NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

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STO TECHNICAL REPORT **TR-HFM-266**

3D Scanning for Clothing Fit and Logistics

(Balayage 3D pour l'ajustement des vêtements et la logistique)

Findings of Task Group HFM-266.

Published March 2020

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The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

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List of Acronyms

3D	3 dimensional
CAF	Canadian Armed Forces
CBRN	Chemical, Biological, Radiation and Nuclear
CCIEP	Combat Clothing, Individual Equipment and Protection
DSSPM	Directorate of Soldier Systems Program Management
ET	Exploratory team
HFM	Human Factors and Medicine
NATO	North Atlantic Treaty Organization
RTG	Research and Technology Group
SM	Supply Manager
STANAG	NATO Standardization Agreement
STANREC	NATO Standardization Recommendation
TA	Technical Authority
USMC	United States Marine Corps

Glossary

3D Body Scanner	A system that digitizes the surface features of the human body as XYZ-coordinates

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3D Scanning for Clothing Fit and Logistics

(STO-TR-HFM-266)

Executive Summary

Proper fit of military clothing and equipment is important for the health, safety and operational performance of NATO military personnel. When fit is too tight, movement range is restricted and when fit is too loose, snagging hazards may occur. Respirators with incorrect fit lead to leakage and may lead to inhalation of toxic materials.

For proper fit, the clothing and equipment sizes should reflect the body dimensions of military personnel. These dimensions change over time which impacts the sizing of military clothing. Therefore, it is important that an up-to-date database of body dimensions of military personnel is available for the design and evaluation of clothing and equipment.

Increasingly 3D whole body scanners are used to capture the human shapes and dimensions. NATO RTG HFM-266 recommends using 3D body scanning for military clothing and equipment supply because the derived body dimensions are more reproducible than manual measures, can be integrated in the logistic chain and 3D scans allows for virtual fitting of military clothing and equipment. Human shape analysis leads to human models that can be used for clothing and crew station design and evaluation.

3D Body scanning comes with challenges. Conversion of scans to the best fitting clothing and equipment size is a complex process and real-life fitting is generally still required. Privacy issues are important and technical solutions can be considered. The technique of virtual fitting of garments is promising, but needs validation and needs to move away from static fitting to dynamic fitting. It is important that the clothing supply staff is trained in 3D scanning and data processing technology and that experiences are shared between NATO countries and allied forces in order to benefit from this technology.

Many NATO countries indicated that a manual on how to size and fit garments would be beneficial. Therefore, HFM-266 drafted a STANREC titled “Sizing and fitting of military combat clothing, individual equipment and protection” to address this need.

Balayage 3D pour l'ajustement des vêtements et la logistique

(STO-TR-HFM-266)

Synthèse

Il est important que les vêtements et l'équipement militaires correspondent à la taille du personnel militaire de l'OTAN, afin d'assurer sa santé, sa sécurité et ses performances opérationnelles. Lorsque la taille est trop petite, l'amplitude du mouvement est limitée et lorsque la taille est trop grande, le vêtement ou l'équipement peut s'accrocher à une aspérité. Une taille de respirateur non adaptée entraîne des fuites et peut provoquer l'inhalation de matières toxiques.

Pour être adaptés, les vêtements et l'équipement devraient correspondre aux mensurations du personnel militaire. Ces mensurations varient au fil du temps, ce qui a des conséquences sur le dimensionnement des vêtements militaires. Par conséquent, il est important de mettre à disposition une base de données actualisée des mensurations du personnel militaire pour la conception et l'évaluation des vêtements et de l'équipement.

Les scanners 3D du corps entier sont de plus en plus utilisés pour relever les formes et les mesures du corps humain. Le RTG HFM-266 de l'OTAN recommande d'utiliser le balayage 3D du corps pour l'approvisionnement en vêtements et équipement militaires, parce que les mensurations qui en découlent sont plus faciles à reproduire que les mesures manuelles et peuvent être intégrées dans la chaîne logistique et que les balayages 3D permettent une adaptation virtuelle des vêtements et de l'équipement militaires. L'analyse des formes humaines mène à des modèles humains qui peuvent servir à la conception et l'évaluation de l'habillement et des postes d'équipage.

Le balayage 3D du corps présente plusieurs défis. La conversion des balayages en taille de vêtements et d'équipement la plus adaptée est un processus complexe ; un ajustement dans la vie réelle est généralement nécessaire. Les questions de vie privée sont importantes et des solutions techniques peuvent être envisagées. La technique de l'ajustement virtuel des vêtements est prometteuse, mais nécessite une validation et doit s'éloigner de l'ajustement statique, pour passer à l'ajustement dynamique. Il est important que le personnel d'approvisionnement en vêtements soit formé aux technologies du balayage 3D et du traitement des données et que les pays de l'OTAN et les forces alliées partagent leurs expériences afin de bénéficier de ces technologies.

Beaucoup de pays de l'OTAN ont indiqué qu'un manuel de dimensionnement et d'ajustement des vêtements serait bénéfique. Le HFM-266 a donc rédigé un STANREC intitulé « Sizing and fitting of military combat clothing, individual equipment and protection » (dimensionnement et ajustement des tenues de combat, de l'équipement individuel et de la protection militaires) pour répondre à ce besoin.

