CHALMERS

Clothes for the Operator of the Future

Development of Work Wear for Swedish Manufacturing Industries for the Year 2020

Master of Science Thesis in the Master Degree Programme Industrial Design Engineering

ALVA MÅRDSJÖ

Department of Product and Production Development
Division of Design & Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2013

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Cover:
The developed work wear, adapted to manufacturing factories in Sweden for the year 2020, made in light blue shirt fabric and dark grey jean fabric

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Aknowledgements

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Glossary

Abrasion: wearing down by friction

Clo: unit describing the amount of clothes needed given the prevailing conditions.

Clo tool: tool for finding the clo value.

Clothing system: the totality of the clothes worn including underwear, middle layer and outer layer, hats, gloves, and jackets.

Conduction: transfer of heat from the person to the clothes worn.

Construction: the make of the clothes; fit, functional parts and closures.

Convection: transfer of heat from the person caused by circulating air removing heated air above the skin, allowing more heat to be removed.

Dross: material created during welding consisting of small hot metal particles.

EC type-examination: the procedure whereby a notified body ascertains and certifies that a representative sample of the production covered fulfils the relevant provisions of this Directive.

Hazard: A source of potential damage to the health of the operator, or a risk of getting injured.

Basically, a hazard can cause harm or adverse effects (to individuals as health effects or to organizations as property or equipment losses).

ICT device: Information and communication technology device allowing the person to do one or more of the following actions: receive, search for and send information

LCA: Life Cycle Assessment. A group of assessment methods to find the total impact of a product or service on the environment during its entire lifetime.

Met and Metabolic Equivalent: unit for describing work performed by humans measured in energy consumption for different work tasks and their effect on the metabolic rate.

Notions: All tools and material needed for completing a garment apart from the fabric.

PPE: Personal Protective Equipment. Clothing or equipment specifically developed to protect users against hazards in the work environment.

Raditation: Energy coming from a source travelling through material or space.

SIS: Swedish Standards Institute. Develops standards for all fields of operation.

SLCA: Sustainability Life Cycle Assessment. A method to find the total impact of a product or service on the environment during its entire lifetime.

Vaporisation: The transformation of liquid into gas, in this instance, sweat into vapor.

Work Wear: Clothes developed for use in work environments

Abstract

The work was performed for the Department of Product and Production Development at Chalmers University of Technology within the framework of the Operator of the Future, a project funded by Vinnova. The Operator of the Future Project aims to explore the needs and requirements of the industrial operator in the year 2020, and how the value adding processes can be supported. The project identified the ability to change and development of processes as key factors for success in the future. While the manufacturing industry has an ever-increasing need for trained professionals, the proportion of the population who are willing to work within the industry in general is decreasing, and the portion that are educated to work in industry is decreasing as well. Young people today say that they want to work in teams, with few position limits, and with an opportunity to be creative in their work. Today's industries do not allow these aspirations, and the clothes aid in cementing that image.

The thesis explores how the population and industry conditions change for the year 2020, and what role work wear can have in that change. Today's manufacturing industries were investigated through literature studies, observations and interviews. The symbolic and physical functions of today's work wear, and the desired functions for 2020 were examined. By identifying two typical work environments and putting them in relation to the work wear currently used, the realization was reached that today's clothing is inappropriate. In the first environment, the clothes are significantly better than they need be, and in the second they are considerably worse than they need to be.

Key factors for successful work wear were identified for users, economy and the environment. A new way of using anthropometric measurements was identified; dynamic measurements using fixed points on the body put in different configurations. The project resulted in a concept for future work wear, where a version of office clothes with improved mobility can be used in the first identified typical environment. These clothes have improved mobility compared to current work wear while they are better adapted to the conditions that actually exist in the industry. By allowing the appearance of operators and managers to converge, cooperation is facilitated which is desired by the future labor force. Concurrently, it may change the erroneous image which many have of the industry: that it is heavy, dirty and dangerous.

KEYWORDS: systematic product development, work wear, ergonomics, operator of the future

Sammanfattning

Arbetet utfördes för institutionen Produkt- och Produktionsutveckling på Chalmers Tekniska Högskola inom ramarna för Framtidsoperatören, ett projekt som är finansierat av Vinnova. Projektet Framtidsoperatören syftar till att undersöka vilka behov och krav som finns för industrioperatören till år 2020, och hur de värdegenererande processerna kan stödjas. Projektet identifierade förändring och utveckling av processer som nyckelfaktorer för framgång i framtiden. Samtidigt som industrin har ett allt ökande behov av kunnig personal minskar den del av befolkningen som är villig att arbeta inom industrin över huvud taget, och den del som utbildar sig för att arbeta i industrin. De unga idag uttrycker att de vill arbeta i lag, över positionsgränser, och med en möjlighet att vara kreativa i sitt arbete. Dagens industrier tillåter inte de önskemålen, och kläderna hjälper till att cementera den bilden.

I examensarbetet utforskades dels hur befolkningen och industrins förutsättningar förändras till år 2020, dels vilken roll arbetskläder kan ha i den förändringen. Dagens verkstadsindustrier undersöktes genom litteraturstudier, observationer och intervjuer. De symboliska och fysiska funktionerna hos dagens arbetskläder samt de önskade funktionerna för år 2020 undersöktes. Genom att identifiera två typmiljöer och sätta dem i relation till de arbetskläder som i dagsläget används i de miljöerna nåddes insikten att dagens kläder är opassande. I den ena miljön är kläderna överdimensionerade jämfört med vad de behöver vara för att ge rätt skyddsnivå, och i den andra är de underdimensionerade jämfört med vad de vara för att ge rätt skyddsnivå.

Nyckelfaktorer för framgångsrika arbetskläder identifierades för användare, ekonomi och miljö. Samtidigt identifierades ett behov av att undersöka ett antal dynamiska antropometriska mått vilka inte finns i litteraturen i dagsläget. Arbetet utmynnade i ett koncept för framtidens arbetskläder, där en version av kontorskläder med förbättrad rörlighet kan användas i den första typmiljön. Dessa kläder har förbättrad rörlighet jämfört med dagens arbetskläder samtidigt som de är bättre anpassade till de krav som faktiskt finns ute i industrin. Genom att låta utseendet på operatörernas och ledarnas kläder närma sig varandra underlättas det samarbete som önskas av den kommande arbetskraften samtidigt som det kan förändra den felaktiga bild som många har av industrin; att den ska vara tung, smutsig och farlig.

De arbetskläder som har undersökts och utvecklats är för den svenska tillverkande verkstadsindustrin, vilket utesluter exempelvis kläder för medicin- och livsmedelsindustrierna. Examensarbetet tog fram ett förslag på arbetskläder för den första miljön där de ursprungliga kläderna var betydligt bättre än vad som krävdes. Avgränsningen gjordes då väl fungerande arbetskläder finns för de tuffare miljöerna, även om de inte används i så stor utsträckning som vore önskvärt.

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1. Introduction

When picturing work wear for the manufacturing industry, one often imagines rugged clothes made to endure welding sparks flying, sprays of mineral oil, heavy lifting and a constant risk of being crushed. This is not what the manufacturing industry looks like in Sweden today but an image which remains from previous years. The preconception of what the industry is like prevents people from applying to jobs and to educate themselves to be able to work in more complex manufacturing industries, meaning that the industry as a whole lack skilled labourers.

This project aims at investigating what work wear could look like when using the actual work environment as a basis for product development, compared to simply continuously improving the clothes that already exist. By looking at the situation from that perspective, the resulting work wear is more fitting to the needs and demands of the work environments.

1.1. Background

There is a history of academically developing work wear in Sweden, especially in the late 1970s and early 1980s. The research was performed at STU which was later transformed into Vinnova. Already then, rational product development processes were used in order to design and manufacture work wear fitting to the users and to the work environment. The framework of the early years provide a work process which can be used still. Since then however, little work has been done to academically look at work wear and what can be achieved within the work environments. Development of work wear in Sweden has subsequently been performed by clothes producing companies instead of in an academic manner. Within the framework of the Vinnova project Operator of the Future, different master thesis projects were suggested, one of which regarded work wear and their ability to carry cognitive information devices.

1.2. Purpose and Objectives

By investigating the actual needs and demands on work wear within the manufacturing industry, work wear can be produced which better fits into the factories of 2020 compared to simply continuing to use the same type of clothes that have been used the last 40 years. Apart from showing the importance of the physical functions of the clothes, this report intends to outline the symbolic functions of work wear, and how these functions affect the wearers.

The investigated material should result in a bill of demands which is written in such a way as to be applicable in the development of work wear in any work environment. This bill of demands should be used in the project to develop prototypes and a concept for the work wear for the future operator. The concept should be presented in a fully functional physical form.

1.3. Delimitations

The fabrics investigated are a sample of the vast number of materials available, the most promising being selected for further investigation. Similarly, while there are several different options available for solving the functional and symbolic values of work wear, the most promising were selected within the context of the overall study.

The focus of the project is to create an alternative to the existing work wear, for the investigated work environments, looking at what could be done in regards to work clothes for the year 2020, to attract the youth to the industry. This means that the project is aimed at a part of the population who are currently not of working age. Concurrently, the work is aimed to attract parts of the population who are currently unwilling to work in the industry. That is, target group of the project are people not currently working there. Therefore the work is partly based on interviews and observations, and partly on literature studies.

The project is carried out in Sweden, taking the Swedish population into account in regards to anthropometry and work conditions. Similarly, the focus is manufacturing industry which is different compared to other industries. The project methodology can easily be used for other populations and other work conditions, but the findings will be different compared to the ones reached in this report.

1.4. Report Disposition

The report is structured with background information first, followed by detailed information on everything regarding clothes and their construction, ending with the final concepts. Readers wanting a quick overview of the material can read chapter 1 Introduction, 4 Bill of Demands and 10 Results. Readers interested in the human factors affecting clothes will be most interested in chapters 3.1-3.7 Readers more interested in economy and sustainability of clothes can read chapters 3.9-3.14. Sustainability of Work Wear and 10 Results. Readers more interested in the work process can read chapter 2 Methodology and 8 Discussion.

2. Methodology

2.1. Project Planning

2.1.1. Gantt Schedule

A Gantt schedule is used in order to correlate different activities against each other, set up on a time scale. It is primarily used to show the timing of activities, to estimate the duration of the activities, and to make sure that the deadlines are met in a timely manner by allowing the user to see for how long time they should be performed. They are also used to show interdependencies between different activities. During this project, the Gantt schedule was used as a tool to keep several ongoing processes going concurrently.

2.1.2. Mind Mapping

A mind map is used to quickly map different idea routes, or to display connected information. A comprehensive mind map was set up at the beginning of the project in order to show the different aspects of the project, and how those aspects were connected to each other.

2.2. Data collection

2.2.1. Literature Study

Literature studies are performed in order to reach a number of different goals. It can be used to find information in a research area which is new to the researcher and to answer specific research questions that arise during the investigations. Literature studies can also be used to find state of the art within the research question and supplement facts for the other research methods. During this project, the literature study was used to supply information of the whole field, and to supplement facts to the LCA and economic investigations.

2.2.2. Observation Study

In order to investigate to usage of a product, and find problems in the interaction between user and product, observations can be used (Karlsson, 2008). Observation studies is an umbrella term covering investigations where the user is to varying degree aware of being observed. To observe the most natural interaction with the product, an covert observation is used, where the observer watches the user without them knowing of the observation. This type of observation is especially valuable when the research area is new to the researcher. In later phases, or if the research area is well known to the researcher, a structured observation can be performed where the researcher asks the user to perform tasks which are more relevant. Thus the actions are performed which are more interesting to the observer, either because they need to be researched more, or because they are the most relevant to the researcher. The observation studies were used in order to find movement patterns, and objects commonly carried by the operators.

2.2.3. Interview

Just like observations, interviews range from unstructured to structured (Karlsson, 2008). The unstructured interviews allow the interviewee to talk about whatever they want to within the given subject of conversation, without being steered by the interviewer. During semi-structured interviews, the interviewee is encouraged to talk about a given topic, and the interviewer makes sure that all the posed questions are answered, without them necessarily being asked in the predetermined order. During the interviews, the interviewer probes the interviewee further in order to get more information than is at first volunteered. In the project, semi-structured interviews were used to find opinions on the symbolic and practical functions of work clothes from operators, managers and bystanders. The finalized product was also benchmarked against opinions of operators to find the validity of the garments.

2.2.4. Antropometric Measurements

Anthropometry, or the art of measuring the body of the population is used in order to determine the range of sizes of standardised body parts in a population (Pheasant and Haslegrave, 2003).. The measurements are carried out by measuring from a defined point of the body to another defined point of the body, commonly from one bone point to the next, as these are easy reference points. Before the measurement, the body is put in a predefined pose. That is, all people are measured in the exact same way and in the same circumstance, in order to get as correct a measurement as possible. The found measurements are put into a table which also show what range of the population which is represented in the table. Normally the 5th to 95th percentile is represented, which are the measurements found within the normally distributed bell curve with the 5th smallest and 95th largest measurements excluded. This exclusion is used as most people of the population are within the 5th to 95th percentile and to include every single member of the population is not feasible in the production of common goods. For this project, the 5th to 95th percentile was used. During the project, dynamic anthropometric measurements were innovated and used. That is, the measurement between two fixed points on the body with the body put in two different predefined positions. This was used to find the needed ease in the garments for full movement.

2.2.5. Selection of Sample

Both interviews and observations use a sample of the population during the performance of the methods. The sample is chosen both on a qualitative and quantitative basis, i.e. what qualities the subjects should have, and how many of them to have. One method which can be used in order to choose the qualitative participants is to choose theoretically representative participants which encompass the demographic, attitudes, physical and cognitive abilities and background, of the researched area. The selection criterion is then based on finding participants fitting into that profile. The quantitative criterion can be seen as the more subjects, the better. However, to use an infinite number of participants is time and resource consuming compared to the results actually obtained. Griffin and Hauser have shown that 90-95% of all data is obtained after 20-30 hours of research (1993).

2.3. Analysis Methods

2.3.1. Life Cycle Analysis

Life Cycle Assessment, LCA, is an umbrella term covering a wide range of methods which aim at estimating the impact of a product during its life cycle (Johannesson et al, 2004). An LCA can be used to evaluate a current product against new concepts, to evaluate new concepts against each other, or to judge different theoretical concepts against each other. The impact during the different stages of the product life cycle are weighed against each other depending on, for example, duration of that stage of the life cycle, the materials in that part of the life cycle, and impact on the environment in that stage of the life cycle. During this project, the LCA was used to find the environmental impact of typical work wear.

2.3.2. Life Cycle Analysis Calculator

The material gathered for performing an LCA quickly get monumental, meaning that it can be hard to draw conclusions on the material. By using the LCA Calculator, or similar tools, the user can easily evaluate different options against each other. Input such as weights, materials and production country for the different stages of the life cycle are judged against each to both find which step that is most harmful to the environment, and to judge different products against each other, to see which has the best overall footprint (lcacalculator, 2013). The tool used the EcoInvent database as a basis for all judgements on the overall footprint of the product, and the included materials (EcoInvent, 2013). The calculator was used to find which stage of the work wear lifecycle which had the largest environmental impact, and to map were improvements could be made.

2.3.3. Road Distance Calculator

For calculating distances in Sweden, the road search service Eniro can be used, which uses a database on land surveying as material for giving information on the distance between two fixed points. Different options are provided, as choosing to only go on highways, to choose between the shortest route and the quickest route (Eniro, 2013). This resource was used for input data into the LCA calculator.

2.3.4. Sea Distance Calculator

For calculating the travelled sea distances of materials and components, the sea distance calculator was used. It allows the user to input data as the starting and ending country and port, the known costs of different fuels, and fixed rates of fuels. The data is used to calculate the cost and time of a journey, as well the distance. (sea-distances, 2013) This resource was used for input data into the LCA calculator.

2.3.5. Sustainability Life Cycle Assessment

Sustainability Life Cycle Assessment (SLCA) is a tool for communicating product sustainability, and to get an easy overview of the different sustainability areas of a product or service (The Natural Step, 2013). The tool includes both ecological and social sustainability. By doing an SLCA for several products, the user can easily see which product is the most sustainable. If the SLCA is performed at different points in time for the same principal product, the user can see whether the product has improved or not.

The different steps of the process are as follows:

1. Define goal and boundaries
2. Set a definition for the sustainability product system
3. Define system boundaries and life cycle of the production
4. Perform an LCA
5. Assess the weaknesses and strengths of the product LCA
6. Find the key impact areas
7. Find solutions
8. Prioritise the solutions
9. Create a strategy for getting to the solution
10. Measure the change and repeat the process

During step 5, table 1 is filled in using the question "what is our product like during the different life stages?"

