALUATION OF ANTHROPOMETRIC FIT AND ERGONOMICS

Date:		**Participant CODE:**		**Clothing CODE:**	



CLOTHING FIT:	Very easy	Easy	Moderate	Hard	Very hard
Donning and doffing	–2	–1	0	1	2
	Extremely small	Slightly small	Corresponding	Slightly big	Extremely big
Size conformity	–2	–1	0	1	2
	Very light	Light	Neutral	Heavy	Very heavy
Clothing weight	–2	–1	0	1	2
	Very comfortable	Comfortable	Moderate	Uncomfortable	Very uncomfortable
Fasteners and regulators	–2	–1	0	1	2
	Extremely tight	Too tight	Moderate	Too loose	Extremely loose
Looseness of clothing	–2	–1	0	1	2
	Extremely short	Too short	Moderate	Too long	Extremely long
Sleeve length	–2	–1	0	1	2
	Extremely short	Too short	Moderate	Too long	Extremely long
Trouser-leg length	–2	–1	0	1	2
	Totally not restricted	Not restricted	Neutral	Restricted	Extremely restricted
Joint restrictions	–2	–1	0	1	2

← In the picture, additional problem areas should be indicated and commented on - restrictions on movement or other effects affecting the performance of work (areas can be outlined, coloured, or otherwise visually indicated and commented on in the text).

	***FREEDOM OF MOVEMENTS*:**	Very easy	Easy	Moderate	Hard	Very hard
1.	Stand	–2	–1	0	1	2
2.	Walk (make steps)	–2	–1	0	1	2
3.	Raise hands above head	–2	–1	0	1	2
4.	Hug yourself	–2	–1	0	1	2
5.	Bend forward - lift small object	–2	–1	0	1	2
6.	Squat	–2	–1	0	1	2
7.	Kneel	–2	–1	0	1	2
8.	Reach object kneeling on both knees	–2	–1	0	1	2
9.	Reach object kneeling on one knee	–2	–1	0	1	2
10.	Sit	–2	–1	0	1	2
11.	Climb the stairs	–2	–1	0	1	2

Place for other comments (optional):

Fig. 4.3. Questionnaire for subjective evaluation of clothing fit and ergonomics.

The research phase leads to the conclusion that there is a partial awareness in the structural units about the wearer's body parameters without a defined and reliable procedure for obtaining them, which can be further used to prepare the procurement size distribution. Purposeful and formalized anthropometric research of uniform-wearer firefighters and, consequently, statistical processing of data for the development of the size distribution is not carried out, delaying the execution of orders that have a reasonable type and number of sizes. In turn, this forces manufacturers to act arbitrarily, basing the type and number of clothing sizes to be supplied on data from similar supplies or very approximate distributions. The findings in the feasibility study indicate the anthropometric survey of the target group included in the method and also required in this case. Furthermore, traditionally, an appropriate sample set would be sufficient for anthropometric study, but in this case, a total population (whole service) is required, considering that in the long term a complete data of the service are not obtained. As a result, there are no reliable statistics to rely on when compiling orders.

4.1.2. Evaluation of anthropometric fit and ergonomics

The third stage of the evaluation includes a summary of the demographic and anthropometric indicators of the wearers, an analysis of the anthropometric data and the suitability of the uniform size system for the target group, as well as a summary of the subjective evaluation of ergonomics.

1. **Summary of demographic and anthropometric indicators of subjects**

In total, 59 SFRS employees were involved in the study. The distribution of body height measurements was analysed to determine the uniformity of the research dataset. A comparison of the body height distribution of the given dataset with the normal distribution curve shows that most fall within the normal distribution. The data were checked against normal distribution to analyze whether the dataset at least approximately presents the entire population of 3,000 firefighters. Although it is concluded that the correlation is quite close in general, the deviations at the ends of the dataset can be explained by its small size. Thus, a statistical size distribution based on these measurements may not be prepared and requires a complete re-examination of the population or at least a population-representative sample dataset (at least 10 %).

2. **Conformity analysis of the sizing system and the uniforms worn**

After obtaining and processing anthropometric data, an analysis was performed comparing the frequencies of the size distribution of the following jackets and trousers:

- distribution by sizes of clothing in use (participants have indicated in the registration protocols);
- size distribution compiled according to body measurements (based on an anthropometric study of the dataset).