3D SCANNING FOR CLOTHING FIT AND LOGISTICS

1.0 INTRODUCTION

Proper fit of military clothing and equipment is important for the health, safety and operational performance of NATO military personnel. A good fit is the result of a match between body shape/size and product shape/size. Movement restrictions may occur when fit is too tight and snagging hazards may occur when fit is too loose. Inadequate fit is not only related to discomfort but may also affect effectiveness of military operations and logistic processes (e.g., higher rate of wastage). Even more, inadequate fit will also affect the safety, for example with regards to fit of Chemical, Biological, Radiological and Nuclear (CBRN) protective clothing and equipment where a protective mask that is too wide may result in leakage. NATO HFM-ET-134 showed that secular trends in body dimensions, new operational demands and integration of new devices in the clothing system aggravate the issue of clothing fit. There is a considerable difference between the investigated NATO countries in approach and methodology of clothing fit, which leads to difficulties in international co-operation.

It is the expectation that the NATO forces will benefit from the new techniques that lead to improved garment fit. Also, interoperability may be enhanced if knowledge is shared regarding methodology to optimize fit within NATO countries.

Therefore, the objectives of RTG HFM-266 are to investigate the need and requirements regarding:

1) The identification of research gaps and opportunities in the area of 3D body scanning for clothing fit and logistics;
2) The facilitation of integrated research initiatives in 3D whole body scanning and processing;
3) The facilitation of integrated procedures for clothing deployment to ensure similar fit over NATO countries; and
4) A review of novel approaches for 3D scanning and processing.

This report describes the results of the work of the program committee. The committee met six times (Paris 2016, Ottawa 2016, Erding 2017, Quantico 2017, Amsterdam 2018 and Paris 2019) and organized meetings with academia and companies in Canada, US, Germany and the Netherlands to be fully informed about the newest developments in 3D scanning and logistics.

2.0 SURVEYS

In order to identify the needs of military clothing and equipment organizations in NATO countries, several surveys were organized in 2013, 2016 and 2017. This was done with the help of the NATO Combat Clothing, Individual Equipment and Protection (CCIEP) working group that acts under the NATO Army Armament Group/Land Capability Group Dismounted Soldier Systems (NATO/NAAG/LCG DSS).

2.1 2013 Survey

The survey construction was based on a small survey from 2013 (Table 1). This survey showed that most clothing and equipment was supplied by the defence organization, only Germany outsourced it. The supply was generally based on a combination of body dimensions and additional fitting. Manual measures were most common, 3D scanning was only done in four countries. The available data are used for stock control, procurement and product design by most countries.

Table 1: Results of a Survey in 2013 in Which 10 Countries Participated.

	BEL	CAN	CZE	DEU	FRA	NLD	PRT	SWE	USA	ZAF
Supply by Defense	x	x	x		x	x		x	x	x
Supply by Others				x						
Supply based on body dimensions		x*	x	x	x	x	x	x	x	x
Supply based on fitting only	x									
Additional fitting	x		x	x	x	x		x	x	x
Body dimensions by hand		x	x	x	x		x		x	
Body dimensions by scanner		x			x	x			x	
Self reported stature and weight								x		
Manual data processing		x	x	x	x		x	x		
Automated data processing					x	x			x	x
User responsible for data		x	x			x				
Defence responsible for data					x		x			x
Other				x				x		
Data for stock control		x	x	x	x	x		x		x
Data for procurement		x	x	x	x	x		x		x
Data for product design		x	x			x	x	x		x
*= and personal preference										

2.2 2016 Survey

Ten nations participated in the 2016 survey: AUS, BEL, CAN, CZE, DAN, DEU, NLD, POL, UK, US.

STANAG 2335 [1], the NATO standard on size designation, was only used by 3 nations (DEU, NLD, UK). Four countries (CAN, DEU, NLD, UK) reported the use of body scanning systems and showed interest in future developments; these are the "usual suspects", and most countries still employ manual measurements. However, it is good to note that more countries are currently using body scanning (e.g., USA and Luxembourg) as a research tool or to supply clothing.

Almost all contributing nations measured military personnel to issue correct garment size (mostly with tape on the spot); however only UK and NLD reported the storage of these data. Later correlation/matching between issued sizes and body dimensions was only reported by UK. This means that limited databases on body dimensions are available. Storage/processing of issued sizes for stock control/logistics and future procurements is common.

Only two countries (NLD and UK) use data (body dimensions, sizes, feedback) for design of new products.

2.3 2017 Survey

The 2017 survey was small and dedicated, so that more response could be expected. Indeed, 35 responses were noted of 20 countries.

The questions and their answers are shown in Table 2. Most measurements are done manually and 3D scanning is only mentioned in 9 out of 35 responses. Most respondent indicate that the data is stored. Although most respondents report that the sizing system is adequate, 68% note significant complaints in fit. Based on the answers to question 6 a manual was drafted under the title ‘Sizing and fitting of military combat clothing, individual equipment and protection’ and proposed as STANREC to the CCIEP for further processing to the NATO standardization office. CCIEP will take the lead and intends to link the STANREC to a revised STANAG 2335.

Table 2: Results of the 2017 Survey.

Question	Yes	No	Unsure
1) Do you measure the body dimensions of military personnel?	29	3	3
2) Do you use 3D body scanning techniques to measure military personnel?	9	22	4
3) Do you store the determined body dimensions of military personnel?	19	12	4
4) Do you consider your clothing and equipment sizing system to be adequate for your military personnel?	19	13	3
5) Do you notice significant complaints concerning the fit of your military clothing and/or the need for improvements in this area?	24	8	3
6) Would you appreciate a brief manual how to make and optimize a sizing system?	27	6	2
7) Which country are you representing?	USA-8, EST-5, DNK-3, CAN-2, NLD-2, SVN, POL, UKR, SVK, CHE, HUN, BEL, GBR, FIN, NOR, CZE, GER, AUS, SWE, ESP		

3.0 ANTHROPOMETRY

3.1 Methods

Anthropometry is the science of human body measurements. Anthropometric data are essential to make and select the appropriate dimensions of military clothing and equipment.