1. Does the product life cycle contribute to the build-up of substances on the earth's crust?
2. Does the product life cycle contribute to the accumulation of substances produced by society?
3. Does the product life cycle contribute to physical degradation of nature?
4. Does the product life cycle contribute to any conditions that undermine people's capacity to meet their needs?

Table 1. For filling in information found in the LCA procedures

	Raw Materials	Production	Packaging and Distribution	Use	End of life
1					
2					
3					
4					

During step 7, table 1 is filled in, with the question "what can we do to improve our product, and make it sustainable?" or "how can we overcome the obstacles found in step 5?"

The method was used to find the current state of work wear, to identify the issues that needed to be adressed and possibilities for change in work wear in the future.

2.3.6. Morphologic Matrix and Zwicky Boxes

The General Morphological Analysis (GMA) methodology was first described by Fritz Zwicky, who showed how information can be displayed using multi-dimensional matrixes, thereby allowing the interpreter to choose between several choices and reach a valid conclusion. That is, the method allows the user to clearly show the different variant solutions, and to find the different possible relationships between different morphologies within a predefined range of parameters and dimensions (Ritchey, 2002).

Two of the usages of GMA are the morphological matrix and Zwicky boxes. The first step of performing a morphological matrix is to set up the boundaries for the different parameters, thereby framing the research question. The second step is to create, and fill in, numerous solutions for each parameter. If this matrix is created in n dimensions, the result is a Zwicky box. More dimensions than three are hard to visualise for the human brain; however, assessments can be done in a computer. The Zwicky box can also be used to summarize facts and to find the different possible spaces for solutions to exist within.

Morphological matrix was used in order to find different combinations of practical solutions in the work wear. A Zwicky box was used to show the temperature, activity rates and contamination level found during the literature study and the factory visits.

2.3.7. Measuring the Temperature of Comfort using the Clo Tool

The Clo Tool, first developed at Berkley University, is a tool to determine the appropriate amount of clothing given a set of conditions (Hoyt et al, 2013). These conditions are to be measured at the location where the clothes are to be used. The amount of clothing and the protection they give are measured in the unit "Clo", which gives the tool its name. Before using the tool, temperature, wet globe temperature, air speed, metabolic rate and mean radiant temperature are all measured. Inputting these into the tool gives the output as the amount of clothes which should be worn. The tool was used in order to find the feasible amount of, and type of, clothes for the two found typical environments.

2.4. Bill of Demands

The end result of a project should reach to goals posited before, or at the beginning stages of, the project. In order to reach the desired goals, a bill of demands is set up which states which goals and tolerances should be met, and if possible, how it can be measured that this goal has been reached (Johannesson, 2004). Often these goals are weighted as not all goals are equally important. The bill of demands can be used for guiding the design process, to make decisions on designs, and as a tool for the client to make sure that the ordered product has been developed. If the person setting up the bill of demands has not made a proper pre-study into all the different aspects of the product, chances are, that the finished product will not correspond to what s/he had in mind when setting up the bill of demands. The created bill of demands was used to benchmark the different concepts and as a basis for the Pugh matrix.

2.5. Idea Generation Methods and Visualisation Methods

During the project, the idea generation methods and visualisation methods have overlapped, and have been used for both purposes. They have primarily been used to generate ideas, but also as a means to communicate ideas with others. It is inherently hard to describe a model for the creative process (Lawson, 1997). The methods knowingly performed are described here, but there are several processes known and unknown to the designer going on apart from the methods, which are too not fully understood (Purcell and Gero, 2006). Apart from this, each designer in turn makes their own process over time, including a reference frame, image bank, and process choice which is familiar to the designer (Verganti, 2009).

2.5.1. Brainstorming

The umbrella term brainstorming is primarily used for methods which are aimed at quickly creating and developing ideas. Sessions are held on a specific task, commonly for a specified time duration, during which time as many ideas as possible are jotted down without them being criticized. The ideas can be developed upon by others, for example by switching papers to write on, or by developing a single idea further in many different directions. Sketching, quick prototypes and writing are all commonly used to communicate and document the ideas (Karlsson, 2008). During this project, brainstorming was used in order to map out the different areas which needed to be researched. It was also used during the ideation and prototyping phase.

2.5.2. Sketching

Sketching is used for both idea generation, and for visualisation. It enables the drawer to quickly get a multitude of ideas out of their brains and onto paper, thereby freeing up space in the brain for more ideas to emerge, acting as a memory record (Lawson, 1997). Seeing the sketches laid out encourages reinterpretation of the ideas and therefore more ideas can come from one starting image (Goldschmidt, 2003). The reinterpretation of the sketches can be in both lateral and vertical transformations, the lateral showing greater differences between ideas and the vertical showing a greater depth in the sketches, exploring finer differences. (Purcell and Gero, 2006) By sketching an object and sketching it from several angles forces the designer to more closely examine the idea which instantly shows obvious flaws in the design. During the project, sketching was performed mainly by drawing, but also by making quick samples in fabric. The sketches were used to understand the 2D shape of fabric put on a 3D body and in order to understand how different solutions work and how they can be manufactured.

2.5.3. Prototyping

By making prototypes of concepts, the concepts can more easily be evaluated. There is a range in the refinement of the prototypes, from quick'n'dirty to fully functional products (Johannesson, 2004). Quick'n'dirty are just prototypes where objects are assembled into the intended shape, without any refinement, to help in judging sizes and placements. On the other side of the scale are products which are so fully functional including shape, materials and design that they could be the actual product about to be produced. During the project, the full range of prototypes were used. The prototypes were used in order to understand, develop and evaluate both parts of concepts and the full concepts and final solution.

2.6. Evaluation of Concepts

The systematic evaluation and subsequent choosing of concept or concept trail to follow is done by using different methods. These methods are used in order to choose the strongest concept not on gut feeling, but on a factual basis, a way to "kill your darlings". The most promising concepts are evaluated against each other, against the original product, or against the bill of demands. After the evaluation of the concepts, the most promising aspect of the concepts can be combined into a stronger concept.

2.6.1. Pugh Matrix

When using a Pugh matrix, the found solutions are posited against the reference product in order to see how many of the demands that have been met (Johannesson, 2004).

The result is that the product reaches the posited demand, or that it does not reach the demand. Summarising each solution shows whether they are worse or better than the original product. Solutions that are neutral or worse, can be considered for elimination. Products that are potentially better are taken to the next stage.

3. Result from Data Collection and Analysis

3.1. What the Future Holds for Factories and their Operators

There will ge some significant change in the future for the operators. The demands on the operators will increase in terms of education, skills, and mindset. Concurrently, the demographic profile of Sweden and Europe will change. There are some definite challenges in the close future in order to ensure that the industries of Sweden have a competitive edge. This chapter is aimed at giving an insight into the demands, challenges, and opportunities of the future, for the future operator, and for the industry.

3.2. The Future Demographic of Sweden for the year 2020

The population in Sweden is steadily increasing over time, as can be see in Figure 01. The data points of 1950, late 1960s and 2004 are recorded by SCB and the data points of 2024 and 2060 are projections of the future. The life expectancy of women is expected to rise from 83 years in 2008 to 87 years in 2060, whereas the male life expectancy for 2008 is 79 years and 85 years in 2060. Fertility is projected to decrease from 1,9 child/woman in 2006 to 1,8 child/woman in 2060. The net immigration is projected to 19 000 persons annually for 2060.

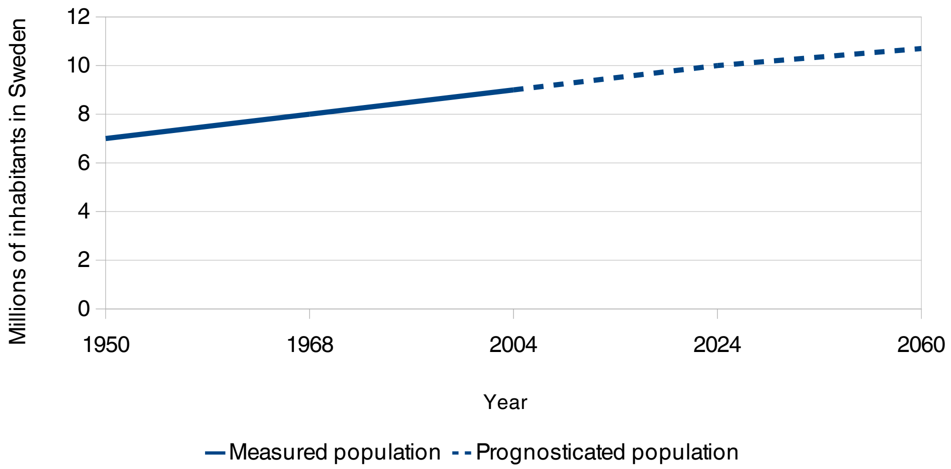


Figure 01: The population over Sweden over time. Diagram created from data from Statistics Sweden, Demographic reports 2009:1, The future population of Sweden 2009–2060.

18% of the Swedish population are currently over 65 years old. Over time, that part of the population will increase whereas the part of the population between 20-64 will decrease, and the part of the population ages 0-23 years old will stay the same. If pension age remains the same, 25% of the population will be pensioners in 2060. Even though the percentage of the population in the middle age range changes, the absolute numbers remain approximately the same, please see table 08. There is an expected baby-boom in 2020, as the large population born 1990 are expected to settle down and have a family around that year. (SCB, 2009)

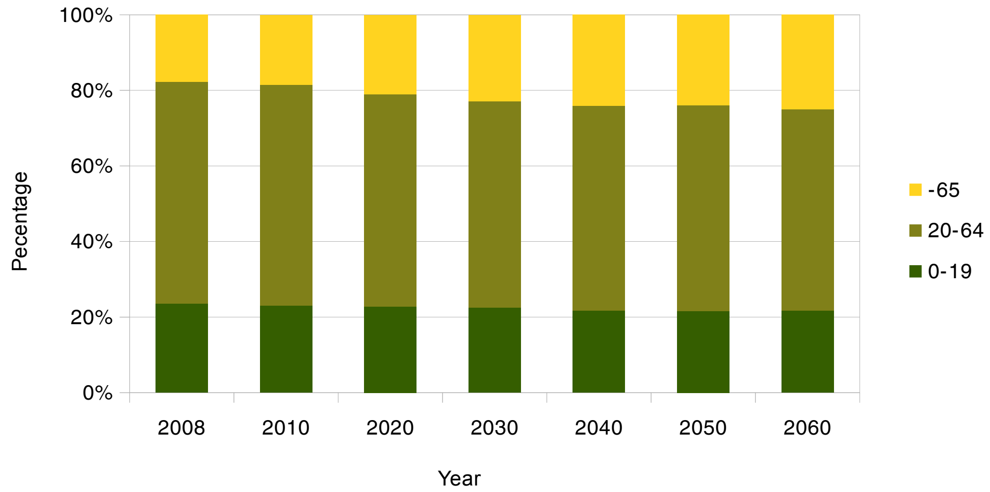


Figure 02: The percentage of the population in the different age intervals. Diagram created from table 8, (source: Statistics Sweden, Demographic reports 2009:1, The future population of Sweden 2009–2060.)

Sweden has the last 80 years had a net immigration, and the percentage of the population born abroad is steadily increasing. The population of 2060 is expected to have a population where 18 percent are born abroad. If there where no immigration, the total population in Sweden would decrease, as every woman is prognosed to give birth to 1,9 children, i.e. less than the needed number for sustained or increased population. (SCB, 2009)

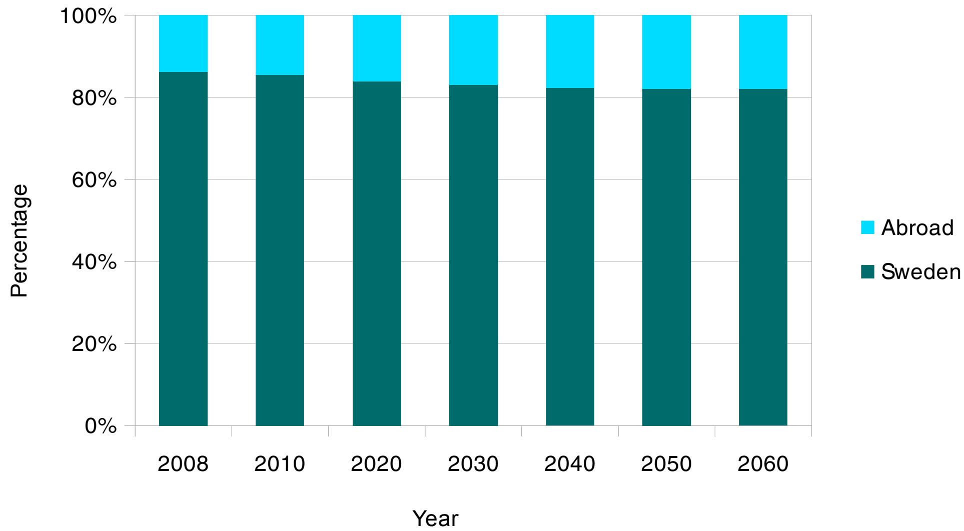


Figure 03: The percentage of the population born in Sweden and born abroad. Diagram created from table 8, (source: Statistics Sweden, Demographic reports 2009:1, The future population of Sweden 2009–2060)

In the future, there will be a fewer females than men, as more boys are born than girls, and since the life expectancy of males increase more that of females. The difference is not even over the different age groups though. Males are dominant in the ages 25-60, and females are dominant in the older group, though not to as large an extent as today. The change in percentage between females and males is less than the change for percentage of population born abroad and the change in age distribution. (SCB, 2009)

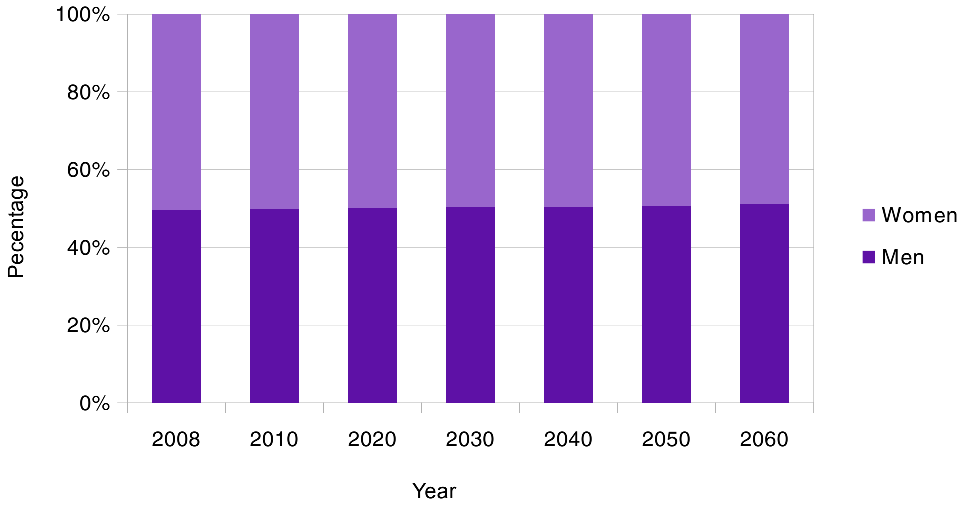


Figure 04: The percentage of the population born in Sweden and born abroad. Diagram created from table 8, (source: Statistics Sweden, Demographic reports 2009:1, The future population of Sweden 2009–2060.)

Table 8. The population of Sweden, projected from the year 2008. The numbers are presented in thousand. Statistics Sweden, Demographic reports 2009:1, The future population of Sweden 2009–2060. Figures presented in thousands.

		Sex		Age			Country of birth	
Year	Total	Women	Men	0-19	20-64	-65	Sweden	Abroad
2008	9256	4653	4604	2184	5427	1645	7975	1282
2010	9385	4711	4675	2169	5482	1735	8016	1369
2020	9863	4916	4947	2244	5545	2074	8270	1593
2030	10219	5074	5145	2304	5580	2336	8483	1737
2040	10398	5146	5252	2262	5630	2506	8560	1839
2050	10578	5216	5362	2284	5757	2537	8677	1901
2060	10721	5217	5450	2334	5698	2689	8789	1932

3.3. The Effect of Changing Demographics on the Industry

The effect of an ageing population leads to a higher dependency ratio for the part of the population who are working. That is, the proportion of the population in the age range of 20-64 years old are supporting the lower and higher ages. As the percentage of the population in the age range 20-64 years old is projected to decrease in the following years, fewer people need to support more people. Currently, 100 working persons support 70 persons, whereas for the year 2060, 100 working persons need to support 88 persons.