First, the frequencies of the distribution of chest circumferences are compared (key dimension – chest girth), which show significant differences in both jackets and trousers, indicating that the specific supply of uniforms is inadequate in terms of size system, and therefore inefficient. As can be seen (Fig. 4.4), jackets with a size of 100 (interval 98–102 cm) are the most (25 %) given to the sample dataset, but in the distribution according to anthropometric data, the most represented are sizes 108 (106–110 cm) and 112 (110–114 cm), both collecting 17 % of the sample dataset.

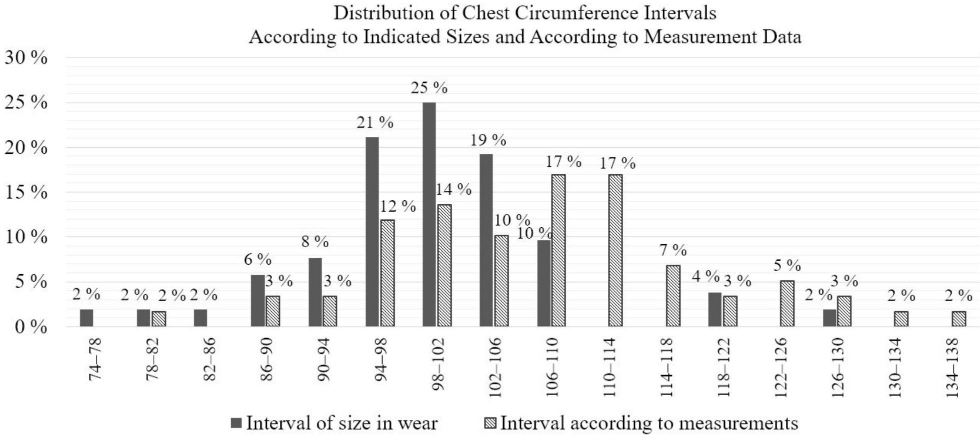


Fig. 4.4. Jacket size analysis – distribution of chest circumference intervals.

In addition to the above explanation of the choice of the waist girth as the most suitable primary measurement in the trouser size system, the waist circumference distribution according to the chest circumference indifference intervals in the existing size system has been developed. It shows that several waist circumferences may be comprised within one chest interval. For example, the most worn trouser size 104 (interval 102–106 cm) includes wearers with a waist circumference of 78–90 cm (3 size groups by waist circumference) and size 112 (110–114 cm) even 5 size groups with a waist circumference of 86–106 cm. It proves that chest girth as a key measurement will make it difficult to choose trousers that match body characteristics.

At the end of the size system evaluation, a size distribution (based on the indifference intervals of the existing size system) was developed according to the obtained sample dataset somato-measurements (Fig. 4.5), grouping all test subjects by sizes according to the key measurements – chest circumference and body height.

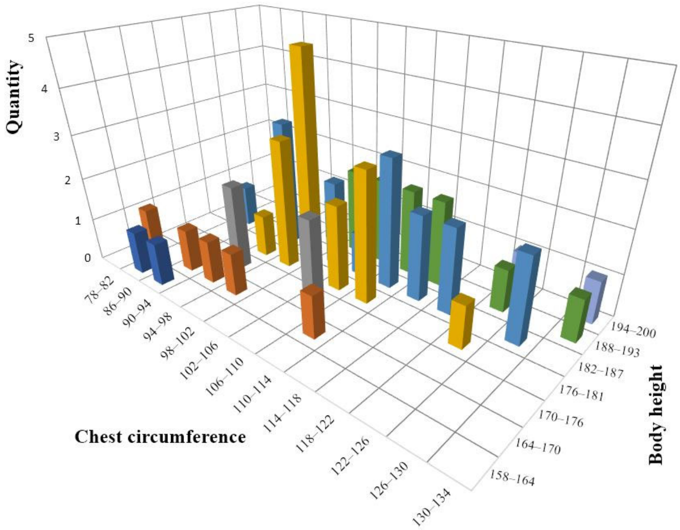
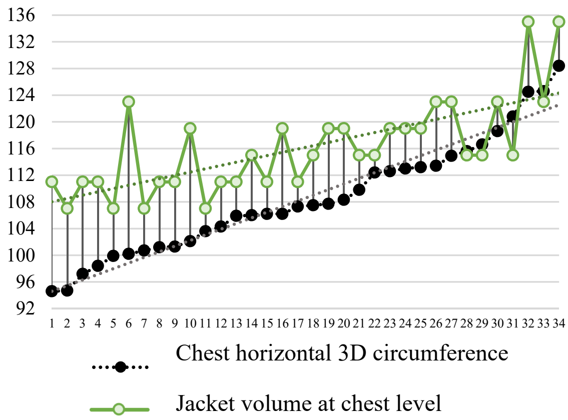