The methods to measure anthropometric data for clothing and equipment are specified in ISO 8559 [2]. STANAG 2335 [1] is dedicated to military clothing and equipment sizing.

The traditional tools used to measure human body dimensions are calipers and measurement tapes. Over the last decades 3D whole body scanners are increasingly used to make a 3D copy of the human body and the standard body dimensions are derived from the scan data. Table 3 summarizes the plus and minus points of 3D scanning compared to manual measures. 3D scanners are more expensive and it takes time to learn to work with the systems. Manual measures are inexpensive and linked to ISO standards but yield less reproducible data. ISO standard 20685 tries to bridge the gap between scanning and manual measurements.

Table 3: Manual vs. 3D Scan-Derived Body Dimensions: Pros and Cons.

	Plus	**Minus**
Manual	• Inexpensive • In line with ISO standards	• Measurer-dependent • Inaccurate • Time-consuming • Limited data • Extensive training required
Scan-derived	• Reproducible • Shape info • Fast • Multiple applications (e.g., medical)	• Investment • Privacy issues

A disadvantage of 3D scanning may be related to privacy. The face and body are easily recognizable, like a photograph. Some methods to solve this issue are:

1) Delete the scan after the calculation of the body dimensions for clothing and equipment;
2) Scramble the face area of the scan and other individual markers such as tattoos;
3) Protect the data using encryption or password protection; and
4) Make a model of the scan so that individual characteristics such as face details and tattoos are lost.

For methods 1 and 2 valuable data are lost and this is not recommended. For the design of respirators, for instance, data of the face is necessary. Method 4 is recommended: only information essential for clothing and equipment design is retained and can be shared without risk for privacy issues [3]. The method is based on a general model of the human male and female body that is scaled to the individual military member (see Figure 1).

Figure 1: Example of a Human Model (Based on an Individual Scan Such That the Face Cannot Be Recognized) That Is Used for Virtual Fitting of a Combat Jacket.

Some important aspects to consider for both traditional and 3D anthropometry are as follows:

- Education is required for accurate measurements;
- Standards should be considered for optimal data exchange (ISO 7250, STANAG 2335);
- The acquired data should be stored in a database with an interface for easy access; and
- The acquisition of additional demographic data (e.g., age, occupation, sex, race) that are correlated to body dimensions should be considered.

3.2 Databases

Databases of military NATO personnel anthropometric data are constructed by only a few NATO member states (see Section 2.2), but most of them are not openly distributed. Only summary statistics are available.

An overview of databases prior to 2012 is available in a recent book [4].

The methods and summary statistics of the US Army are available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a611869.pdf [5].

The methods and summary statistics of Canada are published at http://cradpdf.drdc-rddc.gc.ca/PDFS/unc224/p803174_A1b.pdf [6].

The methods and summary data trends of Dutch military personnel are published [3].

4.0 SCANNING SYSTEMS AND PROCESSING SOFTWARE

3D whole body scanners first appeared to the market in the nineties with Cyberware as pioneers in the US, Vitronic in Europe and Hamamatsu in Japan [7]. Over the year systems dropped in price and increased in accuracy with laser scanning systems being partly replaced with stereo photogrammetry systems [8]. Currently, 3D scanners can form a part of the automation chain in garment manufacturing [9]. Appendix 1 provides a list of current manufacturers. A good 3D scan is a prerequisite for adequate further processing. A manikin representing a NATO military member may be a useful object to assess the quality of a 3D scanning system. It is recommend to specify such an object along with processing procedures [10], [11]. 3D data scan formats (e.g., dxf, obj, ply, stl, nurbs, iges, step) can be converted using simple and free tools like Meshlab (www.meshlab.net). Appendix 2 provides a list of requirements for military use of 3D scanners.

The essential body dimensions to be derived from the 3D scans for combat suit sizing are chest circumference, waist circumference, hip circumference, inner leg length and stature [1]. Software that performs these calculations is generally supplied with the scanner and not as separate tools. Due to methodological differences, the body dimensions generated by the scanner are NOT identical to manual measures.

3D body scans can be imported in dedicated software for clothing design and evaluation. The necessary input for virtual fitting of clothing is:

1) 3D body scan;
2) Clothing pattern; and
3) Material properties.

For dynamic virtual fitting a movie file has to be added with the motion pattern of the subject. For military use those motion profiles may, for instance, be walking, adopting a shooting position and so on.

The main suppliers of software that allows for virtual design of garments on a 3D body are:

- Optitex (www.optitex.com);
- Gerber (www.gerbertechnology.com);
- Lectra (www.lectra.com);
- Gemini (www.geminicad.com);
- DCsuite (http://www.physan.net/eng/DCsuite/product_qual.asp);
- Clo3D (www.clo3d.com); and
- Assyst/Vidya (http://www.human-solutions.com/group/front_content.php?idcat=214&lang=2).

GruntSim, developed for the USMC, uses SANTOS-generated manikins, as part of the SANTOS simulation suite is dedicated to military equipment.

3D whole body scans can also be used for crew station design using other tools like Safework/Delmia, RAMSIS and Jack.

3D body scans can be individually imported in the mentioned software, or models or manikins specific for population extremes can be used.