The effect of the demographic change depends on retirement ages and participation in the work force of the elderly (Fésüs et al, 2008). Lifelong learning and continued training at a higher level is a key factor to sustain the human knowledge capital, especially in the face of technological development and the continued advance of the information age. Sweden, Denmark and southern Finland are notably good at lifelong learning. There is a strong correlation between tertiary education and employment. For the European region, university graduates had an employment rate of over 70% compared to primary schooled who had an employment rate of 56%. One way to decrease the dependency ratio is to raise the pension age. Another is to motivate more people to work in the industry, where there is a net deficit in skilled workers.

3.3.1. Trends and Prognosis for Education and the Labour Market in Sweden

Demand for personel with at least secondary education, high school or similar, is expected to increase during the investigated time period according to Labor Force Projection (2009). For the entire population, supply is higher than demand with the exception of the fields of nursing and healthcare and the services. Concurrently, demands for staff in manufacturing is expected to continue to decrease. The industry professions are expected to involve more qualified tasks. New technology and increased automation has changed the way the industries work, and what is expected of the worker. An increase in the demand for being able to handle and programme advanced machinery puts new expectations and demands on the workers. There are few women educated within the industry field, and those who are educated often work outside of the industry. This trend does not look like it will change over time. Overall, the number of people educated

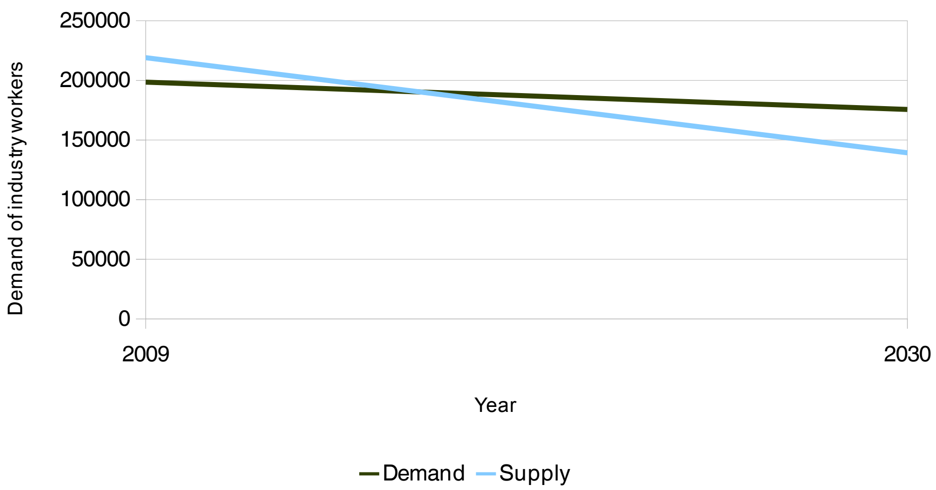


Figure 05: The current and projected demand and supply of high school educated industry workers. The figure for 2009 is measured whereas 2030 is projected. Only these dates were provided in the source (Source: Statistics Sweden, Trends and Forecasts 2011.)

within the field is decreasing over the time period, which can be seen in Figure 05. The supply and the demand is projected to decrease until the year 2030. As the supply decreases more than the demand, there will be a projected net deficit of skilled industry workers. (Statistics Sweden, 2011)

3.3.2. The Operator of the Future

In the future, operators want autonomy, decision-making, creativity and lifelong learning, for factories to be an appealing environment to work in (Grane et al, 2008). Another factor which has been identified to attract skilled labour, is a safe work environment (Noort and McCarthy, 2008).

The level of automation within the manufacturing industry is continuously increasing. A correct level of automation balanced with manual work and decisions will ensure both good quality, and manufacturing competitiveness. Concurrently, the operators need to be educated to a greater extent, be able to shift between work tasks and be flexible in the work situation. The operators also need to take a larger responsibility in the decision making process, and in increasing the value of their work and the value adding activities. (Grane et al, 2008)

Currently, Swedish factories have well developed information technology in place, as well as a decentralized decision making process, which is crucial for quick adaptations and on-the-spot decisions. The information flow is continuously increasing, and with the increase in automation, efficient and trenchant exposition of information is paramount to the success of the industry. New means of showing information is currently being explored, such as augmented reality, haptic signals and visualisations. (Grane et al, 2008)

A factor for success for handling the intensified information flow, increased responsibility and autonomy, is an increase in communication. Communication and relation building will become more important and valued than it currently is. (Grane et al, 2008)

3.3.3. Efficient Factories and Attractive Jobs

Efficient factories are often equaled to factories which are run on Tayloristic principles with assembly lines and little personal development for the operators. Attractive jobs are jobs with autonomy, team work, variation, lifelong learning, a safe work environment and be adapted to the persons working there. (Wikberg-Nilsson, 2011)

The work environment affects both the physical and psychosocial work environment. A well-lit and correctly designed work environment will lead to a better health for the employees, and will encourage better work morale. The current premises are often dark, and the jobs as a whole are depicted as dirty, dark, heavy and dangerous. This leads to fewer youths wanting to work within the industry, and even fewer females. (Wikberg-Nilsson, 2011) Above all, it is often not true, as the work is neither heavy nor dangerous.

One vision of the future was a factory where there was no division between the factory-workers and the office-workers, the job would be divided equally after interest and ability. The workers would affect decisions such as flexible schedules, extra unpaid vacation days, the design of the factory floor. The factories are built with modern materials with good lighting and windows. The corporate identity should be clearly seen throughout the factory and contribute to the pride of working for that company. (Wikberg-Nilsson, 2011)

3.4. *Human Physiology, Human Anthropometry, Comfort and the Ergonomics of Work Clothes*

Most products work together with the body, but clothes work more closely together with the body than almost any other product. Before the clothes are put on the body, they are just cloth. In conjunction with the body, the clothes become functional products (Lindqvist, 2013). The way the body works both seen from a physiological perspective and from a biomechanical perspective affect how it should be treated and what limitations one has when developing products for the body. In the case of work wear, movement patterns affect the confectioning and functionalities. Anthropometric measurements provide the information needed to provide the right sizes and composition of the clothes. Poorly fitted work wear will lead to a decreased protection level. Physiology and comfort determine the way seams are made and placed, ventilation openings, cleaning intervals and cloth distribution on the body. Work wear need to work not only on an aesthetic level, but also on a comfort level in order to provide the user with the desired protection (Raheel et al, 1994).

3.4.1. *Movement Patterns*

The movement patterns of a specific work environment with associated tasks give an indication as to which anthropometric measurements that are useful to use in these circumstances. Movement patterns in the context of clothes coupled with anatomical knowledge show the areas of the body which change constitution during work, and therefore, what areas of the body that need to be taken into special consideration in the confectioning of work wear. The movement patterns can also give and indication as to what functionalities and services the clothes need to provice for the work task to be efficiently and safely performed.

3.4.2. *Antropometric Measurements*

Pheasant and Haslegrave (1996) provides most anthropometric measurements used in product development. In the case of development for clothes, I found the need to develop a new method for recording anthropometric measurements. Normally measurements between fixed points are recorded in only one pre-defined stance, normally a neutral stance. Here measurements were recorded for two pre-defined extreme stances in order to find the needed ease in the clothes. There are directions in the pattern construction literature on how much ease of movement that should be added but the ease of movement is erratically stated, giving too much or too little freedom to move and badly fitting clothes. Ease of movement is commonly shortened to “ease” in sewing instructions. In order to get more accurate measurements, a representative conveniance sample was measured using anthropometric principles. The found measurements are not statistically correct as only a small part of the population was measured meaning that further research needs to be performed in the area, but the results do give a pointer towards the ease needed. All measurements were taking with the person standing upright with a neutral stance, unless otherwise stated. Aiding in finding the correct measuring points of the body was the Innerbody Body Atlas (2013) and the knowledge of the ostheopath Daniel Söderberg. (2013-04-02)

The following paragraphs describe measurements which were identified as crucial for the development of work wear, but could not be found in literature.

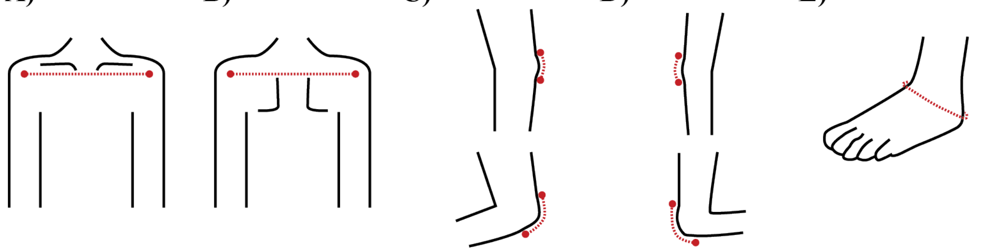


Figure 06: Overview of the dynamic anthropometric measurements. A) Dynamic anterior shoulder width. B) Dynamic posterior shoulder width. C) Dynamic anterior knee length. D)Dynamic posterior elbow measurement. E) Distance around ankle via the heel.

A) Dynamic Anterior Shoulder Width
The distance between the anterior acromion on each shoulder in a relaxed stance, and the distance between the anterior acromion on each shoulder with the shoulders pulled back are measured. The measurement is used for finding the ease needed on the upper ventral side of the torso.

B) Dynamic Posterior Shoulder Width
The distance between the the posterior acromion on each shoulder in a relaxed state, and the distance between the posterior acromium when the shoulders are pulled forward are measured. The measurement is used for finding the ease needed on the upper dorsal side of the torso.

C) Dynamic Anterior Knee Length
The distance between the patellar tendon and the quadriceps attachment to the patella when the leg is straight and the distance between the patellar tendon and the quadriceps attachment to the patella when the knee is bent 90 degrees are measured. The measurement shows how much ease which is needed in the knee joint.

D) Dynamic Posterior Elbow Measurement
The distance between the joint capsule of the elbow and the point of the ulna vertical to the joint capsule and horisontal to the radial notch of the ulna when the elbow is straight, and the same points when the elbow is bent 90 degrees are measured. The measurement shows how much ease which is needed in the elbow joint.

E) Distance Around Ankle Via the Heel
The distance around the ankle measured at the diagonal going between the talar dome and the heel plate is measured. The measurement is corrected with the estimated thickness of a work boot in order to find the maximal allowed width of trousers of the trousers are to not drag on the floor.

3.4.3. Load on the Body from Clothes
The load from clothes on the body should not be underestimated, especially from heavier work wear and personal protection equipment. The load of the garment is distributed on the body depending on its confectioning. Shirts, overalls and jackets rest on the shoulders whereas trousers and skirts rest on the hips. A clothing system using separate parts will divide the load more evenly on the body compared to a system where the load is put on just the shoulders. Load should generally be put as symmetrically on the body as possible to avoid the body being twisted or distorted (ISO 13921:2007). In the

case of work wear, the load is compounded by both the clothes, and by all the tools and objects which are carried in the clothes. Assymetric load is easily caused by one-sided loading of objects.

3.4.4. Physiology and Comfort

The main interaction between the physiological properties of the body and the work wear is the effect on body temperature and heat,sweating, and chafing and other skin irritations. The physiological reactions are not only affected by the clothes in themselves, but also the environment they work in.

3.4.5. Body Temperature and Heat

Temperature and thermal comfort are the most important physical factor in determining the ability to work (Rosenblad-Wallin and Kärrholm, 1976). In many countries, the ambient temperature is much higher than it is in Sweden, meaning that high temperatures are a very real problem during work. This is seldom a problem in Sweden (Bohgard et al, 2008) During extreme cold or warm temperatures, the ability to work is reduced as the body is put under pressure. This ability affects both the physical and cognitive abilities. Once again, these extreme temperatures are seldom reached in Sweden during indoor work. (Bohgard et al, 2008). One exception to this is fire fighters and lumberjacks who work in, respectively, very warm and sometimes very cold temperatures. For most of the population, indoors and indoor-outdoor work is the standard.

Heat is created as the body transforms chemical energy into thermal energy and kinetic energy which can perform work. The heat developed is measured in watt, [W]. On average, a body at rest develops 100W and one in heavy labor develops 600 W. This can also be expressed in met [met] where 100W equals 1 met. Met is the unit used in describing labour and the intensity of the labour. (Gavhed and Holmer, 2006)

The body can change its own temperature and adapt to the surroundings, to a certain degree. There are four ways in which the body gain or lose heat from the environment. Each way can be helped or prevented by environmental factors, individual body differences and clothing factors. (Gavhed and Holmer, 2006; Kroemer et al, 2010)

- convection: the air is heated by the skin, the air travels upwards. The heated air is transported away by wind and body movement.
- radiation: heat is lost to the surrounding air through infrared electromagnetic waves, or gained through infrared electromagnetic waves if the air is hot.
- conduction: heat is transferred to/from the skin directly from the surrounding material, such as from/to clothes
- vaporisation: heat is lost form the body in the form of vapor from sweating or the skin being soaked, high air humidity, materials not letting steam through, and impenetrable clothes that fit tightly will decrease the vaporisation rate

Table 2. Factors affecting the loss/uptake of heat. Based on Gavhed and Holmér 2006, and Bohgard et al , and Kroemer et al, 2010

Heat Transfer	Individual body factors	Environmental factors	Clothing factors
Convection	Skin temperature, the shape and texture of the surface, body movement	Air temperature, Air speed	Thermal resistance
Radiation	Surface temperature	Surface temperature	Thermal resistance
Conduction	Surface temperature	Surface temperature	Insulation, conductivity of material
Vaporisation	Body movement	Air humidity, air speed	Vapor resistance of clothes

3.4.6. Sweating

The eccrine sweat glands are spread over the whole body and secrete sweat which is a fluid consisting of water, salt, urea and uroconic acid. It also contains trace minerals and vitamins. The body sweats more during heavier exercise or other high body temperature. As the sweat is secreted and vaporised, the blood temperature is lowered, thereby lowering the whole body temperature. (Kent, 1997. Food and Fitness: a dictionary of diet and exercise)

In warmer climates, sweating is the most important method of maintaining the correct temperature balance in the body (Gavhed and Holmer, 2006). Sweating leads to a decrease in body temperature as the energy required to transform the liquid water into gaseous water is derived from the skin, leading to a net loss in energy (i.e. heat) from the skin. Simultaneously, the loss of water through sweat leads to a loss of fluid in the body. A loss of fluid can severely lower the ability to work and think (Gavhed and Holmer, 2006). As the water is vaporised from the skin, the salt chrystals and other substances from the sweat remains on the skin, or in the clothes.

3.4.7. Chafing and Skin Irritation

Human skin is sensitive to repeated abrasions and contact. The repeated contact can lead to either blisters or to a rash. Skin irritation is more likely to arise when the material rubbing is coarse and causes friction against the skin. The friction can also arise because of the material being sticky, dirty, sweaty, wet, or made by non-natural materials. (MedlinePlus, 2013)

3.5. The Work Environment and Conditions in the Manufacturing Factories

In order to investigate the conditions in the manufacturing industries, three different factories were visited. The factories in themselves are different from each other seen from experience level of the employees, the number of employees, the kinds of goods they manufacture. To supplement the visited factories, literature studies and interviews were performed.

3.5.1. Characteristics of the Visited Factories

One condition for being permitted to visit the factories was to not mention their name in the report, for confidentiality reasons. Therefore the factories are named A, B and C throughout the report. The factories represent different sectors of typical Swedish Industries, and all place different demands on their operators. Apart from the work tasks performed, the factories work with different materials, with different degrees of automation, and different work force sizes.

Company A: Manufacturing of Fine Mechanics

The first visited company manufactures fine mechanical parts which are supplied for other industries. It is a global company active in most countries, and some 1800 employees in the visited factory, 1300 of which work within the manufacturing department. The parts manufactured range in size from a couple of millimetres up to a couple of metres, common for all sizes is the need for exactness in manufacturing and function. Even small mistakes will lead to a greatly reduced durability of the part. Manufacturing of the parts are largely automatic with some lighter manual work being performed. The work is being performed in teams, each working mainly with one operations line. Automated operations allow the operators to supervise the work and intervene when problems arise. Problems which arise are discussed with operations managers at the end and start of every work shift by the team leaders.

There are few injuries reported from working in the manufacturing. Operations managers which had been in the company for 40+ years reported on the work environment improving greatly over the years. At the start of their working at the company, the work was heavy labor with poor air quality. Mineral oils had been replaced with water based lubricants which are non-toxic to the skin. Changing lubricants also improved the air quality, together with the improved ventilation.