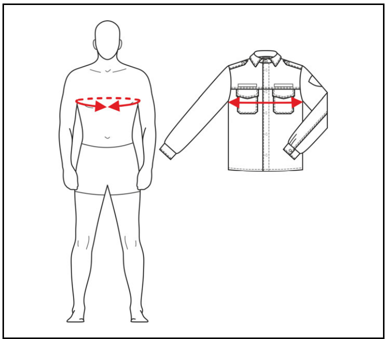
Fig. 4.5. Size distribution by somato-measurements of sample dataset.

A significant variation in sizes is observed (13 chest girth intervals, 7 body height intervals – making a total of 91 combination options), moreover, with a different, mostly small proportion of wearers. It can be concluded that a reasonable procurement policy requires an extensive anthropometric study of the target group and a review of the distribution of sizes, as a result of which the customer purchases a sufficient but also an economically justified variety of sizes.

For additional research on the ease allowances introduced for the delivered clothing – for conclusions on compliance with the somato-characteristics of the target group, control measurements of the available set of uniforms were performed, determining the chest ease allowance for jackets (resulting in an average of 15 cm) and sleeve and jacket lengths for the corresponding sizes. The perimeter measurement of the belt and the trouser inseam length was obtained for the trousers. Control measurements were analysed in conjunction with the corresponding somato-measurements traditionally used in pattern design. The smallest, largest, mean, and standard deviation values for the differences between these measurements were determined. Some examples of analysis:

- The jacket's volume at chest level for the corresponding size is compared with the value of the wearer's chest circumference (Fig. 4.6). The trend up to a chest circumference of 116 cm shows that for a particular part of the wearers, the jacket has sufficient ease-allowance and, in some cases, even significantly increased. However, from this 116 cm boundary, the dimensional correspondence at chest level varies from sufficient to insufficient when the volume of the jacket at chest level is less than the wearer's chest circumference. Given the importance of upper-body garments' chest level volume for providing fit and ergonomics, deviations indicate the need to review the sizing system and/or control supply processes.





Indicator	*min*	*max*	*mean*	*SD*
cm	–5.8	22.8	7.6	5.7

Fig. 4.6. Analysis of the chest ease allowance of a duty-jacket.

- A similar trend in trousers shows that the value of the belt's ease allowance is sufficient and exceeds for the waist circumference in the range of 70-90 cm. After that, it is very small or insufficient, and by reaching the waist circumference of 106 cm, it shows only an insufficient amount of allowance. Thus, starting from the 90 cm boundary, trousers can cause discomfort, limiting the ability to move and causing defects. For solving the problem, 1) appropriate key measurements must be introduced in the trouser sizing system (inferred from the analysis of the sizing system); 2) adequate ease allowances must be used in the design; and 3) the elements for adjusting the volume of the trouser belt (drawstring, elastic straps) must be considered.

3. **Results of subjective evaluation questionnaires**

Before the analysis of subjective evaluations, the Kendall coefficient *W* was obtained to determine the degree of consensus of evaluators (consistency of opinions) – subjective evaluations of observers (22 rescuers), experimental group (37 rescuers) and the whole dataset (59 rescuers) [87]–[89]. It was done on the principle that at an Alpha value of 0.05 (1–0.95 to 95 % confidence level used in engineering), the result is considered statistically significant (because the p value is lower than Alpha) $p = 1{,}4437 \times 10^{-42}$. As a result, the Kendall coefficient for the whole dataset $W = 0.234$, the observation (superuser) set $W = 0.300$ and the experimental set $W = 0.217$. The greater consensus in the observations can be explained by the fact that the representatives of this group have more experience in wearing special-purpose clothing, similarly in assessing the clothing. On the other hand, the experimental dataset members are cadets who have recently started wearing uniforms, so a narrower experience influences their opinions.