Challenges for the future include the following:

- 3D scans or models currently do not have tissue deformity. Adding this would increase validity.
- The target population can be better represented when the human models are improved.
- Motion patterns for military tasks should be constructed to allow for better analysis of the interface between the human body and clothing/equipment (multi-layer garments, stiff textile materials) (e.g., https://blog.siggraph.org/2019/03/achieving-body-realism-with-the-human-touch.html/.

5.0 SIZING AND FITTING

Ideal sizing of garments and equipment leads to a minimal number of sizes with maximal coverage of the user population. There is a trade-off between number of sizes and coverage of the user population. Generally, the aim is to cover 95% of the military population and make made-to-measure products for the remaining part. However, this threshold differs between products: helmets, for instance, are not made to measure. The process of sizing contains several steps and is described in detail in the STANREC. Traditionally, sizing of garments is made in fixed steps, called grading. However, new insights show that clustering of human shapes [12], [13], captured using 3D scans, can be a more effective way for sizing (e.g., https://towardsdatascience.com/would-this-clothing-fit-me-5c3792b7a83f and http://link.springer.com/chapter/10.1007/978-981-13-0080-6_14).

Fitting is the process of finding the correct size for a certain subject (see also STANREC "Sizing and Fitting of Military Combat Clothing, Individual Equipment and Protection"). The most common process of fitting is that the individual tries on several sizes of the product [14]. This is time-consuming and is difficult when the military member is not in the same location as the clothing. Increasingly, internet tools are used to determine the correct size of the garment for the user. These tools are:

1) A list of questions or a plug-in on the website that asks the military member for demographic data and body dimensions that are translated into a product size;
2) A converter that asks the subject for the size of a well-fitting product of a certain brand and converts this to the size of the product to be supplied;
3) A smartphone that can be moved over the body as a measurement device (e.g., http://mysizeid.com/) or a smartphone camera that can capture the outline of the human body (e.g., http://quantacorp.io); and
4) Virtual fit tools that use a 3D body scanner to digitize the outside of a military member and virtually fit the garments on the body. Virtual fit tools enable three options to visualize fit:
    a) Show the perpendicular distance between the body and garments using color maps;
    b) Show the strain in garments fitted to the body using color maps; and
    c) Make the garments transparent so that the fit on the body can be seen.

The complete list of options for using internet tools to fit garments is available at http://members.ziggo.nl/daanen/mode/Techupdate8.pdf.

6.0 LOGISTICS

6.1 Case for the Netherlands

Determining the correct garment size is only a part of the clothing and equipment supply process. In the Netherlands, the 3D scanner is integrated in that process, described here as a business case.

In the Netherlands the supply of military clothing and personal equipment is centralized in Soesterberg, in the middle of the country. It is a small country where distances are no issue, which makes it possible to have only one location for this purpose. Both recruits and operational staff receive their clothing and equipment in Soesterberg. Figure 2(a) and Figure 2(b) summarize the procedures.

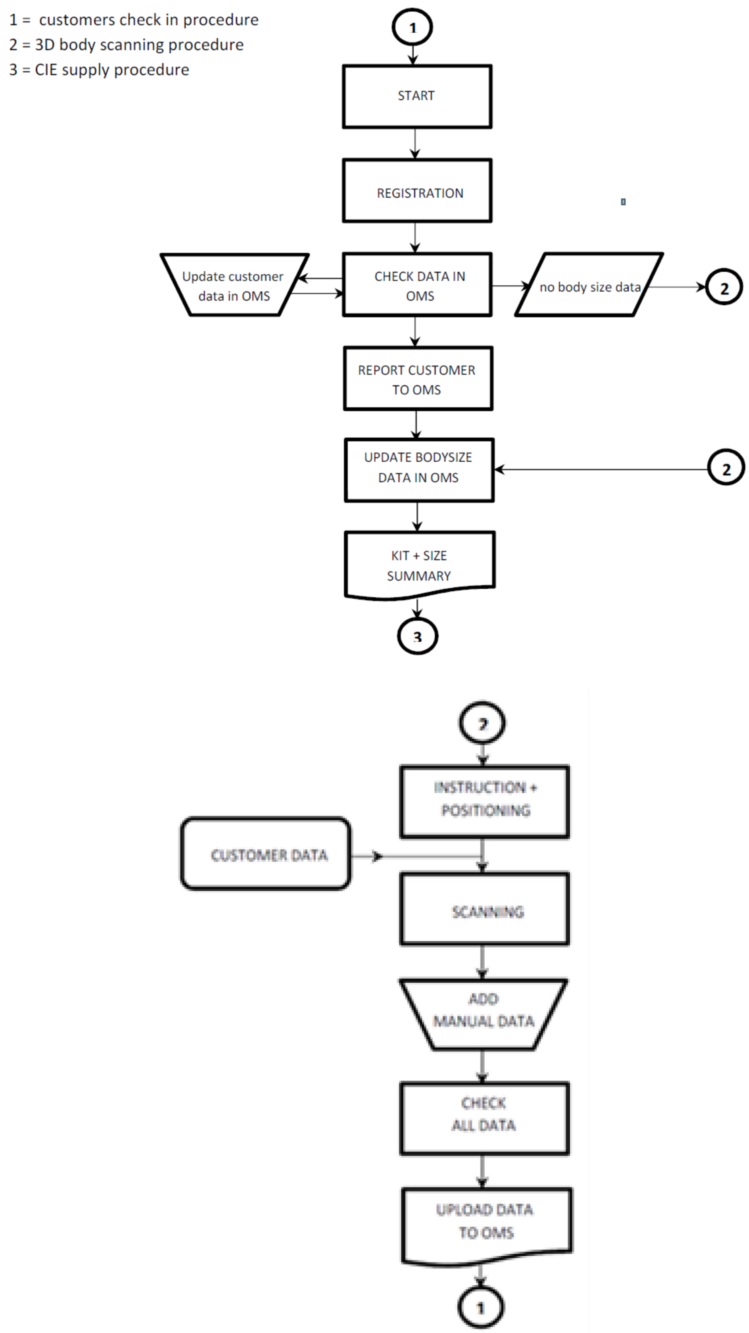

Figure 2(a): Visualization of the Clothing and Equipment Supply Process in the Netherlands.