Work temperatures within the factory ranged from 19-24 degrees with some higher temperatures registered near heating ovens used for tempering steel. Little work was performed near these ovens. The humidity was controlled in order to provide a good working climate, and to keep control over the manufacturing process.

All manufacturing personnel were provided with free work clothes as part of their benefits package. They had a set of different clothes models to choose between, but commonly wore craftsman trousers or flat front work chinos with jean pockets. On top a t-shirt, polo shirt underneath a flannel shirt or sweatshirt, sometimes covered with a jacket. Despite having male and female shoe models, all chose to use the male shoe model. The female model was perceived as not providing protection for the foot. All personnel are prescribed by law to wear safety shoes in this type of environment. Clothes models were chosen on personal preferences, not male or female. All manufacturer clothes were loose fitting and made in the same colourways. The observed operations managers commonly wore light chinos paired with a light shirt and a darker cashmere sweater or jacket.

Most interviewees and observed operators only carried a pen, paper and their phone. In rare cases, they also carried their wallet in the back pocket. Dispensers for ear plugs were distributed throughout the factory. The few tools needed for operations were placed at the workstations. Maintenance personnel carried the needed tools in their craftsman trousers and carried objects such as hammers, carpenters rulers and electronic measuring devices.

There was little complaint about the current clothes. The company had previously developed their own clothes, but were currently buying them from one of the larger work wear manufacturers in Sweden, and were reasonably happy with them. At times, the bottom hem of the trousers were folded up to adjust their size to the worker. Breaking down of the clothes occured due to normal wear and tear of the clothes.

Clothes were washed centrally by an external company. Each worker had two sets of clothes, one always being at the cleaners. The clothes are sent back to their owners using integrated barcode labels and a locker system. During cleaning, the clothes were mended, and if needed, replaced.

Previously, the clothes were washed and repaired centrally, now however, it is up to each person to take care of their clothes. The operators admitted not washing and repairing them as often as they should do for several reasons:

- having only one set of clothes made it hard to find the time to manage to both wash and dry them until the next day,
- having to lug the clothes back and forth, and
- not knowing what kinds of chemicals that would be released from the clothes all contributed to them not being washed
- landlords did not permit work clothes to be washed in the communal wash-house
- there was no flame retardant fabric available to use for mending the clothes with.

Company B: Manufacturing of vacuumed formed details

The second visited company shapes plastic sheets into details mainly supplied to the vehicle industry. The details range in size from a few decimetres to two metres across. A range of smaller and larger vacuum forming machines, bandsaws and handheld electronic workshop equipment were used. The first stage of manufacturing was shaping the actual plastic sheets, followed by post-processing and finally assembly. Most personnel were trained to occupy one or two workstations whereas some could work in the entire factory. There were currently 50 people working at the company, until recently there had been some 75 persons working at the site.

Normal working temperatures varied greatly between the seasons according to the operations manager. During the time of visit, the temperature was around 20 degrees centigrade, but varying within the site. At the visit there was a shift change during which the floor was swept and wiped from any residue. During manufacturing, shavings are created when the vacuum formed parts are sawed from the sheet they were manufactured from, resulting in great amounts of shavings. These can be slippery, therefore the entire factory was swept between each shift, and during shifts if needed. Some water based solvents and bonding agents were used in the assembly stage of production, in ventilated conditions. Safety regulations regarding the contingent dangers of the chemicals were posted on prominent positions. Most interviewees and observed operators only carried a pen, paper and their phone. Other objects and tools were placed at their designated work station.

The personnel were free to choose their own work clothes from the nearby workwear store which was situated in the same building as the factory. Operators were also free to use their private clothes during work. As the workwear was chosen by the operators themselves, a wide range of styles, models and materials were observed. Most wore craftsman trousers or baggy jeans, a t-shirt and sweatshirt. There were many modifications to the clothes, especially the trouser legs which were commonly folded, cut at the knee or tucked into the shoes. All personnel are prescribed by law to wear safety shoes in this type of environment.

The clothes were maintained and washed by the operators themselves. The company provided a laundry department for the operators to wash the clothes regularly, and the operators were instructed to wash their clothes often, but this was not enforced. As the factory was in the process of moving locations, they were also changing to one line of clothes provided, maintained and washed by the company and an external laundry company both to create a higher degree of feeling united within the company as well as raise the standard of the clothes.

Company C: Welding School
The third visited company was a welding school. By visiting a school, the opinions of the youth which had just begun their training could be obtained, together with the opinions of the teachers, who had worked as welders for 20+ years. In the school, different kinds of welding apparatus were taught and used. The work also included using various types of workshop equipment. The pupils learnt the different machinery in steps, finishing each stage with a test which needed to be approved by the teacher. Each new stage started of with instructions of the vital parts of this stage. The learning sessions and tasks were mixed practical and theoretical work.

Working as a welder involves several risks, from getting burns from welding sparks to breathing in noxious gasses. There are tools to aid in heavy lifting, but these are often not used as they are perceived as not giving an immediate benefit and slowing the work. Few things are dropped during the work.

Normal working temperatures for the welders was around 18 degrees, but varying with the seasons, and on the work site. Work afield is dependent on the outside temperature and can therefore be from several degrees minus centigrade up to several degrees plus, and in different degrees of humidity. The range considered in the scope of the project is for indoors climate in Sweden. The working environment was very dirty both because of the dross created during welding, the filing done before and after welding, and the welding process in itself. The pupils claimed that the tidied their working space regularly, however there was much dirt on the floor, walls and furniture.

The clothes need to cover the entirety of the body for welders, not only for protection against burns, but also to ensure that the skin is protected from the radiation emitted from the welding apparatus (interview 2013-02-26). Despite dangerous gases being emitted, the pupils did not want a warning system for when the levels were dangerously high. Even the pupils who refused to do heavy lifting and used the provided equipment for lifting thought a warning system was superfluous. In their words “the work needs to be finished, therefore there is no point with having a warning system. Concurrently, the users said that each welding could be finished quickly, and that a break could be had afterwards, therefore the point of a warning system could be to show that they needed to take a longer break afterwards, or adjust the safety equipment such as the ventilation, which would greatly enhance the work environment.

The teachers on site wore craftsman trousers paired with a t-shirt and and zip-up sweatshirt, as they were primarily instructing the pupils. While welding, they put on coveralls over their normal clothes. The operators wore loose coveralls over leggings and a tank top or t-shirt. Not included in the coveralls is the scarf worn around the neck to protect the neck from weld sparks, and to prevent weld sparks to get into the coveralls and fall on the naked skin below. One welder suggested that special welder long johns should be developed, which are flame retardant. Few pockets were used in the current coveralls as most objects are in the way during the actual work, and cannot be accessed when wearing the gloves. All personnel are prescribed by law to wear safety shoes in this type of environment.

Most interviewees and observed operators only carried a pen, paper and their phone. In addition, they also brought a cap to wear under the welding helmet, earplugs, soapstone chalk used to mark metal and a wrench used when changing gas bottles. To bring their phone to the work station was not recommended as was subjected to the risk of being burnt by weld sparks. Gloves can also be stuffed in the pockets. The pupils only carried pen, paper and phone.

The seams are usually the first to go, either because they burn up more easily, because they are more exposed than the main fabric, or because they are made from another material, or put another kind of strain compared to the other fabric as the seams are less stretchy. One interviewee stated that while the manufacturer used a kevlar thread, the thread did not break before the other fabric did. Having deep pockets prevents things from being dropped.There are leather aprons available to use when welding, together with loose leather arm protection, which is put on top of the coverall. This equipment is sometimes used, but perceived as cumbersome to work in, even though they give a good level of protection.

The welder coverall have very long legs to ensure that the entirety of the shin is covered by fabric, to prevent welding sparks on the skin, even when the operator is kneeling or sitting. At first the operators were not aware of this and were annoyed with the lenght of the coverall, even folding the leg up as to not stumble on the long legs. After being told the reasoning behind the length, the pupils left the legs unfolded, trying to cover as much as possible of the shoe with the hem of the pant.

Previously, the clothes were washed and repaired centrally, now however, it is up to each person to take care of their clothes. The operators admitted not washing and repairing them as often as they should do for several reasons. Having only one set of clothes made it hard to find the time to manage to both wash and dry them until the next day, having to lug the clothes back and forth, and not knowing what kinds of chemicals that would be released from the clothes all contributed to them not being washed. As for not being repaired, there was no flame retardant fabric available to use for mending the clothes with.

There were serious injuries reported, but burns, eye damage, photokeratitis (similar to snow blindness) getting pinched.

Company D: Manufacturer of Complex Machinery

The fourth visited company manufactures parts for complex machinery, and the machinery in itself. The company is multinational with 1900 employees in the visisted factory. Manufactured goods range in size from a few centimetres for the smaller subcomponents up to several metres for the finished products. Precision and speed needs to be high in the assembly line, which is continuously moving. Aiding the operators are various tools, but the grunt of the work is done manually.

Some types of injuries is common, especially back, wrist and shoulder injuries. There are many heavy lifts and uncomfortable working positions. Even though the ergonomic of the work environment is continuously improving, there are still many problems. The factory is very quiet to limit hearing problems arising for the operators. Work temperatures vary within the factory but lie within 19-24 degrees in most places of the plant.

Free work clothes are provided for all operators who were employed by company D. The work force was supplemented by personnel from temp agencies, who wore clothes from the temp agency. Operators from both companies were detected wearing private work clothes, and tampering with the clothes by folding the legs. Commonly a pair of either pleat front chinos or craftsman trousers was paired with a t-shirt and a sweatshirt. The sweatshirt was sometimes replaced with a craftsman shirt or a jacket. All operators wore work shoes. The operators were allowed to choose between the different clothes models themselves. Managers wore black trousers and a light blue or white shirt, clearly distinguishing them from the operators. Upon probing, the operators commonly preferred the sweatshirt over a shirt, as it was more comfortable to work in. The few operators wearing craftsman shirts preferred to work in them as they were more comfortable than the sweater. Overall, the operators liked their clothes and did not want to change them for other clothes.

Objects carried on the work floor was a pen and paper, cell phone, wallet and keys. On assembly stations, operators wore a tool belt to carry all tools needed for the work. Maintenance personnel wore overalls instead paired with a tool belt.

Clothes were washed partly by Company D and partly by the operators themselves. Trousers could be washed by the company if the operators wanted to hand them in for washing, otherwise they would be washed at home together with the inner and outer top layer. Mending of the work clothes was performed by the operators themselves.

3.5.2. Features of the Different Work Environments

Two distinctly different work environments were noted in the observations and during interviews with both managers and factory operators. The characteristics of the different environments can be seen in Table 6. The same type of clothes was observed in both kinds of environments, with some more protection for body, hands and eyes in the second environment. Differences in the environment occur due to the nature of the work, both seen on degree of automation, and the inherent qualities of the work to be performed. As the same kinds of clothes could be observed in both environments the conclusion could be drawn that the clothes are somewhat overdimensioned for Environment 1 and clearly underdimensioned for Environment 2. In both Environment 1 and 2, work shoes should be used in order to minimize the dangers associated with being hit by a forklift truck or falling objects. In both environments, there is a chance to get stuck on objects or trip.

Environment 1

Environment 1 could be observed in Factory A and B, as well as control factory D. It is clean with few dangerous gases, fluids and particles. It is commonly operated at normal room temperature from 18-24 degrees and with little change in temperature during a single work day. The users are commonly not exposed to hot objects, or to open flame, therefore the clothes do not need to be in inflammable material, impregnated with flame retardants, or be made of materials which do not melt. The work is automated to some degree, with tools available for doing heavier work, even though they are not always used. Usage of the machines and tools can in themselves cause damage to the operator. Operators in this environment range from being unskilled to skilled. Training is done on-site on the different machinery according to need. Objects typically carried in this environment are pen, paper, knife and phone. Wallets are seen, as are keys. The objects were carried on the persons and never placed on work stations or similar.

Environment 2

Factory C and several interviews gave information on Environment 2. During interviews accidents were reported directly linked to the work clothes.

- Operation oils were spread on the trunk, the sides of the trunk and the front thighs of the worker. Stepping close to open welding flames meant that the workers regularly set themselves on fire.
- The front pockets of their work wear trousers could get filled with operation oils and burned like wicks once the fabric was soaked through.
- Welding sparks burnt holes in clothes, especially if they got stuck in pockets or folds of the fabric. Once the fabric was burnt through, welding sparks could get in contact with the body, harming the operator. Therefore immediate mending of clothes which are used is needed in order to ensure that that risk is avoided. Usually the sparks fell right through the garment, but they were also reported to get stuck in t-shirts, long-johns and underwear, meaning that they had the chance to severely burn the operators.
- Glove fingers, especially the thumb and forefinger are burnt off as hot objects need to be manipulated regularly. In Environment 2, the clothes need inflammade fabric and being impregnated with flame retardants, and to be made out of cloth which cannot melt which exclude plastic materials.

Objects typically carried in this environment are pen, paper, phone, gloves, welding cap, knife, carpenters ruler and wrench. Wallets are seen, as are keys. Even though the objects were seen carried on the person, they were just as often observed being placed near the workstation. Operators in this environment are skilled and receive formal training prior to working onsite.

Table 3. Features of the Different Work Environments

Factor	**Environment 1**	**Environment 2**
Temperature Degrees Celcius	18 to 24	10 to 30
Dangerous gases	No	Yes
Hot particles near operators	No	Yes
Incidents caused by work wear reported	No	Yes
Daily check for mending of clothes	Desirable	Required
Immediate mending of clothes	Desirable	Required
Objects carried	Pen, paper, phone, knife, wallet, keys	pen, paper, phone, gloves, welding cap, knife, wallet, keys, carpenters measure and wrench
All pockets used	No	No

Skilled operators	Vary	Yes
Formally trained operators	Vary	Yes
Clothes underdimensioned	No	Yes
Clothes overdimensioned	Yes	No

3.5.3. Temperatures of the Work Environments

Figure 06 shows the Zwicky box comparing the conditions of Temperature, Activity level and Contamination. These three conditions are often used in Swedish literature on work wear, being the most important factors for determining clothing demands (Rosenblad-Wallin and Kärrholm, 1976; Gavhed and Holmér, 2006). The definitions are taken from Rosenblad-Wallin and Kärrholm (1976)

Activity

The level of activity is set from the perceived level of oxygen uptake.

- A1. 0.7 litres or less of oxygen/minute. Sitting, sitting or standing work with little movement
- A2. 0.7-1.1 litres of oxygen/minute. Standing upright with much movement, or walking work
- A3. 1.1 litres of oxygen/minute and above. Very active work with much movement

The activity level varies over the day, and with the work tasks, but generally there is a level 2 activity with standing work and some movement with light to heavy lifting and handling of tools, with a great degree of movement needed.

Contamination

Contamination contain all kinds of external impact, as oils, chemicals, dust and effluents.

- C1. Low degree of contamination
- C2. Medium degree of contamination
- C3. High degree of contamination

The contamination level observed varied greatly both between work places, and between workers in a specific work place. Multiple interviewees reported that over time, the degree of contamination and the harshness of the contaminants had reduced greatly. (intervju SKF)

Temperature

The temperature is measured in Wet Bulb Globe Temperature (WBGT) which gives a combined measurement of the air temperature, convection temperature, air speed and air humidity.

- T1. Very warm climate, WBGT over 28 degrees C
- T2. Warm climate, WBGT 26-28 degrees C
- T3. Normal indoors climate, WBGT lower than 26 degrees C
- T4. Indoor-outdoor work rotation
- T5. Cold climate
- T6. Very cold climate

Measured Conditions during Observation Visits

During the observations, the following conditions where detected:

- Temperature: 2-4
- Contamination: 1-2, rarely 3.
- Activity: mainly 2, with some work on level 1 and 3

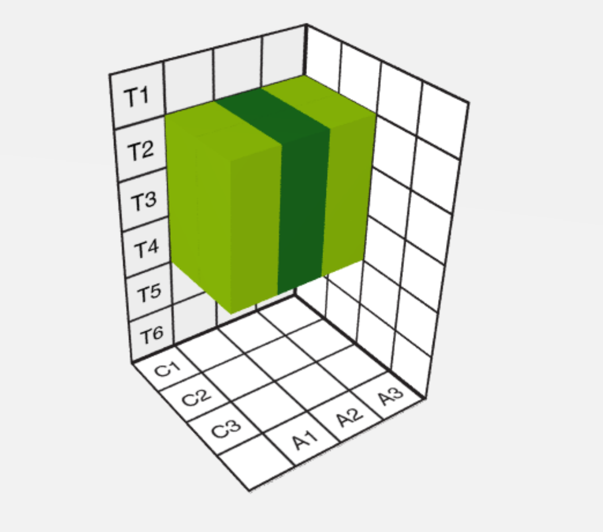


Figure 07: Activity, Contamination and Temperature observed in the visited factories. The lighter green indicate less commonly occuring conditions whereas the darker green indicate the most commonly seen conditions. Areas not filled in were not measured.