The results of the Likert scales are summarized and presented in bar charts (so-called stacked bar charts). Moreover, both within the framework of the whole study sample, by summarizing the evaluations obtained in the observations and analysing the experimental dataset. Some examples of summaries:

- In assessing the overall feelings about size conformity (Fig. 4.7), the majority (above 50 % of all 3 cases) is satisfied with this indicator. Equally, in all three datasets, 27 % indicate that the uniforms are slightly big and 14 % slightly small. Despite the majority's satisfaction, the proportion of size mismatch ratings is significant and again points to problems in drawing up the appropriate type and number of sizes.

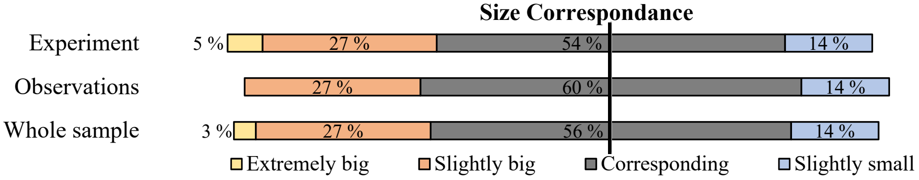


Fig. 4.7. Subjective assessment of uniform size correspondence.

- In all three cases, restrictions on joint movements are assessed neutrally by about 40 % of rescuers, but a significant part (about 30 %) indicate restrictions, some even pronounced. At the same time, a sufficiently large proportion (around 19 %) consider that clothing does not restrict movements, even stating that it totally does not restrict them. Tests of ergonomics provide a detailed picture of movement restrictions, but there are repeated links with shortcomings in the sizing system at this stage of the assessment.

According to the second section of the questionnaire and the developed movement pictures (see Chapter 4; Sub-chapter4.1; Section 4.1.1.), the wearers assessed the freedom of movement in the duty-uniforms. For example, analysing the evaluation of the whole sample set, it can be clearly concluded (Fig. 4.8) that easy-to-perform poses include standing, sitting and walking; slightly more difficult to "hug oneself"; it is followed by a series of even more restricted movements – climbing stairs, bending forward to lift objects, raising hands above the head, and kneeling on both knees; the most restricted movements include reaching object on one or both knees, as well as squatting, moreover, the last ones are specific to the work of rescuers.

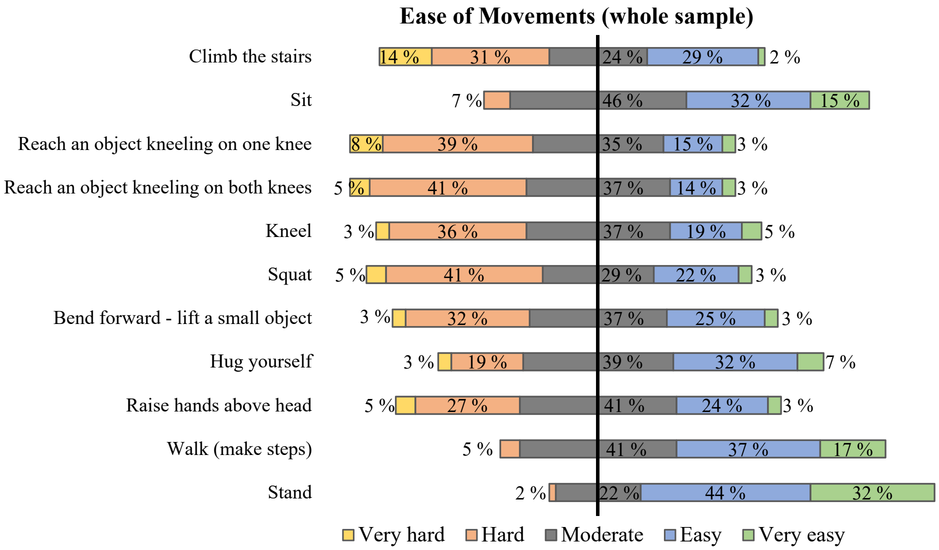


Fig. 4.8. Summary of subjective evaluation results – the whole sample dataset (59 participants).