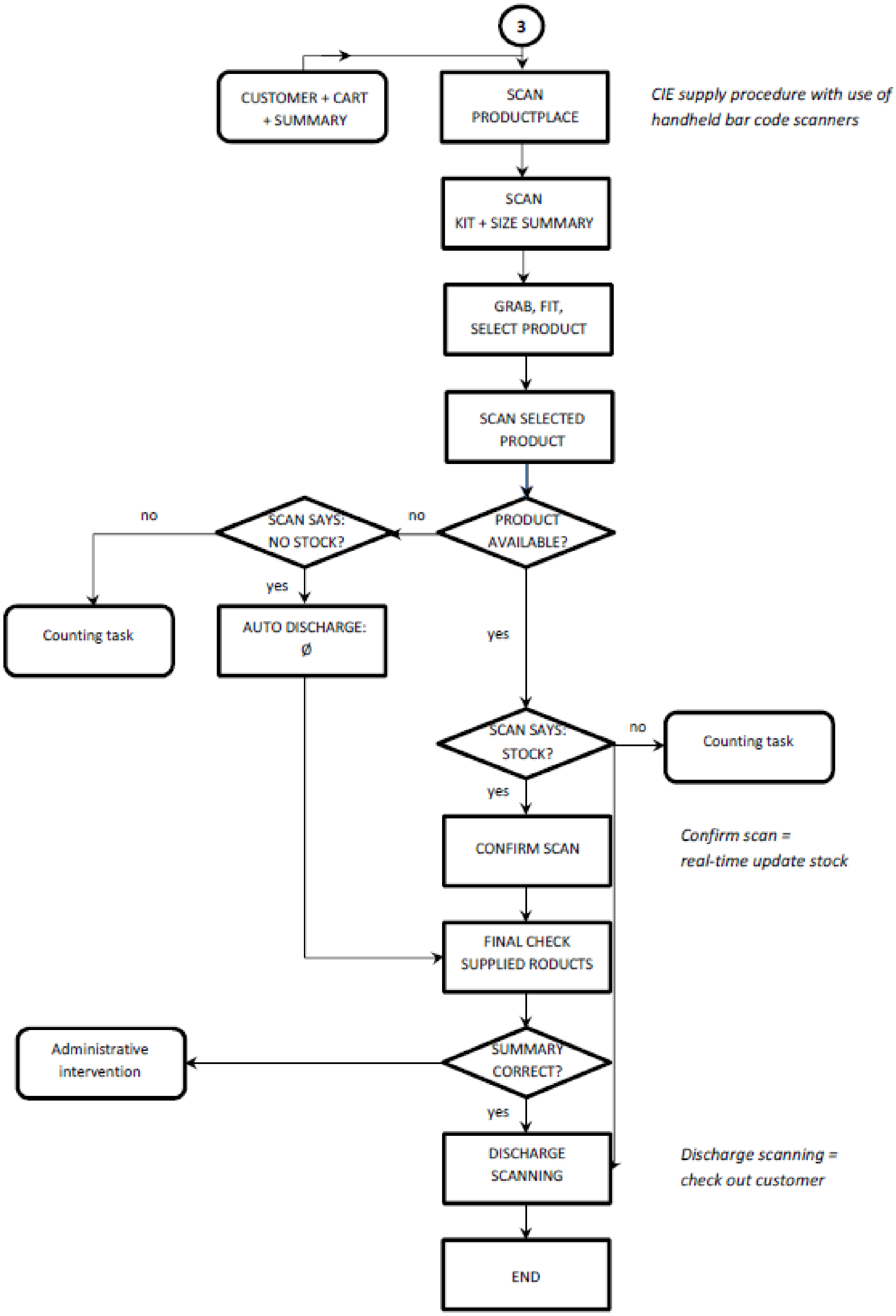

Figure 2(b): Visualization of the Clothing and Equipment Supply Process in the Netherlands.

Somewhere in the first few weeks of their basic military training, new recruits come to the supply centre for clothing and personal equipment in Soesterberg, for their first set of basic clothing and equipment. They report to the reception desk with their military employee number, which is the key to the supply process. It is linked to demographic data like name, age, etc. and thus to the required set of clothing and equipment. In the final stage of the process, this number is linked to the database of 3D scans, the derived body dimensions and the supplied clothing and equipment sizes.

The recruit waits to be called to the changing room where they will be called in groups of five for scan processing. Male recruits are provided with a tight-fitting head cap and, if necessary, tight-fitting boxer shorts to be worn over their underpants. Female recruits receive a set of tight-fitting top and pants to wear on top of their underwear. After instruction on the correct posture to adopt the recruit is scanned with a Human Solutions Vitronic XL 3D scanner. It usually takes 15 seconds to complete a scan. Operating the scanner is separated from processing the scan data for reasons of integrity. Dealing with personal data is strictly regulated in the Netherlands.