3.5.4. Movement Patterns in Factory Work

The litterature study and the observations showed the same result in regards to movement patterns and comfort in factory work. The most commonly found work position was standing interspersed with sitting work. In all observed situations, the stationary work was mixed with walking to, and between, working situations. A need for free range of movement in the upper body region was needed in all observed situations. The most common found work positions are listed below.

- Walking
- Sitting
- Standing
- Bending
- Crawling
- Kneeling
- Reaching in all directions, with one or both hands
- Leaning forwards
- Stepping on top of a stool
- Carrying wide objects
- Lifting heavy objects

3.6. The Functions of Clothes

Clothes have two main areas of function. They have symbolic functions and practical functions, each of which can be divided into subgroups. The fit and design, the fabric and its tactile properties, chosen colours, and almost all other aspects affect both the symbolic function of clothes, and the practical functions. As such, the areas are connected to each other and cannot be completely split apart. When the demands for practical functions decrease, there is more space for the symbolic functions. (Rosenblad-Wallin, 1983). This chapter aims at outlining the main functions within each of these areas.

3.6.1. The Practical Function of Clothes

The practical function of clothes are the physical properties which the clothes need to provide in order to be useful for the wearer. A tenet for the practical functions of clothes is to “keep the user in comfort” (Rosenblad-Wallin, 1983) These functions are connected to the context in which they are to be worn including the body of the wearer, the ambient temperature and the types of contaminants they are to be resistant against. How well the clothes perform their function depends on several factors, such as the total effect of all clothes worn together, the fabric of the clothes, construction and notions (avhandlingen). Even in environments where the protective properties of the garments are objectively most important, without comfort, the probability of the work wear being used is reduced (Rosenblad-Wallin and Kärrholm, 1976)

The market for work wear is immense and somewhat hard to get a grip on, especially if the purchaser of the clothes is not absolutely aware of all the conditions in which the clothes are to be used (Möller and Grant, 1982). The most common practical functions of clothes are listed below, as described in for example (Rosenblad-Wallin and Kärrholm 1976; Gavhed and Holmér 2006) The listed practical functions of the clothes are the ones deemed most relevant to the project.

Protection against Temperatures

Clothes protect the wearer against the experiencing uncomfortable temperatures. Experiencing excessive heat can happen when the surrounding environment is too hot, or the own body too hot. The clothes then need to to either protect the wearer from the heat, or allow heat to be ventilated away from the body. The wearer can also experience being too cold, either because of their own body being too cold, or the surrounding environment to be too cold. The clothes then need to provide warmth, and provide enough insulation to prevent the wearer from getting cold. When working in temperature shifting environments, the clothes need to be either adapted to that, or be easily adjusted. The clothes also need to be adapted to the prevailing wind conditions. Wind and draft removes heat from the wearer.

Resist Mechanical Impact and Abbrasion: Wear and Tear

The clothes need to be resistant against normal wear and tear such as abrasions caused by the fabric rubbing against itself, or against other surfaces. Clothing should also protect against other wear and tear like cuts, scratches and tears, which are prevalent in the intended wear environment. If possible, the clothes should prevent injuries and accidents. The construction and creation of work clothes need to take these factors into consideration (Rosenblad-Wallin and Kärrholm, 1976). The functional details need to resist the force which is imparted on them during normal use as they are commonly exposed to more force.

Motion Comfort

In order to be useful to the user, the work wear needs to allow the user to move in all directions. This can partly be achieved with the accuracy of the fit of the garment. How the fabric stretches, and how it glides over the body also aids in the comfort when moving within the garment. (Rosenblad-Wallin, 1983)

Protect the Wearer from Contamination

The wearer needs to be protected from contaminants in the environment. Contaminants come in different levels of being harmful, and in different forms. Oils, cutting fluids and chemicals often come in liquid form, whereas dust and shavings come in powder form. The human also contribute contamination through sweating and shedding skin. (Rosenblad-Wallin and Kärrholm, 1976)

Therefore the clothes do not only need to be able to repel dirt and to keep the contaminants out, but also be able to be washed in order to prevent the build-up of harmful elements in the clothes (Kläders totalekonomi). Protection against contamination needs to be maintained even when the wearer is stretching in extreme directions. Snow and rain can also be added to this category.

Tactile Skin Interaction, User Experience of the Clothes

As the clothes are the closest barrier between the wearer and the surrounding, the tactile interaction with the skin is important in the experience of the clothes. The tactile interaction with the clothes is one of the key determinants in the experience of clothing comfort. Pressure, load and surface texture can lead to skin abbrasions. Unpleasant plastic materials lead to an uncomfortable experience of wearing the material, especially if it is closest to the skin, which restricts the appropriateness of some materials (Kläders totalekonomi).

Static Electricity

Clothes need to ensure that the user does not build up static electricity if the user interact with sensitive electronic devices.

Transportation of Tools and Information Devices

Clothes need to be provided with the functional details which aid in the transportation of the needed tools and information devices within a given work area, in order to be useful for the wearer.

Summary of the Practical Function of Clothes

The physiology material and the practicalmaterial functions of clothes are summarised in figure 08.

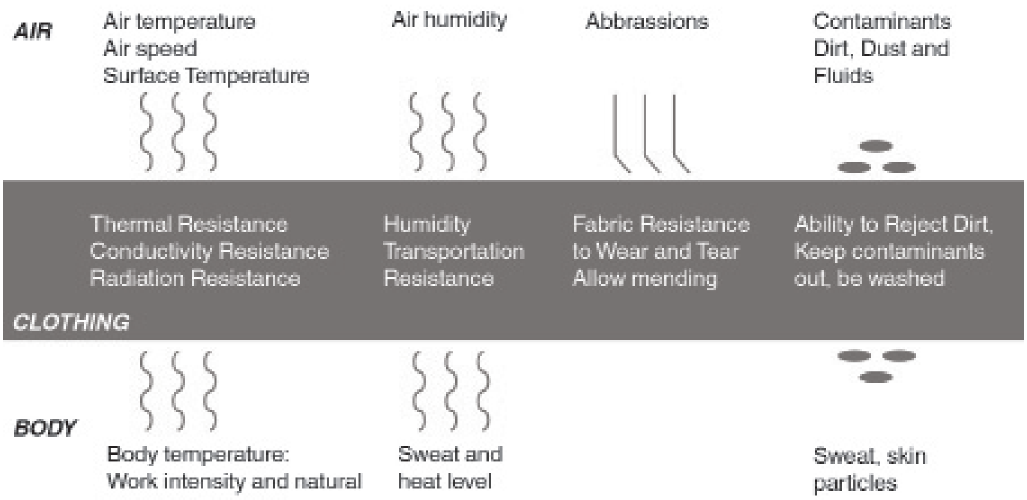


Figure 08: The interaction of physiological factors, environment factors, and the clothing system

3.6.2. The Symbolic Function of Clothes

The symbolic functions of clothes are the semantic, emotional and aesthetic values provided by the clothes to the wearer and the audience. These values change over time and culture, and can be hard to measure. Work wear have traditionally relied heavily on their protective function, and functional parts. As the practical demands are lowered, the symbolic function of clothes can become more important, and the expression of the clothes have a wider possible range. Clothes can have symbolic values attached to them which can add to the survival rate, chance of success, and life path which the wearer is able to take. To successfully choose the most suitable clothes and adornments will enable the wearer a wider range of options.

The basic demand on clothes is to provide modesty and decency to the wearer (Rosenblad-Wallin, 1983). The amount of fabric, and the cut of the clothes, needed to provide decency is relying on the environment, gender, culture and the era in which they clothes are to be used (Entwistle in Entwistle, 2001).

People from all trades of life can play with clothes and the expectaction put on them from their audience based on the clothes. The audience commonly buy into the illusion created by the clothes believing that it is the true expression of the people, not just a surface put on to fool the audience. From here, we can draw the conclusion that both in literature, and in real life, to the audience we are what we wear. The wearers themselves can still feel like they are faking their expressions. John Harvey (Harvey, 2008) expresses this as that we are hiding behind our clothes.

In the case of work wear, the clothes worn by managers and by operators clearly show who belong where. The clothes a person wears will put him or her in social context and a role, and can denote hierarchy, class, race and status (Soper in Entwistle, 2001; Harvey, 2008). What we wear, our decorations and our hair will affect what how we are perceived. Simultaneously, what we wear guides how we are supposed to act within a given context (Harvey, 2008).

Normally we do not notice what we wear; the clothes become an extension of ourselves. However, when we wear something which is uncomfortable for physical or symbolical reasons, we become acutely aware of where our body ends and where the rest of the body starts (Entwistle, in Entwistle 2001). Being uncomfortable can be due to fit and material, but also on the context in which the piece of clothing is worn in relation to the surrounding.

Could it not then be argued that the work uniform that factory workers wear inspires them to work in accordance to the clothes they wear? By accepting the group membership of the factory, and take on the role of the desired factory worker a certain behavior could be encouraged not only by the management and group dynamics, but also by the clothes worn. The expression, fit and style of the clothes will complement the practical functions of the clothes to create desired behaviors.

3.7. The Creation of Clothes Patterns

In order to create clothes, a number of decisions need to be made. In the case of work wear, the environment in which the clothes are to be operational and the functions they are to provide is paramount. After the environment and tasks have been decided, the clothes patterns need to be created.

3.7.1. Block Patterns

The most commonly used method for constructing clothes patterns is construction from blocks (Lindqvist, 2013; Öberg, 1999) Using block patterns, the clothing is drafted onto a flat piece of fabric. Starting off from given points on horizontal and vertical lines , straight and curved lines are drawn connecting the given points thereby giving each part of a garment its shape. Multiple pieces are normally sewn together to form the complete piece, and straight and curved darts give the garment shape. This method is more complex than draping, and wastes material, but give a wider range of options on fit and style than draping does.

3.7.2. Sizing Systems

Creating clothes from blocks is the most used method . The method uses standardised clothes measurements as a starting point. The Swedish system for construction of clothes are regularly revised, as the population composition changes over time. (Öberg, 1999). Clothing measurements need to be updated over time as the measurements for the bodies of the population change over time. Generally, the population tends to get taller and heavier (Pheasant and Haslegrave, 1996)

Different countries use different measurements for the construction, both seen to the sizing system and to the measurements used (Öberg, 1999) According to Inger Öberg and Hervor Ersman (2010) the currently used Swedish system for clothes sizing has been in place since 1980. It has undergone several revisions. A 3D scanner was used in the latest revision in order to get more accurate measurements compared to the earlier measurements which were made with measuring tapes. The measurements for females come in three different heights which cover 92% of the female population.

- 20-series: 160 cm +/- 4 cm
- 40-series: 168 cm +/- 4 cm
- 60-series: 176 cm+/- 4 cm

There are three different width descriptors:

- B: small width
- C: normal width
- D: broad width

The thesis will use torso size C40 and bottom size C42. These are the sizes of the thesis writer, making the prototyping more efficient. An experienced pattern maker kan easily turn the found concepts into standardized measurements using the same tables for sizing.

The Swedish military instead uses a system where each height, weight and gender can get their own size instead of relying only on height and width (Karlsson, 2013-03-21)

3.8. Fabrics

The right type of fabric for any clothing does not only consist of its colour and pattern, but more on its inherent qualities of weight, drape, and the method of which the fibre has been turned into cloth. Naturally the fibre origin affects the quality of the cloth, but fibre thickness and manufacturing and method of turning it into cloth is more important. Fibres of different origin can appear the same, but their qualities will differ according to their origin. Even though the materials might feel similar at first, they still have different qualities regarding withstanding fire, melting points and heat retention. (Thompson, 1995)

3.8.1. Fibre Origin

Almost all materials can be turned into pliable fibres, which are in turn made into fabric. The most obvious fabric choice depends on colours and patterns, but the actual behaviour of the fabric depends on its weight and its quality. The quality in turn of the fabric depend on the fibre quality. Most important is the length of the staple which is spun into fibres, i.e. the length of the particles which are spun as this affects the durability of the fabric. Fibre content can range from having just one component to a number of different components within the same fibre. The final fabric appearance largely depends on the fibre thickness and weaving method rather than the contents of the fibre. (Thompson, 1995) The main groups for fibre origin are animal, vegetable, synthetic and metallic.

3.8.2. Animal Fibres

The hair of animals can be turned fabrics ranging from the thickest tweed coat to the lightest wimple. Wool is the most common fibre but camel hair and goat hair is also commonly used. The materials are commonly warm even when they are wet or damp. Another example of animal fibres is silk, which is made from the chrysalis of the silkworm, a type of moth. (Thompson, 1995)

3.8.3. Vegetable Fibres

The production of fibres from vegetable matter take different origins, from bark to seed capsules to using the whole stem of annual plants. Cotton is one of the most used fibres combining good qualities, durability and price. Linnen is another common fibre fabric which is very durable and improves over time as it is washed and used. Hemp, ramie and jute are fabrics growing in popularity, and are made of plants with the same name. Commonly, vegetable fibre based fabrics grow colder when they are wet. (Thompson, 1995)

3.8.4. Synthetic Fibres

Synthetic fibre have to main different origins; the synthetic ones, and the ones made from cellulose. The synthetic ones can have different origins, and contain among others PET, nylon and terylene. These are commonly durable, easy to wash and need no ironing. On the other hand, they are hard to press and do not drape gracefully. (Thompson, 1995)

Cellulose based fibres is created from cellulose which go through an intense chemical process in order to turn wood into pliable fibres. This group produce comfortable fabrics, that are not as durable as synthetic fibres. (Thompson, 1995) Example of cellulose based fibres are tencel, modal, rayon and viscose

3.8.5. Metallic Fibres

Recently metallic fibres can be turned into both knit and woven pieces which have a wide range of industrial applications, but are not used for clothes. The hard meshed created are used as concrete reinforcements, for medical applications and for decorative purposes. As the method of knitting metals has just been researched and developed, there will likely be other applications in the future. (Smart Textiles, 2013-02-26)

3.8.6. Turning Fibre into Cloth

Several different methods exist for tu rning fibres into cloth, such as weaving, knitting, crocheting, knotting and felting. The most common for clothes on an industrial scale are knitting and weaving, and as those have been identified as most valuable for the project, these will be described.

3.9. Anthropometric Measurements for Clothes

During investigations, it became apparent that new anthropometric measurements needed to be recorded in order to find the ease for the pattern construction of the clothes. This analysis of the anthropometric measurements performed shows how the different parameters change within the measured sample against height and gender, and also shows what impact these parameters have on the construction of work wear. For the table containing the anthropometric data, please see Appendix B.

3.9.1. Knee Length

The knee length before and after bending the leg varied within the population, both seen to height and gender. Both males and females have a mean change of 3.5 cm over the knee with the 5th percentile having a 2 cm difference and the 95th percentile a 5 cm difference. The effect on clothing and construction is that work wear needs to have either extra space in the knee region to allow a free movement within the garment, or to have on average 3.5 cm extra fabric on the front part of the trousers spread over the bent knee distance. Another solution is to make the trouser leg 3.5 cm longer given that the trouser is wide enough to allow bending of the knee.

3.9.2. Elbow Length

The elbow length before and after bending the elbow varied within the population both seen to height and gender but on average, the difference was larger in males. Females had a starting measurement of 5.9 cm and an ending measurement of 7.7 cm whereas males had a starting measurement of 5.4 cm and an ending measurement of 8.5 cm. This means that the difference was 1.8 and 2.6 cm respectivelly. This extra space needed should be accounted for either by making the sleeve longer, by making the sleeve roomier, or add extra space at the elbow.

3.9.3. Anterior Acromion Length

The difference between relaxed stance and shoulders pulled back was slightly greater in females compared to males, normally being 2-3 cm. This distance can be accounted for in clothing by adding ease to the whole garment, or just on the front. The difference can partially be accounted for by making wider sleeves, allowing the sleeve to creep up on the arm and provide movement for the shoulder.