Once the restricted movements (daily and work-specific) have been identified and communicated to both the supply specialists and the clothing designers (manufacturers), a complex process of interpreting the assessment results follows. Then all stakeholders by appropriate operational policies need to agree on appropriate solutions to develop improved clothing models.

4.2. Comparison of manual and non-contact somatic measurements

The author's experience in anthropometric research [83], [90] has highlighted observations of differences between manual and non-contact somato-measurement data, including the data on horizontal chest/breast circumference. This measurement is considered one of the most important in anthropometry. It is included in the total morphological features, and it is the key (primary) measurement of the garments for the upper body. Body characteristics affecting chest circumferential somato-measurement are: the size and location of the mammary glands; the inclination of the trunk; the symmetry of the trunk; the type of torso posture; and the distribution of soft tissue into muscles and adipose layers and their location. Non-contact measurement techniques, including 3D scanning technology, allow the horizontal perimeter of the body to be obtained at a certain level – geometrically based on the bust point or the most protruding point on the breast muscle. By taking the plantar plane as the reference level (placing the measurement parallel to it), obtaining the horizontal circumference of the chest is according to the definition. In turn, the chest perimeter is obtained manually by measuring the two-dimensional measurement volume with a tape measure and using an anthropometer for the horizontality. However, there are doubts about the ability of the meter to obtain a precisely horizontal measurement of the chest circumference – it depends on professionalism, the ability to control both the horizontal position of the measuring tape in relation to the plantar plane and the encircling of the measuring tape around the body.

Within the framework of the study, data on the horizontal circumference of the chest for two sample datasets were obtained manually and by the non-contact method (3D scanning). Figure 4.9 summarizes the differences in measurements for a group of average and well-trained people sample set (51 people analysed in the approbation – SFRS active service). Each measurement subject's 3D horizontal breast circumference is plotted on the ordinate axis, arranging them in ascending order according to breast circumference value. The measurements obtained by the tailoring method (manual measurement) are arranged according to the ordinal number of the subject.

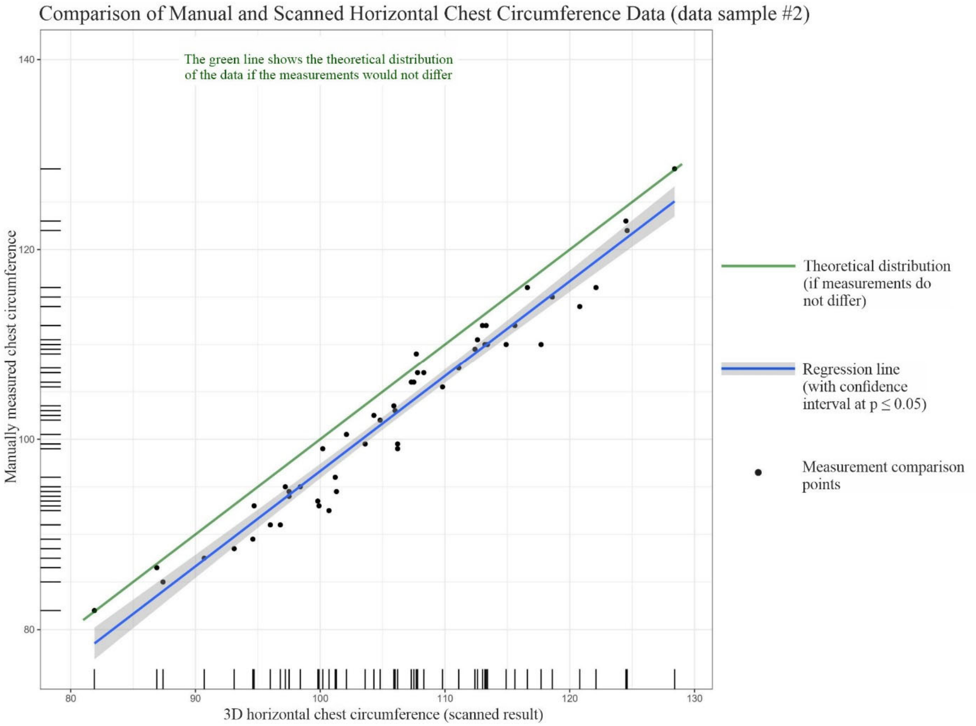


Fig. 4.9. Comparison of non-contact (3D) and manual (tailoring) somato-measurements [*R* [91]].