A scan is immediately checked for errors in an adjacent room and data are corrected manually when necessary. To complete the data, head width, finger length and foot size are added to the data file. Each data directory is coded by year / week of year / military employee number and contains three essential files: the 3D scan in .obj format, a list of 96 derived body dimensions in .csv format and a picture of the scan in .jpg format. The time needed to scan and to process all data for use is 2 minutes. Theoretically, it is possible to scan 960 people per working day. Data processing limits the number of scanned people to handle to 240. The available staff to serve the customers narrows the amount down to a maximum of 180 per day.

Recruits receive a printout showing their set of clothing and equipment, personal data like name, number, position and size and amount per garment. The garment size is calculated from the scan-derived data. After entering the store, they take a shopping cart to run through ‘shopping’ lanes to collect their clothing and equipment. Upon showing the printout to the staff providing the garments, they receive the garment in the size indicated on the list. The supplied items are removed real time from the stock and as a result stock data are up to date. This enables just-in-time stock control. Recruits have the opportunity to fit the garments and to change the originally provided size if needed. Changes are registered in order to improve the size-generating routines.

Operational Military staff incidentally visit the centre in Soesterberg when they are assigned to be deployed or when they change positions. In both cases an additional set of garments is issued. They follow the same procedure as recruits. After reporting to the reception desk, the latest date of scanning is checked. The customer in question is invited for a scan if a period has been longer than two years since the last scan.

Challenges in the process include:

- The introduction of 3D scanning;
  - As it is a new technology for many employed in different positions and at different levels;
  - Because it is used as an instrument to improve logistics which can be seen by staff as a threat to their job;
  - As it most likely means that changes to the existing business processes have to be made.
- Training of staff involved in using 3D scan technology and interpreting the derived data;
  - To convince them of the advantages of the technology to motivate them;
  - Underlining the essence of the collection of data for the business process and for development;
  - Ensuring a reasonable problem-solving ability.

- The myth: staff members tend to think that their subjective assessment of the correct size is superior to the size supplied by the scanner and calculated from 3D data;
  - The quality of data and the algorithm for size calculation;
  - Alternative procedures like manual measurements in case the scanner has a technical problem; and
  - Maintenance of the scanner system.

Besides being used for the selection of garment sizes, scan-derived data are analyzed for scientific purposes on a yearly basis. The results are the basis for the acquisition of new clothing and personal equipment systems and for continual development and improvement of existing systems.

6.2 Case for Canada

Contrary to the case of the Netherlands, it is unfeasible for military members to come to a single location in Canada as the country is so vast. BoSS, a body scanning system, which is anthropometric data specific, was introduced to the Canadian Armed Forces (CAF) in 2002. The system was deployed in different base locations across the country. The fleet of BoSS machines is used in multiple ways in the following, but is not limited to:

1) **Standard Clothing Issue**: If CAF members do not know what size they take, they have the option to use the BoSS machine to obtain an initial list of clothing or equipment sizes to try on.
2) **Special-Size Requests**: When CAF members do not fit into the “normal” size ranges of issued clothing or equipment, they can request a special size at their base Clothing Stores. They are then typically scanned, using a BoSS (if one is present), or measured manually. These measurements are sent to Directorate of Soldier Systems Program Management (DSSPM) for validation, and if accurate, custom clothing or equipment is manufactured to fit them. Note: this use case is described in detail in Section 6.2.1 and Figure 3.
3) **Unique Population Anthropometric Data**: The BoSS machines are used for collecting body measurement data, size recommendations and anthropometrics for unique groups, i.e., Search and Rescue Technicians (SAR Techs), firefighters and snipers. This info informs design and size range specification, how much to buy of each size, special-size procurements, and informs decision making on the addition of sizes or deletion of sizes from the size range development of sizing standards.

6.2.1 Use Case: Special-Size Request

A special-size clothing item is defined as a size varying from the stocked standard sizes. It also may be referred to as outsize, plus size, custom size. A special size can be larger or smaller than the stocked standard sizes.

Stocked standard sizes of the operational clothing items, as designed, do not cover all CAF members. It is required that special-size items be supplied to members when standard sizes do not fit. These members require these items to do the job in which they are employed. Failing that can cause safety concerns (for example, if the clothing is personal protective equipment or cold-weather clothing) and career implications and retention (if the member cannot perform duties due to lack of equipment). Ordering special-size clothing items is a collaborated chain process between the Technical Authorities (TAs), and/or pattern design, acquisition and industry manufacturers. Details of this use case description are as follows:

1) A military member goes to his/her base Clothing Stores and requires a specific clothing item. The Clothing Stores does not stock a proper size for this member. All available stock sizes are either too small or too big for this member.