3.9.4. *Posterior Acromion Length*

One of the largest differences in the anthropometric measurements was the posterior acromion length. Males had a substantially wider back than females with an average of 45 cm and 41 cm respectivelly. The lowest difference in the acromion distance was however similar for males and females being 2 cm. The largest difference was 10 cm for males and 14 for females, meaning that females have a greater flexibility. For both males and females however, the need for clothes with built in ease is clear. The ease could be distributed around the clothes or just in the back. The difference can partially be accounted for by making wider sleeves, allowing the sleeve to creep up on the arm and provide movement for the shoulder.

3.9.5. *Foot Measurement*

The foot measurement was one of the measurement changing the most among gender and heights. Shorter persons generally had smaller feet than taller, and the females generally having smaller feet than males. Work shoes add a substantial width to the feet in all directions. Using the found constant of 1.44 times the foot width gives the trouser circumference. As this measurement varies per shoe size and length, further research needs to be performed to evaluate the recommended trouser width per user length to ensure that the clothes fit the users and do not drag along on the floor, which is one of the factors causing users to fold their legs up. For females, this measurement varied between 43.2 and 48.9 cm, and for males 45.7 and 54.7 cm.

3.10. *Laws, Regulations and Standards*

There are several laws, regulations and standards regarding work and work wear, especially for extreme conditions. There are some more general guidelines regarding work wear and personal protective equipment. This chapter presents the most relevant material on a national and European level, as well as found relevant ISO standards. The Swedish laws are harmonized with the European Directives, therefore only the EU regulations will be discussed.

3.10.1. *The European Directive 89/686/EEC: Personal Protective Equipment*

European Directive 89/686 EEC considering personal protective equipment, or PPE. The national laws can vary greatly and go into detail about design, manufacturing and quality level, testing and certification. The directive ensures that the work wear is harmonized with the different national laws, and the minimum requirements that need to be fulfilled to ensure the safety of the individual against health and safety hazards. The PPE include the devices and appliances incorporated which is used to avoid risks and to perform an action. The laws regulated within European Directive 89/688 EEC discuss the broader scopes of free movement and market within EU, but also the different functionality which must be provided by the PPE. The demands can be summarized as follows:

- The workwear need to comply with the EU Directive 89/686 and accompanying approval verifications. Production and products should be homogenous in order to ensure that that all products are the same, thereby ensuring that the verifications are valid for all products
- The workwear need to protect the health of the wearer, and mean no harm to persons, goods, animals or the environment around the wearer. The clothes should

not have sharp edges, get stuck in machinery, or be a chemical risk when degrading with use. If there is a risk that the PPE can get stuck in moving machinery parts, the clothes need to break at a determined threshold.

- The protective equipment should allow the wearer to perform the intended work in the intended environment, and need to take both risk level and protection level into consideration in light of the activity to be performed. The clothes should not hinder free movement or chosen postures, and should not hinder the sensory perceptions more than absolutelly neccesarry. The clothes must put as light a load as possible on the user, including by reducing the weight of the clothing.
- The clothes must either provide sufficient ventilation of sweat, or have absorbing elements.
- The personal protective equipement should be seen as a total systems, the sub-parts within the systems must be compatible if produced by the same manufacturer. The equipment should be adjustable by the user, but should not be able to be adjusted in such a way as it is not protective, during foreseeable use.

3.10.2.ISO Regulations for Workwear

There are several ISO regulations for work wear,. The main report is 15321:2006, titled Guidelines on the selection, use, care and maintenance of protective clothing, which is based on The European Directive 89/686/EEC. The guidelines cover risk assessment, how to define the protection needed with the work conditions prevailing, having the users test the clothes to assess the practicality as well as the comfort and ergonomic legitimacy of the clothes. The regulation also cover various other considerations such as laundry, maintenance and sizing available. Regulation *13921:2007 Personal Protective Equipment: Ergonomic Principles* regard the ergonomic principles of personal protective equipment. Demands extracted from the ISO regulation 13921:2007 is shown in the Bill of Demands.The ISO regulations in ISO Regulation 13921:2007 is summarized as European Directive 89/

3.11. Sustainability of Work Clothes

Sustainability is a combination between many different factors, the main ones being ecologocial, economic and social. Without the product being sustainable on three accounts, and all gradients between them, the product can not be sustainable in the long run.

Sustainable development (SD) is often defined as:

> *Development that meets the needs of current generations without compromising the ability of future generations to meet their needs and aspirations (WCED, 1987)*

The definition encompasses two different aspects of sustainable development; the development performed must both meet the actual current needs, as well as not risk the future quality of life for generations to come. Sustainable should not be read as a static condition, but as an imperative to continuously improve products, without risking the future (Morse and Bell, 2003). This chapter outlines the different factors in the viewpoint of work wear. There are also examples of how sustainability can be reached within the different areas.

3.11.1. Sustainability from an Ecological Viewpoint

The ecological sustainability from an ecological viewpoint encompass many different areas. The tools used in this research have different focus, in order to give a full picture of the ecological footprint of the existing work wear, which is presented further on in this chapter. Environmental impact has been estimated as there are many different producers of the products, and the tracing of textile production is unsure at best.

Most human activities have an impact on the environment, be it industrial , agricultural or personal. The production of textiles and clothes affect most life cycles on earth; CO2 is released during production. Dyes are released into waters, and the same dyes poison the workers having to process the textiles. Fossil fuels are used in the manufacturing of fertilizers, and during the production. (Slater, 2003)

Life Cycle Analysis

The work wear observed in case studies are very similar in all three visited companies and regularly consist of a trouser, a t-shirt and a sweatshirt. The sourcing of materials and the included materials are based on information from the largest work wear manufacturers in Sweden. Complementing these items are underwear, long-johns and socks. By researching the most sold work wear in Sweden, the components of the clothes could be established. As the manufacturing companies are unwilling to provide details of origin and material of the work wear, except fabric material, the materials are assumed to be of the cheapest origin. At times, the exact material could not confirmed, in those cases reasonable assumptions have been made. This is the case for the metal alloys, plastics, dyes and flame retardants. A detailed list for each clothes item can be found in Appendix D. For the calculations regarding energy and water usage, please see Appendix C.

The following weights collected in table 7 for the materials were collected from product samples, and used in the LCA. All weights are expressed in grams.

Table 4. Contents of existing work wear

Material presence	Trousers	Sweater	T-shirt	Shirt
Unknown metal alloy	10			
Unknown plastic	10			10
Unknown flame retardant	?			
Unknown colorants and dyes	?	?	?	?
Steel	30			
Copper	10			
Cotton	1000	550	350	350
Virgin PET	10			

Result after LCA Calculations

The largest footprint is contributed by the washing of the clothes. The used LCA Calculator tool was limited in that it did not take dyes and other chemicals into consideration, and the available materials were limited. Therefore the results are a sign of where the energy, CO2 and water consumption is used during the lifecycle of the product. Most of the water is used during the estimated 2 years of product usage. However, a substantial amount of CO2 is also produced for cotton, plastic and metal production.

3.11.2. Sustainability Life Cycle Analysis

The Sustainability Life Cycle Analysis or SLCA below concern the different life stages of the products according to a number of different criterion. As there are many products on the market, the result are an estimate of the aggregated knowledge from literature studies and research done on existing work wear found for sale. The result below is from answering the different stages of the SLCA method as outlined in the methodology chapter.

1) Find the issues at hand with the currently most used work clothes consisting of a pair of craftsman trousers, a tshirt and a sweatshirt. We are using the assumption that the trousers are washed one time per week and that the tshirt and sweatshirt are washed three times per week.

2) A sustainable product is system is one which uses minimal resources during all steps of the life cycle, with a Cradle to Cradle perspective.

3) The product(s) should not contribute to a deterioration of Earth seen in a longer perspective. This means that metals and chemicals harmful to Earth should not be allowed to pollute and that any resources used up should be replaced. In the previously performed LCA, the impact on Earth is measured in CO2 footprint. Therefore this investigation will focus on other aspects of environmental impact such as chemical and metal impact for finding key issues. The estimations assume that the cheapest material available are used within each category. This is especially relevant for the cotton which has a big climate impact when traditionally grown and a much smaller impact when grown using more modern techniques. Traditional dyeing methods are assumed. The work wear is assumed to be produced in the Nordic countries.

4) The life cycle could not be firmly established in the current system due to many manufacturers producing similar goods, and being unwilling to fully disclose their production. When relevant information was available, it was used as a basis for exploring the different stages of the life cycle.

5) See table 05 for the impact of the work wear during the different stages of the life cycle.

i. Does the product life cycle contribute to the build-up of substances from the Earth's crust such as metals, minerals, fossil fuels, etc?
ii. Does the product life cycle contribute to the accumulation of substances produced by society? E.g. persistent chemicals, natural compounds produced in volumes that nature cannot handle, etc?
iii. Does the product life cycle contribute to physical degradation of nature? Such as overfishing, land destruction, erosion, etc?
iv. Does the product life cycle contribute to any conditions that undermine people's capacity to meet their needs? Such as unsafe working environments, health issues, financial stability, freedom, etc?

Table 5. The impact of the work wear during the different stages of the life cycle

	Raw Materials	Production	Packaging and Distribution	Use	End of Life
i.	Yes; metal in zippers and rivets. Oil for PET. Inorganic fertilization of cotton.	Yes, if the production uses carbon based energy	Yes to a small extent. Boxes and plastic tape used for transport	Yes, if the laundry uses carbon based energy.	Metal from zipper and rivets, oils for PET
ii.	Dyes in fabrics, cotton production, pesticides and insecticids from cotton production. Metals and chemicals used for dyeing fabric.	Cuts from fabric contain dyes which in turn contain chemicals and metals	Yes to a small extent. Boxes and plastic tape used for transport	The detergents can contain harmful chemicals.	Dyes in fabric are deposited into landfills meaning a buildup of metals and chemicals.
iii.	Over usage of water during cotton production and dyeing. Erosion caused by monocultures. Dyeing fabric contribute to land destruction.	Spillage from production stored in landfills. Energy used during production.	Distribution worldwide with ferry. Distribution to the Nordic countries by truck.	Water usage during washing, detergents can be detrimental to environment. Washing water degraded by substances caught by the work wear from factory.	Worn out products stored in landfills or used for energy.
iv.	Production of materials and fabric in countries abroad meaning the work conditions can be unregulated. Dyeing fabrics is notoriously hazardous.	No, working conditions are regulated in the Nordic countries	No, working conditions are regulated in the Nordic countries	No, if the correct level of production from the work wear or PPE has been selected by management. Otherwise yes.	Yes, landfills inhibit the possibility to use the land differently. Improper storage of fabric

6) The identified areas with the greatest potential for being changed in the context of work wear are presented in the list below.

- Change material of the clothes to fibres which are sustainably sourced
- Improve recirculation of materials, ensuring that they return to their own life cycle
- Ensure that washing and maintenance of the clothes does not contribute negatively to the environment.
- Change to fabric dyes which are not harmful to the environment, and that the dyeing of fabric does not contribute negatively to the environmental

7) Possible solutions that could be implemented in order to affect the key areas, and in order to create better products are found in table 6.

Table 6. Improving the impact of the work wear during the different stages of the life cycle

	Raw Materials	Production	Packaging and Distribution	Use
i.	Sustainably sourced materials, and if possible, avoid using virgin materials.	Avoid fossil fuels	Use more efficient vehicles, minimize plastic in packaging material. Package vehicles efficiently, minimizing transportation of air.	Usage of fossil fuels should be avoided during washing
ii.	Harmful dyes and other chemicals should be avoided. Fibres not needing pesticides and insecticides are favourable.	Maximum usage of fabric to avoid unnecessary scraps.	Avoid glueing lables onto packages as this makes recirculation near to impossible. Package efficiently.	Use durable materials and construction fo a longer product life cycle. The whole product should break down at the same time to ensure optimal usage of each component.
iii.	Materials should be sustainably sourced including land and water usage during production	Promote efficient land use. Use safe dyes.	Plast packaging materials need to be biodegradable to avoid plastic buildup	Dyes need to not be harmful to the environment both when being washed, and by the wear and tear
iv.	Avoid harmful dyes, insecticides and pesticides. Use sustainable manufacturers.	Avoid harmful dyes. Use sustainable manufacturers.	Abstain from using food sources as fuel. Ensure that packaging material is not detrimental to nature.	The usage of work wear should not pose a danger towards the user or the environment in wear, washing and maintenance.

8) The solutions and changes that are prioritized are those where the impact of that factor is most negative to Earth and the sustainability principles, and those where there is a great possibility of change using small means. Both are areas where changes have the greatest chance of having a real and lasting change in the product footprint. These areas are:

- Changing to sustainable materials and dyes
- Ensuring the recycling is feasible and easily done

9) The way that these goals can be reached is as follows:

Investigate what other materials and dyes are possible in the work wear production, using the bill of demands as a starting point to ensure that materials and confectioning reach the goals set. The materials and dyes need to be investigated to make sure that their footprint and their capabilities are good. Recycling is affected by both the materials, all dyes, and all haberdashery used. Ideally, the whole work wear should be recyclable in one piece without dismantling being done, both to improve the chances that they are actually recycled, and to ensure that all pieces are recycled the best possible way. If it is unavoidable that materials need to be separated, then the process of separation needs to be easily performed.

Eco-Friendly versus Eco-Efficient

In literature regarding sustainability, eco-friendly is used to describe processes which are not harmful towards the environment and which cause as little negative impact as possible. The goal of eco-friendliness is simply to neutralise any negative effects. Eco-efficiency is introduced by Michael Braungart and William McDonough in Cradle to Cradle (2009) and describes processes which mimic the natural ecosystems which produce an abundance of resources for the benefit of the whole local and global system. In eco-efficient processess all stake-holders thrive; the workers, the managers, quality of life and the nature alike. An example of an eco-efficient factory plant is one where the water leaving the factory is cleaner than the water coming in, where planted trees and grass on the plant roof leads to an improved habitat for wildlife, and where the workers work in light and pleasant conditions. These conditions exist in places such as the Ford car plant in Rouge which was built on the Cradle to Cradle principles, and they add business value (Braungart and McDonough, 2010)

3.11.3. Sustainability from a Social Viewpoint

In order for the development to be sustainable, local and global communities must participate. Values and needs expressed by people are equally important for sustainability as ecology and economy. Both values and needs change over time, and are hard to quantify as they are personal. People are often forgotten in sustainability, Bell and Morse (2003) argue that this is because check lists are feasible to construct using science and common sense for ecological and economical sustainability, whereas social sustainability is not.

Social sustainability is both a top-down process and a bottom-up process. In the top-down process, society as a whole is involved in sustainability building processes both seen from the mood of society and the laws and regulations imposed by the government to ensure that companies follow the decided directives. In the bottom-up process, each individual is responsible for the sustainable development. Individuals often want sustainable development but are seldom willing to take responsibility to move towards a sustainable society as changes often affect them negatively. Most agree on pesticides being bad for eco-diversity, but few are willing to buy organic goods due to the higher price. (Bell and Morse, 2003)

In the case of work wear, the social sustainability is not only achieved in the manufacturing of the work wear, but rather the effect they have on the operators wearing them. How the operators are perceived partially depend on what they wear. It will also affect the perception they have of their own role.

3.11.4. Sustainability from an Economical Viewpoint

The economy of the work wear can be seen both from the viewpoint of the manufacturer, and the viewpoint of the buyer. The cost from the manufacturer perspective consist of material cost, labour cost, manufacturing time and factory cost, to name a few factors. In this chapter, the cost of work wear is mainly discussed from the viewpoint of the buyer, as the clothes will spend most of their lifetime being used.

3.11.5. Economy of Work Wear

Choosing the wrong work wear system can give consequences on protection, comfort and cost not only for the work wear, but for the work performed. Total cost for work wear is compounded by the whole life cycle of the clothes including mending and washing. This chapter aims at providing a background into the economical aspects of choosing the right work wear for the employees from a buyer perspective, given that the buyer is the employer who also provide the work wear to the employees. It is concluded by guidelines for choosing the correct clothes for the workshop environment.

There is a large number of different models of work wear on the market, the main difference is between:

- model
- material
- confectioning

3.11.6. The Durability of Work Clothes

Several factors impact the durability of the work clothes. The durability in turn affect the cost of the work wear seen per month. Choosing a more durable garment can make the monthly cost of the garment lower even though the initial cost is higher.