The straight line (green line) in the graph indicates the theoretical distribution – if the measurements do not differ. The regression line marked with a confidence interval at $p \leq 0.05$ shows that the measurement used in tailoring is not sufficiently correlated with the anthropometrically correct measurement – most of the measurement comparing points are outside the amplitude range (–6.7 cm, +1.4 cm). This result explains the widely accepted practice in tailoring to make a garment pattern roughly and then adapt it to the individual's somato-specifics. Moreover, although tailor-made measurements are often used in industrial practice, databases that have been developed in more extensive studies, which are much more reliable, are most often used there. Anthropologically correct measurements also show different levels of difference, most often reaching a positive difference, which gives the comprehension that the non-contact measurement tends to be larger than the one obtained manually. Therefore, differences in measurements are included in measurement errors when, for example, a tape measure has slipped or a value has not been read/recorded properly during the manual acquisition of a measurement. It can be concluded that the only influencing factor is the morphology of the tissues and the surface – a deep, focused study is needed to see the closeness and tendency of the relationship. At this stage of the study, it can be concluded that non-contact measurement is considered more reliable due to its objective and precise mathematical nature. In addition, the differences obtained are not considered to affect the quality of the product – the range of differences obtained in this sample set is 8.1 cm. 15 cm are used for special tasks uniforms for SFRS, but 28 cm for NAF uniforms. Therefore, the whole range of measurement differences falls within the indifference interval. Thus, the scanned measurement is suitable for ensuring the anthropometric fit of uniforms.

In addition, as the study is based on a small sample set of well-trained people, the data were examined by the same method based on a random sample of women with different parameters but with a tendency of increased adipose tissue content in the body (opposed to the previous set). It is a sample set of 42 women whose special task does not require good physical fitness. Moreover, the motivation for the study of the sample is a large amplitude of the breast circumference (the min value of the horizontal measurement is 86 cm, and the max value is 139 cm). Manual measurements have shown that very large breast volumes are difficult to measure even with the anthropometrically correct method, which explains the more significant variation in differences. Thus, the conclusion is added that measurements of complex individuals in the non-contact method can be performed more accurately.

4.3. Conclusions of Chapter 4

Main **conclusions** of Chapter 4:

- The aim of approbation has been achieved – directions of method improvements have been clarified and process detailing has been performed. As a result of the approbation, it has been established that the algorithm essentially does not require any corrections; it works according to the given sequence of processes and appropriately initiates the next step. However, attention should be paid to the preparation of each individual target audience for the study – instructions are needed on the importance of steps for purposeful assessment of anthropometric fit, excluding aspects such as demonstration of personal ability (strength), failure to follow instructions (if the purpose is not understood), etc.
- In general, the opinions of the wearers obtained allow assessing the shortcomings of the existing uniforms and identifying the necessary systematic anthropometric examinations. As a result of practical approbation, it has been concluded that there is no systematic approach to the evaluation of clothing, and there is a lack of cooperation between supply services and uniform users. It allows to confirm and validate the criteria for evaluating uniforms, which are embedded in the Doctoral Thesis method.
- The case study findings have contributed to the knowledge of users and supply services about the problem of clothing anthropometric fit and ergonomics, their causations, and solutions, contributing to the efficiency of future procurements, tender evaluation, and decision-making.
- The ergonomics of the clothing can be ensured and its assessment reliable by first introducing a sizing system corresponding to the anthropometric profiles of the population. It is impossible without a complete re-examination of the population. The comparison of the data at the end of the approbation allows the industry to accept the 3D non-contact anthropometric method for introducing database and size systematization for each service that uses special-purpose clothing and PPE.

- The repeatability and adaptability of the algorithm facilitate the use of its variations in the evaluation of different clothing assortments.