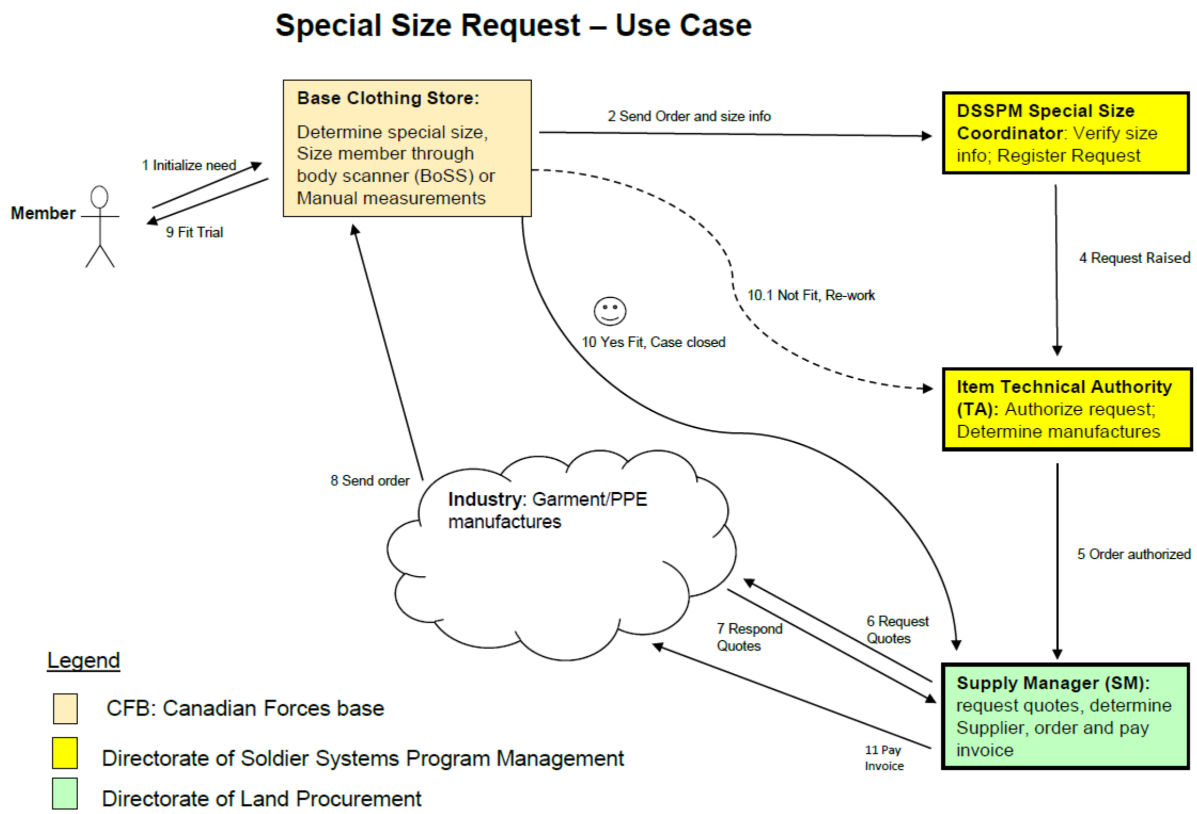

Figure 3: Use Case: Canadian Military Operational Clothing Item Custom Made.

2) The Clothing Stores determines that this member requires a special size. The member is then either scanned by BoSS or manually measured. Member’s body size info and order info are sent to special-size coordinator at DSSPM.

3) The special-size coordinator reviews the completion of the request information, the BoSS scan or the measurement data; validates the body size information; registers the order; and sends the order to the related Technical Authority (TA).

4) TA reviews the technical information of the required clothing item, approves, or gives instruction for further fit trial, and determines manufacturers that can produce the requested item, then sends the file to the item Supply Manager (SM).

5) SM requests quotes from the industry, and the manufacturers send quotes back.

6) SM determines the best-value manufacturer and makes contracts for producing the item.

7) The manufacturer puts in production of the order and sends it to the related clothing store.

8) Clothing Stores calls in the member and conducts a fit trial to ensure appropriate measures.

9) If the ordered garment fits the member, Clothing Stores informs the SM of the trial “OK” results. If not, the results are fed back to the TA, who determines correction measures, and the manufacturer may have to adjust or reproduce the garment.

10) SM makes payment of the produced order.

7.0 GENERAL RECOMMENDATIONS

NATO HFM-266 focussed on four major objectives. This chapter discusses how these objectives were met. Thereafter, the main recommendations are summarized.

The first objective was to identify the research gaps and opportunities in the area of 3D body scanning for clothing fit and logistics. The technology of 3D scanning is rapidly increasing in accuracy and dropping in costs. A high-density digital copy of a human body can be made in less than a second. However, the software to process these scans, such as the calculation of essential body dimensions from these scans, is still in development. The area of virtual fitting is promising and the first packages such as Clo3D are in the market. There is a research gap regarding the accuracy of these models. Issues like the inclusion of material properties in the analysis, converting static to dynamic body representations and the inclusion of military tasks should be addressed. There is a need for training of personnel using these new techniques. The increasing detail in 3D scans increases the problem of privacy. This issue should get more attention and technological solutions, such as human models, may work.

The second objective was to facilitate integrated research initiatives in 3D whole body scanning and processing. HFM 266 brought together parties from the industry and military stakeholders during the meetings. For instance, one industry partner (Scanologics) included the STANAG 2335 sizing charts in the scanner output, so that the scan-derived body dimensions were converted to garment size for the NATO countries that supplied sizing info to this standard. Since smart wearables, including cooling devices, depend on a tight fit, interaction with other NATO groups on this issue was made and information was exchanged.

The third objective was to facilitate integrated procedures for clothing deployment to ensure similar fit over NATO countries. The three conducted surveys illustrated the need for a manual on sizing and fitting. Therefore, the initiative was started to draft a STANREC titled ‘Sizing and fitting of military combat clothing, individual equipment and protection’. This document is now in consideration as an attachment to STANAG 2335 in collaboration with CCIEP and the NATO standardization office.