- The properties of the textile fibre: the weakest fibre in a textile blend will be the one limiting the durability of the material. Both the properties of the fibres and the weaving method will affect the usefulness of the material, and the experience of the material on the body.
- The thickness of the material, measured in g/m2, is linear to the durability of the material, given that the seams have the same properties as the material. Thicker materials are commonly used in more heavy-duty environments. Thinner materials are preferred as they are more comfortable seen from movement and climate comfort.
- Making-up of the clothes (sw: konfektionering). For optimal economical efficiency, the whole piece of clothing should become worn out at the same time. Normally, the seams need to be adapted to endure a much higher load than the fabric itself. The seams also have a tendency to shrink and cause distortion if not properly created.
- Usage environment; abbrasions, dirt, dust, chemicals and oils can affect both appearance of the fabric, and the fibres.
- Carefulness on the part of the user affect how long lasting the garment is. If the garments are personal to each user, they normally last longer than if they are not personal.
- Washing method: during washing, the clothes are put through both mechanical and chemical wear and tear. Washing in water normally give a higher degree of mechanical wear and tear compared to dry-cleaning.
    - Water wash is needed to remove sweat salts and organic matter.
    - Dry cleaning is used to remove chemical stains as oils and fats. During dry-cleaning, the weaker fibres will be affected by the chemicals, especially cotton

is sensitive.
- Washing can lead to shrinkage of the clothes if they are not properly pre-shrunk. The tendency to shrink is less prominent in thinner fabrics compared to thicker.
- Cotton can be washed at a higher temperature than cotton/polyester blends. Cotton/polyesters can however endure a more potent detergent.
- Washing interval

3.11.7. Benefits from the Employer Providing the Work Clothes
Providing free work clothes with a unified expression gives the employees a feeling of belonging together and of working together, which in the end, leads to a better work performed (interview at Company B). Choosing the correct work clothes can also lead to a higher efficiency, and a higher job satisfaction (Möller and Grant, 1982)

The work wear should be personal, but maintained centrally, and bought centrally. This way, the person feels a responsibility to take care of their clothes, but at the same time, the clothes are properly washed, maintained, and changed when they are worn out. (interview with clothes manager, 2013-04-27)

- The protection level can be increased
- Clothes are not used longer than appropriate because of personal stinginess
- Clothes which are not intended for the work environment are not used
- Goodwill: more professional than personal clothes, give a cohesive impression
- Taxes, social social-security contributions etc can be used to buy work wear, and are more economic than reimbursing users for the wear and tear on their private clothes
- Some landlords forbid washing of work wear in communal washhouses, forcing the users to use clothes not intended as work wear, as work wear, to hand in the workwear to dry-cleaning, or to not wash the clothes.

3.11.8. The Actual Cost of Work Wear
Given the large supply of work clothes, aimed at different professions and environments, it can be very challenging for the persons in charge to choose the most appropriate work wear, seen from both an economical perspective, and providing a correct amount of protection for the workers. The prices of the work clothes vary greatly, both depending on their level of protection, their brand, and their country of origin. Over the course of the lifetime of the work wear, the total cost of the items not only consist of the initial cost of buying the items but also all the maintenance that the work wear needs, and the cost of the work wear having a sub-par performance which in turn affects the performance of the wearer. (Möller and Grant, 1982)

In order for the actual cost of the work wear to be found, the initial cost cannot in itself be seen as the total cost. The following formulae 1 was devised by Möller and Grant (1982) in order to find the total cost of a work wear item:

Formulae 1. The cost per annum for work clothes

$$A \times B \times (C/12) \times D \times E = \text{cost}$$

A=number of employees using the work clothes item
B=number of each work wear items per user; each user has commonly at least 2 of each item to ensure that they have something to wear whilst the other item is in the laundry
C=the actual life expectancy for the clothes in months including wastage
D=the gross charge cost for the work wear item
E=correcting factor for discounts and extra cost for odd sizes

The clothing cost with respect to just the purchase price for keeping the employee with work wear per annum is then the sum of this formulae used on all different work wear which is used by the employees. As can be seen from the formulae, the endurance of the items clearly affect the total cost of the clothes. A cheaper piece of clothing might in the long run cost more as they need to be replaced more often.

In addition, there is an added cost for maintenance and washing of the items, which is described in formulae 2, which is an adaptation of the cost for washing used by Möller and Grant (1982)

Formulae 2. Cost for washing and maintenance per annum

$$A \times I \times K \times P \times W \times M \times T = \text{cost for washing and maintaining}$$

A=number of employees using the work clothes item
I=frequency of laundry in changes per week. Depending on the industry, clothes can be washed every day or as seldom as once per month.
K=laundry quote, the number of items actually handed in for laundry compared to the number which should be handed in. Depends on how much is handed in, and on how large the sick leave has been. During leasing, the number is fixed unless the company gives new directions to the leasing company on for example extended sick leave, whereas external companies only charge for the clothes actually handed in
P=price for wash per item
W=weeks worked per year

M=mending quotient: how often clothes need to be mended
T=cost on average for mending the clothes, depends on the time it takes to mend the clothes and how much is charged for mending.

3.11.9. Different Maintenance and Acquisition Models for Clothes

Both in literature and in the case study visits, different methods of buying, washing and maintaining clothes have been found. In table 7, the different models are outlined. Each company chooses one alternative from column A and one option from column B. The models are based from the work of Grant and Möller (1982) and complemented with the case study visits. The chosen combination is then depicted by a number combination. In the rest of the report, the maintenance and acquisition is marked with the combination as AABB where AA is the number from column A in table 7 and BB is the number from column B in table 7.

Table 7. Aqcuisition, Washing and Maintenance Models of Work Wear

	Options for dressing the employees:		Washing and Maintenance
01	Internal development of clothes	01	Washed and maintained by internal department
02	Leasing of clothes from external company	02	Washed and maintaned by external leasing company
03	Buying clothes from external company	03	Washed and maintained by external washing company
04	Employees choose and buy clothes	04	Washed and maintained by the employees themselves at the company
		05	Washed and maintained by the employees themselves at home

Company A previously used 0101 but have changed to 0303 in order to be able to focus on their core area of operations (interview at company A). Simultaneously, the quality of their work environment has increased.

Company B uses 0404 but are planning to change to either 0202 or 0303 in order to get a unified company expression, and ensure that the operators are sufficiently protected against the work environment.

Company C uses 0305 which leads to the clothes being neither washed, nor repaired. One operator stated that they did not want to wash them at home partly because it was cumbersome to transport the clothes to/from the home, partly because they did not know what kinds of chemicals that could be released into the water.

Company D uses 0303 and 0305 whereas the interview with a clothes manager at another company used 0301 in order to protect the workers and the general public from being exposed to the dangers metal powders which were abundant in their work environment.

Möller and Grant (1982) concluded that using 0101 is not a viable option unless there is personel which cannot be used for other work tasks, and that 01BB is in itself not the best solution as companies specialised in work wear are more likely to get a better result. AA01 means that the company itself needs to wash clothes, usually only using water washing, which means that all chemicals cannot be cleansed from the work wear. This is also true for AA04 and AA05, which have the added drawback water soluble particles being freely released into the water. Yet another drawback of AA01 is the time it takes for the personnel to become skilled at maintaining and washing the clothes which takes considerable time. The most viable option is therefore 0202 or 0303.

3.12. Laundry Interval of Work Wear

The number of work wear items needed per user depends on how often they are used. Exchange rate of clothes is often stipulated by the work wear provider. Frequent changing of clothes not only contribute to a nicer work environment with cleaner colleagues, it also contribute to damages and dirt being detected earlier. If the clothes in themselves are clean, work which makes them dirty can easily be spotted, and corrected. Dirt, dust, chemicals and oil spills all show that something in the work environment is not working properly, and should be adjusted. It could be leaking valves, a malfunctioning ventilation or sub par work routines.

The frequency of washing is a combination between several factors, and different clothes need to be washed differently often. Clothes that are in direct contact with the body need to be washed more frequently, such as underwear, socks and t-shirts. If the wearer is in a dirty environment, in a hotter environment, or has a higher activity level, the clothes also need to be changed more often, sometimes even in the middle of a work shift (Gavhed and Holmer, 2006). Dirt and sweat contribute to rashes and chafing of the user especially where the skin is softer or moist. Therefore it is desirable to change clothes often. On the flip side, the washing in itself contributes to the clothes getting worn out, both the fabric in itself, and the dye being washed out, making the clothes look older. During lighter work in a non-abrasive environment, the washing and drying of the clothes is the main contributing factor to the clothes getting worn out (Möller and Grant, 1982).

If the clothes are repaired by the laundry agent, they can quickly see damages to the clothes, and therefore mend the clothes before larger holes appear. To mend small tears and weaknesses in the fabric just as they appear is much easier than it is to mend a larger hole, and the result is better (Thompson, 1995). This in turn implies that the quality increases and the cost and time for mending decreases the quicker the damage is detected. However, each washing of the clothes adds cost to the company, who might therefore be inclined to wash them more seldomly.

Given that independently of washing interval, the work wear is picked up for laundry and delivered back once a week, Grant and Möller (1982) found that the following number of overalls was needed per changing interval:

- Change biweekly: 2 overalls
- Change weekly: 3 overalls
- Change twice a week: 5 overalls
- Change every day: 11 overalls.

In the thesis, it is suggested that for both Environment 1 and 2, the combination of trousers, interior upper layer and exterior upper layer should be used, instead of overalls. Trousers, interior and exterior uppler layer gives a wider range of movement, and is more adaptable to each individual. I propose that the standard interval for changing clothes should be as follows, as it allows clothes to have a good hygiene and tears be detected early. If a user wants to change work wear more often, that should be allowed, the suggested interval for changing is the lowest permissible interval.

- Interior upper layer changed daily: 11 items needed
- Exterior upper layer changed bidaily: 7 items needed
- Trousers changed weekly: 3 items needed

3.13. Supporting the Cognitive Demands of the Users

Grane et al (2012) have predicted that factories will become more and more automatized over time and that simultaneously, there is going to be a need for operators to take more abstract decisions during operations in order for the factory to run smoothly and efficiently. Both of these factors lead to a higher demand for cognitive support for the operators, in order to help them make good decisions. Information to the operators need to be clearly presented in an efficient manner through the different senses. Grane et al propose that the information devices could either be external, or integrated into the clothes or tools of the operator of the future, with a focus on newer information technologies such as augmented reality (AR) and use of more than one sense for warning signals. Seeing how far screen-based technologies have advanced in comparison with AR and newer technologies, it is likely that screen-based technologies are used. These types of technologies are called Information and Communication Devices (ICT devices) meaning that information can be broadcasted, searched for, and some kind of communication can take place. Any ICT device system should be available to the user at all times for efficient use. An idea was put forth to integrate the ICT devices into the clothes themselves.

As this thesis project is aimed at finding the work wear of 2020, it is yet too early to say exactly in what shape or form that device should have. To put out exact measurements today for placements or pocket sizes is arrogant as those things will change over time. What can be said however is that the work wear should allow ICT devices to be carried with the user, or allow users to use stationary ICT devices. The front pockets of the trousers should be made such that a ICT device can be carried with the user and be easily accessible. As for the top layers, identified placements for ICT devices are on the sleeves where either pockets could be placed, or place made for a bracelet holding the ICT device. For the full description of the possible placements and types of ICT device, see Appendix J.

4. *Bill of Demands*

The found demands are summarized in a Bill of Demands. * shows the importance of each demand with:

1. Absolute demand - without this, the product looses is function and value
2. Desirable demand - it is very desirable to have without it the point of the product is dimished, but the product can still perform its main function
3. Bonus demand - it is nice to have but it is not a make-it or break-it demand

#	**Demand**	**Comment**	*
1	The work wear should be designed for the task to be performed using the work wear, allowing the user normal pursuit of that task	explore all the reasonable movements in the work wear including standing, sitting, climbing stairs, running, reaching, holding objects, going to the bathroom	1
2	The work wear should protect against the dangers in the work environment		1
3	The work wear should be adapted to the duration of which it is to be used		2
4	The work wear should be adapted to the work environments in which it is to be used		2
5	The work wear should take into account that different work environments can be used by the same user	both seen as insulation level, and the possibility to adapt the clothing, and to remove layers	2
6	The work wear should not pose a danger to the users		1
7	The work wear should not irritate the skin during skin contact. Abrasion, rubbing and chafing might hurt the user		1
8	Chemical and metals in the work wear should not hurt the user by allergic reactions or otherwise		1
9	Sharp or hard edges/points should be avoided as not to hurt the user		1
10	Bulkiness, hardness, position of adjustment and closures should be such that the user is not discomforted		2
11	Small straps running over the neck-should junction should be avoided to prevent compression of nerves and blood		1
12	Straps preventing blood flow in groin, neck and wrists should be avoided as to not prevent blood flow		1
13	The work wear should not get stuck on the user's hair or skin including body hair	Closures often get stuck	1

14	The work wear should not pose a danger to others around the user		1
15	The work wear should not pose a danger to animals		1
16	The work wear should not pose a danger to the environment		1
17	The work wear should not pose a danger to the work environment and machinery		1
18	The work wear should be compatible with PPE which is used in the work environment		1
19	The work wear pieces should be mutually compatible		2
20	The work wear should allow free range of motion for the user		2
21	The work wear should not restrict the movement of the user		2
22	The work wear should not prevent movement of the user		1
23	The work wear should not influence the ergonomic aspects of the user in a negative manner		1
24	The work wear should be adjustable by the user only if this does not pose a danger to the user		2
25	The intended fit of the work wear should clearly described		2
26	The work wear must take into consideration the bodily reconstitution created by movement	Arms, legs and back all change shape during exertion and bending	1
27	The distribution of the mass of the work wear should be such as to minimize the overall load on the body of the user	Not all weight on the shoulders or hips	2
28	Asymmetric load of the weight should be avoided	both as to not cause imbalance, and to ensure that the body is not twisted/deformed	1
29	The work wear should allow ventilation when necessary	design and material choice	3
30	Ventilation openings should be made such that the operator is not exposed to hazards	Welding sparks and other hazards risk getting into ventilation openings	1
31	The work wear should allow moisture exchange	design and material choice	2
32	The work wear should have a stated lower and upper range of environmental conditions such as temperature, moisture and degree of activity for comfortable wear	Affected by individual differences of comfort	3
33	The thermal insulation of the work wear system should be suited to the given thermal conditions		1

34	The vapour resistance of the work wear should be low to allow moisture exchange between sweating user and the environment		1
35	The vapour permeability of the work wear should be high to aid in moisture exchange between sweating user and the environment		1
36	The air permeability of the work wear should be adapted to the wind and temperature conditions		1
37	The work wear should not inhibit the vision field of the user		1
38	The work wear should not impact the hearing of the user		1
39	The work wear should have no distinct unpleasant smell in itself		1
40	The work wear must enable cleansing such that any accrued smells can be removed	Materials need to be washable	1
41	The targeted work wear users should be defined		1
42	There must be a sizing system to ensure that the work wear is fitted correctly to the users		1
43	The weight of the work wear should be reduced as much as possible including alternative materials given the required technical demands		2
44	The work wear must be comfortable to the user		2
45	Construction and length of top (t-shirt, shirt, sweatshirt) etc must be made so that it covers the body even when the arms are stretched above the head or to the sides		1
46	Construction and length of bottom item must be made so that it covers the body even when the knees and/or abdomen are bent		1
47	Placement of pockets must be made so that objects put in the pockets have a minimal chance of pushing into abdomen		2
48	Placement of pockets must be such that bending of knee and/or abdomen is not inhibited		1
49	The work wear should give minimal tactile impairment to the user	especially relevant for gloves	2
50	The work wear should allow the user to bring needed tools to the workplace	The tools can be stationed at the work station or carried in other forms than the clothes	3
51	The work wear should protect the user against dust		1

52	The work wear should protect the user against chemicals		1
53	The work wear should protect the user against abrasions		1
54	The work wear should protect the user against wear and tear		1
55	The work wear should not get stuck in machinery	Avoid long straps	1
56	If the work wear gets stuck in machinery, the work wear should break	In order to not drag the user into the machinery, it should break upon getting stuck	1
57	Materials should be sustainably sourced	At the time of intended production and use	3
58	Fabric must withstand being washed and dryed over the expected lifetime	Must not be worn out by chemical/water wash	1
59	Seams must withstand being washed and dryed over the expected lifetime		1
60	Notions and fasteners must withstand being washed and dryed over the expected lifetime		1
61	The work wear should fit the anthropometric measurements of the intended target group.		1
62	The work wear should be manufactured according to the latest available Swedish B, C and D series for men and women.	To ensure that the fit is appropriate for the entire Swedish population	1
63	Allow the users to have a more equal workplace	The clothes should not distinctly set the factory workers apart from team leaders and operation managers	3
64	Allow the wearer to blend in in normal society		3
65	Allow the users to work in teams		3
66	The work wear should be appropriate for all genders working in the designated field		1
67	The work wear should be appropriate for all ages working in the designated field	18-65; the current working ages	1
68	The work wear should be appropriate for the 5th to 95th percentile of the population		1
69	The confectioning of the work wear should be such that the user sees no need to physically alter them	Users should see no need to fold up or cut off trouser legs.	2
70	Allow placement of company logo and/or colours		3

5. Ideation and Prototyping

The ideation and prototyping were performed both for individual solutions to smaller observed problems, and for overall clothing system concepts. Smaller observed problems mainly concern alterations of the clothes, mainly folding of the trouser leg which poses a great risk to the user. There are different possibilites for ventilations, and how to form these.