CONCLUSIONS AND RESULTS

The aim of the Doctoral Thesis to develop a method for assessment of clothing anthropometric fit and ergonomics and to test and approbate the operation of its algorithm has been achieved by implementing several **tasks**:

- Aspects of clothing design have been identified and analysed, allowing to estimate their connection and importance in ensuring the anthropometric fit and ergonomics of clothing, their deficiencies, and directions of improvement. The review has pointed out the importance of evaluating the effectiveness of the principles and techniques used in the clothing design in the circulation of appropriate clothing for wearers.
- The concept components of clothing conformity and their evaluation methods have been summarized and analysed, which allowed defining the elements of the method – algorithm for evaluation of clothing anthropometric fit and ergonomics.
- The methods for assessing the conformity of clothing recommended in industry standards, including anthropometric fit and ergonomics, have been studied and relatively compared. The identified advantages and disadvantages have made it possible to clarify the concept and define the principles for constructing the method – algorithm. The identified advantages and disadvantages have made it possible to clarify the concept and define the principles for the algorithm's structure.
- The algorithm of the developed method has been experimentally approved – the compliance of SFRS duty-uniforms with the wearers has been assessed, attracting a sample dataset, competent contact-persons, and officials of the supply services.

The research identified **problems** in the processes of clothing design and distribution:

- Outdated anthropometric data are mostly available, and new data sets are limited and/or unavailable (expensive, closed), but research on individual target sample datasets is a costly and time-consuming process.
- The lack of data promotes the usage of outdated or from other garment developments inherited sizing systems, leaving deficiencies in the selection of key (primary) measurements and the distribution of size intervals.
- The lack of explanation of the meaning of the clothing labelling causes difficulties and confusion for the wearer's understanding and ability to choose clothing that matches their body characteristics. Moreover, the wearers' own knowledge of their body characteristics, even easy-to-obtain measurements of key measurements, is limited in selecting appropriate clothing.
- The methods and procedures described in the theoretical review (literature and standards) for ensuring the fit and ergonomics of clothing are disconnected, do not cooperate, and lack synergy to achieve the result. In general, there is a lack of synergy between the wearer, the customer, and the supplier.

The following main **theoretical results** have been achieved in the Doctoral Thesis:

- From the point of view of ensuring clothing anthropometric fit and ergonomics, the aspects of clothing design that affect it are described. The components of the concept of conformity, existing approaches and methods for their evaluation are described.

- The developed and proposed method – algorithm for evaluating the anthropometric fit and ergonomics of clothing demonstrates the application of a systematic combination of clothing evaluation methods in the development of real principles for determining the conformity of clothing.
- The developed concept and structure include the implementation of an assessment in two cases – both on the conformity of the clothing in use/worn/delivered and clothing to be implemented as a result of the indications introduced by a new problem.
- The development of different clothing evaluation algorithms can be based on the principles of the proposed algorithm, narrowing or expanding the structure, setting other clothing conformity indicators and expanding the set of evaluation methods.

The obtained theoretical results have been **practically realized**:

- The implemented experiment validating the operation of the method confirms its applicability for the evaluation of the anthropometric fit and ergonomics of special-purpose clothing.
- The application of the method in practical research allows identifying the shortcomings of the information-literacy of the involved parties, identifying the problematics of special-purpose clothing, analysing and improving the supply processes, and promoting objective decision-making on clothing conformity.

Experimental probation of the method operation allows the following **conclusions** to be drawn:

- The study's findings confirm the lack of synergy between wearers, clothing designers/manufacturers/suppliers and supply services, indicating the potential usefulness of the method in promoting the understanding of the parties involved about the parameters of appropriate clothing, their evaluation, and decision-making principles.
- The analysis of the experimental results allows drawing conclusions about the content and scope of the parameters to be included in similar studies, promoting the reliability of these studies and the practical applicability of the results for the implementation of improvements in clothing design and delivery.

The results of the Doctoral Thesis allow **confirming the theses** to be defended. The validation experiment and approbation confirm that the method allows identifying the garment's anthropometric fit and ergonomic shortcomings. The algorithm's structure by defined decision-making principles promotes the objectivity of its users in the prevention of anthropometrically non-fit and ergonomically inappropriate clothing.

Directions for **further studies**:

- By approving the method analyse the implementation of additional and/or other evaluation elements and the resulting decision-making principles in the algorithm, setting the leading clothing conformity components/indicators depending on the clothing assortment and sector specifics.
- In future studies, by conducting several target-group studies and in-depth analysis, a decision-making algorithm with meaningful coefficients can be developed depending on the influence of the developed algorithm processes on the final result, which is not possible in this study due to lack of data.

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