The fourth objective was to review novel approaches for 3D scanning and processing. 3D body scanning has the advantage over manual measurements that the data can be stored and retrieved for further processing. In contrast to manual measurements, new body dimensions can be derived, including shape related variables. A database of scans can serve as a starting point for design of new products. The Netherlands armed forces, for instance, release parts of the anonymized database to producers of equipment so that the products can be made to fit the military population. A good sizing system, based on actual body dimensions, reduce the return rates and thus lower the costs. The number of items in stock can be optimized and reduce the inventory. The database of 3D scans can also be used for other applications in the armed forces such as medical research (e.g., the relation between body shape and injury proneness), the optimization of exoskeletons and orthotics and crew station design and evaluation.

It is recommended to NATO member countries to:

1) Procure and use 3D whole body scanners to record the shape and dimensions of military members;
2) Train staff to efficiently use scanning systems;
3) Store the data and deduct body measurements for clothing development and size selection;
4) Share anthropometric summary statistics with other NATO member countries;
5) Include the scanning system in the logistic planning and pay attention to privacy issues; and
6) Certify the accuracy of the 3D scanner using 3D manikin for scanner calibration and comparison.

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Appendix 1: SCANNING SYSTEMS

Scanning systems are rapidly changing. Therefore, the list below is only an indication of available systems and does not represent all scanners available. The mentioned systems vary considerably in costs and accuracy.

No.	Scanner	Company Name	Website
1	TC2-19B	TC2	https://www.tc2.com/tc2-19b-3d-body-scanner.html
2	MyBody	Styku	http://www.styku.com/bodyscanner
3	Full Body	Instituto De Biomecanica De Valencia (IBV)	https://antropometria.ibv.org/en/body-scanning/
4	Mobile 3D Body Scan	Nettelo	http://nettelo.com/nettelo-app/
5	Artec Eva	Artec3D	https://www.artec3d.com/
6	Sense 3D Scanner	3D Systems	https://www.3dsystems.com/shop/sense
7	VITUS 3D BodyScan	VITRONIC	https://www.vitronic.com/
8	HANDYSCAN700	Creaform	https://www.creaform3d.com/
9	MTailor	MTailor	https://www.mtailor.com/
10	SS20 3D Body Scanner	SizeStream	http://sizestream.com/
11	ShapeScale	ShapeScale	https://shapescale.com/
12	Naked	Naked	https://nakedlabs.com/
13	Twinstant Mobile Full Body 3D Scanner	Twindom	https://web.twindom.com/twinstant-mobile-full-body-3d-scanner/#twinstantmobile
14	Texel Portal	Texel	http://texel-asia.com/en/texel-portal-3d-scanner/
15	OPTAone Botscan	Botspot	https://www.botspot.de/en/3d-scanners/
16	VECTRA 3D	CANFIELD	https://www.canfieldsci.com/imaging-systems/vectra-m3-3d-imaging-system/
17	ProScanner + Success Hub	FIT3D	https://www.fit3d.com/solutions/
18	BodyScan Scanner	TechMed3D	https://techmed3d.com/
19	3D Body Scanner	Shape Analysis	http://www.shapeanalysis.com/prod01.htm
20	Elasizer Head Scanner	Elasizer	http://www.elasizer.com/scanning.php

No.	Scanner	Company Name	Website
21	Portable 3D Body Scanner and Body Analyzer	DIGIME	https://www.digime3d.com/en/
22	SYMCAD III	Telmat Industrie	http://www.symcad.com/eng/products.htm
23	3D Instagraph	Staramba	https://company.staramba.com/3d-instagraph
24	Ditus MC	Human Solutions	https://www.human-solutions.com/
25	Scanlounge	Scanologics	https://www.scanologics.com/#scanlounge
26	Quantacorp	Quantacorp	https://www.quantacorp.io/

Appendix 2: REQUIREMENTS FOR 3D BODY SCANNERS

For military use, the following shall comply:

- Automatically identify common body landmarks and provide anthropometric data collection functionality;
- Provide a feature that users can integrate own clothing charts, so the scanner program can output garment sizes or other personal equipment items;
- Robust hardware and software; easy to install, operate, and maintain;
- Private and comfortable scan experience;
- Provision of security for an individual's data;
- Accurate and automatic post-scan data processing;
- Safety: eye and skin safe;
- Data output format interchangeable with other software programs, allows freedom to choose third party software if required;
- Stability toward working environment (e.g., ambient light condition, temperature change, etc.); and
- Warranty and support.

The following should comply:

- High speed: avoid movement artifacts;
- Measuring sitting pasture capability;
- Automated calibration procedure, if calibration required;
- Fail Safe with certain hardware;
- Smaller footprint (minimize space use);
- Statistic capability to look up collected data; and
- Reverse engineering capability, i.e., feed the program with manual measurements, simulate out subject/profile, etc. for visualization.

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14. Abstract

Proper fit of military clothing and equipment is important for the health, safety and operational performance of NATO military personnel. Clothing and equipment sizing should reflect the body dimensions, that are changing due to secular trends. Increasingly 3D whole body scanners are used to measure the body. NATO RTG HFM-266 recommends to use 3D body scanning for military clothing and equipment supply because the derived body dimensions are more reproducible than manual measures, can be integrated in the logistic chain and 3D scans allows for virtual fitting of military clothing and equipment. Conversion of scan-derived body dimensions to the best fitting clothing and equipment size is a complex process and real-life fitting is generally still required. Privacy issues are important and technical solutions, such as conversion of the individual scan to a human model, should be considered. The technique of virtual fitting of garments is promising, but needs validation and needs to move away from static fitting to dynamic fitting. It is important that the clothing supply staff is trained in 3D scanning and data processing technology and that experiences are shared between NATO countries and allied forces in order to benefit from this technology.

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