5.1. Seen Alterations and Preventing Alteration of Trouser length

The most commonly observed alteration to work wear was alteration of the pant leg, and the most common alteration was folding of the hem. Sweater sleeves were sometimes pulled up but more commonly, the users instead just peeled off that top layer.

Swedish Work Law, European legislation, and ISO regulations, all state that it is illegal to have work clothes which can compromise the safety of the user or others around the user. One very common alteration to the work clothes which can do just that, is folding up of the hem of the trouser length. By folding the hem up, the pant becomes shorter, exposing the leg to hazards, which can be dangerous if the person is subjected to heat, sparks or harmful chemicals. In other situations, the shortening of the trouser in itself does not pose a danger, whereas the action of folding does. The pocket created by folding the pant enables dust and dirt to collect which can harm the outside world. Other threats are hot objects getting stuck in the pocket, enabling them to burn through the fabric and onto the user skin, which would not have happened without the pocket, when the hot object would have just fallen off of the surface of the clothes. This problem was commonly reported by the welders who did not at first realize the result of their alteration. (observation and interview date XYZ) Folding of the trouser leg also makes it much easier to get stuck on objects and machinery, as a natural grip is created. The effects of getting stuck can range from unpleasantness to danger. Yet another observed example of when the alteration posed a danger was a user who had cut off the trousers at knee height without hemming the trouser. After some runs in the laundry, the result was long threads hanging loose from the edge of the trouser. Any of these threads could get stuck in machinery and pose a grave danger to the health of that user. (observation date XYZ andréns plast)

Even when the trousers are not tampered with, they might still pose a threat to the user. If the trousers are too long, they can easily get stuck on objects or machinery. The hem risks being run over by others, or the wearer tripping themselves by stepping on the hem or getting the foot into the other trouser leg.

Therefore, the trouser length either needs to be the perfect length for all users, or be adaptable to the work situation without that alteration posing a threat in itself. The construction of the trouser should be such that it does not risk getting stuck in machinery, does not collect dust and does not permit hazards to reach the skin of the user.

Folding the trouser leg up is the most commonly seen adapation of the trouser leg. The tension of the folding keeps the leg in place meaning that it is a self-locking mechanism. The pocket created by folding makes it easier for objects to get stuck. There have been incidents when the folding in itself causes accidents because the wearer gets stuck on machinery or protruding parts. Molten metals can also get stuck in the pocket causing burns on the wearer.

Folding on the inside is a more uncommon adaptation of the leg. The folding can be kept in place by an elastic band or by the fold in itself. it is a quick adaptation of the leg, and very adaptable. However, the folding easily collapse in on itself when no tension holds it in place. There is no pocket created on the outside making this a relativelly safe alternative for changing trouser leg. Given that the trouser still covers the foot this can be a safer alternative than letting the trouser drag on the floor.

A drawstring can be used to adjust the width of the trouser leg, making sure that it does not drag on the floor. It can also be adjusted to tie at the knee, effectivelly making the trouser shorter. The construction is cheap too, and easy to exchange if the breaks. One downside is the risk of the string getting stuck in machinery. Using an elastic has much the same possibilities as closing with a drawstring. The elastic has the downside that it is more prone to breaking down during washing, or melting if exposed to heat. It is harder to replace than the string. On the flip side, there is no string which risks getting stuck in the machine

External buttons allow the user to make the trouser leg fit closer to the ankle, preventing any risk of them getting objects into the shoe, trampling on the hem. It is quick to adapt, and allows ventilation. On the other hand, that ventilation poses a risk. The usefulness of the solution depends on how many buttons which are provided. The buttons also pose a risk for getting stuck. The folding creates a pocket just as when the trouser is folded up.

Internal buttons could allow the user to shorten the trouser leg by folding it on the inside. This will give a secure fastening of the trouser leg at the desired height. No objects can fall into the pocket created on the inside. It is a bit slower than other methods of shortening the length and depending on the constructioning and width of the leg, the procedure might not be possible to perform if the trouser is on. Just as the previous button solution, the usefulness depends on the number of buttons.

One of the cruder methods for shortening the leg is to simply cut it off. This has only negative aspects as it creates frays which can get stuck in machinery. The process is irreverisble meaning that any miss-cut will make the work wear relatively useless. It is however quick and easy to do. Companies which perform cleaning and mending could also provide the service of sewing the trouser leg, given that the company providing the clothes also measured the users correctly. Using this method, the clothes will fit the users better, decreasing any risk to them. The procedure of shortening the leg is very quick meaning that the cost would be low for the company. However, some materials shrink after use meaning that the trousers might get too short over time.

5.2. Ventilation of the Work Wear:

The meetings at the neck, hands and feet all have similar purposes. As they are positioned on, and adapted to, different bodyparts, they can be designed slightly differently, but the same basic purpose remains. The meeting between body and clothing should allow the user to put on the garment, to allow the appropriate amount of ventilation, and still protect the user from hazards. This can be achieved in many different ways, the most commonly found are described below.

The material can be tightly fitting against the skin of the person using elastic fabric and elastics in the hems of the fabric. A ribbon can serve the same purpose when it is used as a drawstring to tighten the fabric. One of the downsides with using a drawstring compared to an elastic is that drawstrings can get stuck on objects. A downside using elastics instead is that over time they lose their elastic function, especially when exposed to heat or sunlight.

Zippers allow the user to open up the neck, legs or arms of a garment to slip the head, feet or hands through, and then zip the garment up again to ensure that no hazards reach the skin. The same zippers can also be opened up to ensure that the person is properly ventilated. Buttons can serve the same purpose as a zipper both for putting the garment on and opening for ventilation.

At times, openings are made just for ventilation purposes such as slits under the arms to allow ventilation of the armpits, or slits on the back to allow ventilation of the back. These openings increase the risk of the users to get exposed to hazards in the work environment.

5.3. *Ideation for Clothes for the Operator of the Future*

The ideation methods are described in the method chapter and these are the methods that were used in the ideation process. In order to get as many ideas as possible, ideation sessions were performed for different areas of interest. As a limitation during ideation, materials containing elastics were excluded, impacting mainly stretchiness of knit materials. Ideation themes were chosen from observed problems, and as they were perceived as a good starting point for finding different solutions to problems of range of motion or confectioning. The results were evaluated and the most promising ideas, and the ideas that needed physical representations to be evaluated, were prototyped in fabric in scale 1:1. Finally the ideas are evaluated against each other to find which ideation train is worth to take further to a final prototyping and concept stage. The main themes for ideation were

- Whole clothing systems that are in themselves different but still possible in the environment:
  - Tigh fitting
  - Office clothes
  - Offering maximum temperature regulation
- Possibilities for closures at the leg and possibilities for shortening the leg of the trouser

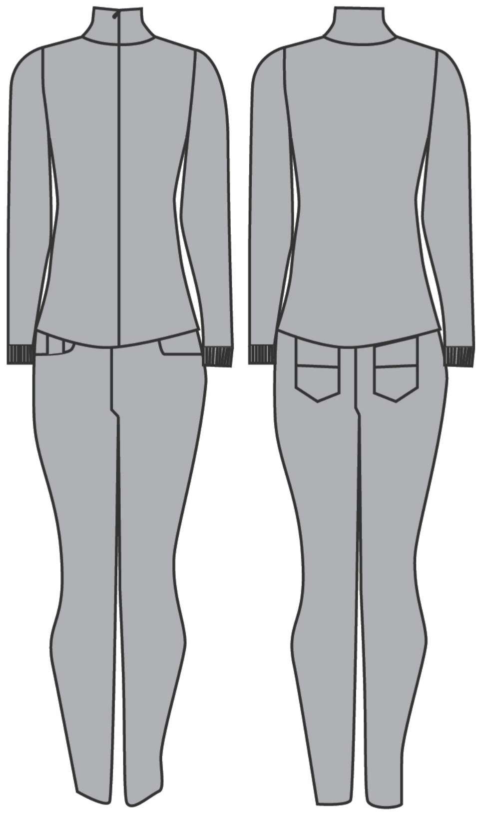
5.4. *Three Ideation Trails to Investigate Further*

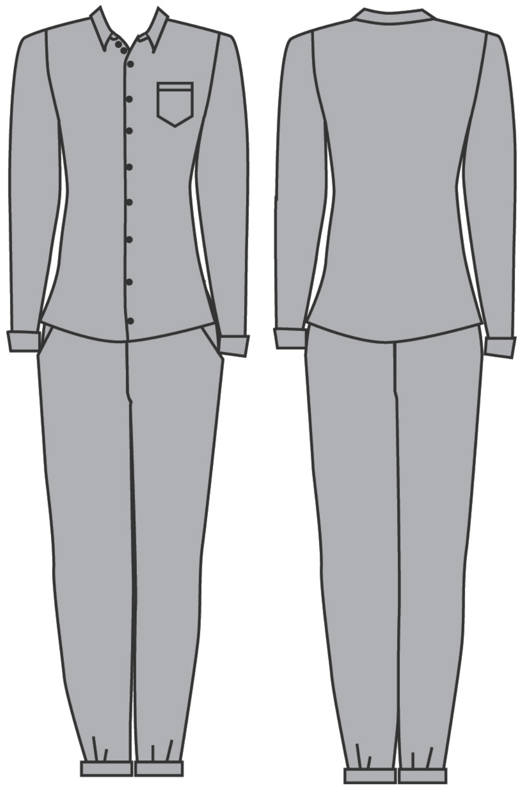
After the different investigations, literature studies and creative methods were performed, three clear trails were distinguished in which the demands of the bill of demands could be fulfilled, while at the same time broadening the possibilities of finding new solutions to the found problems. By exploring the different trails independently and by trying to find the optimal solutions within each trail, as different answers as possible could be found. The three different concepts are introduced below, followed by the result from the further development and possibilities within each trail. The chapter is ended with a conclusion on how the project should continue in order to find the final concept.

5.4.1. *Tight Fitting Clothes*

By exploring how full manoeuvrability on part of the user can be maintained in clothes that are very tight fitting solutions can be found which can be implemented in looser fitting clothes. This exploration aims at investigating the parts of the body which change in size during movement, and how those movements can be permitted. During the investigation of the possible solutions, the bill of demands was not taken into consideration as not to limit the creativity of the process. The demands were instead used in the culling process of possible solutions. Solutions were found from existing garments, through prototyping using fabric, and through sketching.

During prototyping, different fabrics were used to simultaneously research the effect of fabric thickness and stiffness on the manoeuvrability of the finished garment. The thickness of the fabric affects the amount of fabric needed to create the garment. More important in affecting manoeuvrability is the stiffness of the fabric. As can be seen in trouser prototype 2 and 3, the manoeuvrability is greatly affected by the fabric itself and not just by the construction.





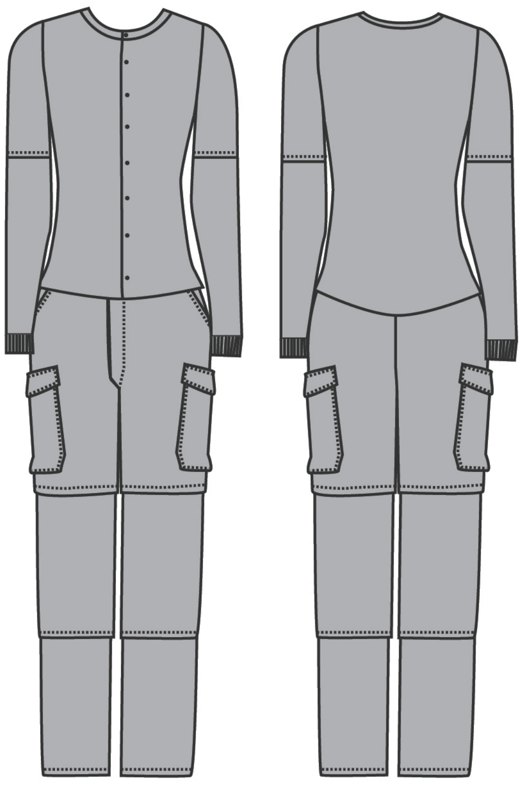


Figure 09: Concept trail 1: tight fitting clothes

Figure 10: Concept trail 2: adapted office clothes

Figure 11: Concept trail 3: easily ventilated clothes

Figure 12: Comparison between fit of jeans and pleather fabric

The main conclusions regarding physical fit for tight fitting clothes are that

- Extra room is needed for movement in
  - the upper back, between the shoulder blades
  - the upper front
  - over the shoulders
  - over the knees
  - over the buttocks
  - over the elbow
- If making an upper and lower clothing item, skin is easily exposed
  - on the lower back
- Compared to other solutions, tight clothes is beneficial for
  - the ankles and calves; the fabric cannot glide up and cause skin to be exposed
  - the wrists; the fabric cannot glide up and cause skin to be exposed
  - dust and dirt; tight clothes mean less wrinkles and folds and therefore less change of material gathering on the fabric.

5.4.2. Office Wear

During the literature studies, clothes as a social barrier was discovered as a phenomenon. This could also be observed during visits to the different factories, and in interviews with both operators and operations managers. In Factory A and B, the difference between machine operator and manager could easily be seen from clothes alone, as could they in Factory D. In Factory C, all present wore the same type of clothing but the students wore clothes they were provided with and the teachers wore their own clothes. The difference then was in quality of the clothes and fit. This difference was explained by the operators themselves; the first months of training means that the students will burn through one or more overalls, whereas more skilled and experienced users do not burn their clothes. Therefore it makes sense to use cheaper clothes during training as they will have to be discarded over time. During observations of the work environments, it could also be concluded that for Environment 1, normal office wear is quite sufficient to protect the operators from the environment. In Environment 2, normal office wear is not sufficient during parts of the operation, but possible during other parts of the operation.

During an interview with an operations manager who had been in the same field of operations the last 25 years, the following quote was collected in regards to the operators clothes at a power plant “why are they dressing so sloppy with these baggy clothes hanging off of their frames? It does not look professional” (Project Manager, 2013-03-10). As the interview progressed and the different concepts were presented to the manager they expressed that “having more similar clothes would definitely bring the people on the floor closer to the people in the offices, especially now that the plants are so clean”, meaning that the environment does not put the same demands on the users as they previously did.

Introducing the idea of having clothes looking like normal office clothes is commonly rejected at first but then embraced by the interviewees. Professionals outside of the factory industry are generally surprised at the notion of having the same type of clothes in the different environments, but they are pleasantly surprised, seeing that it could bridge the gap between different positions. Whether the operators like the idea or not largely depend on what they currently wear. Operators wearing a sweatshirt now want to continue wearing the sweatshirt whereas operators wearing a shirt want to continue wearing a shirt (interviews, Company D)

The increased automatisation and the need for operators to work more independently and make their own decisions, will be one step towards equalising the work tasks of the operators on the floors, and the operators in the offices. There might always be a difference between these positions, both because the difference in the work tasks, and the difference in the personal interests of the operators, but these positions are closing in on each other. Making a change in the work clothes can make this decrease in difference visible to the operators and managers, and bring them closer together by visually bringing them closer.

As for the physical demands put on the work wear, a few possible obstacles and rules were detected during ideation:

- The reach is limited in backwards and forwards direction. This need to be compensated for.
- During reaching up and down, parts of the back is exposed
- The opening in shirt sleeves can cause welding sparks to reach the skin
- The fabric needs to be heavy enough to protect the worker from the different hazards meaning that each workplace needs to be evaluated against dangers

5.4.3. Maximum Adaptation to Different Temperatures

Ideation and investigations showed that there are a few principal ways in which the temperature of the wearer can be regulated. Prototyping was not performed on this category as the solutions can be evaluated by sketching, and as there are sufficient solutions in currently existing products. The methods of regulating temperatures are as follows:

- Remove or add a layer of clothing: feasible in most environs and work situations. The change in clothing can be done either during a break, or during a lull in the work flow. Extra layers can be kept at the work station or in a locker.
- Remove or add a warming accessory: scarfs, hand warmers, leg warmers and hats. The change in accessories can be done either during a break or during a lull in the work flow. Extra accessories can be kept at the work station or in a locker. Any accessories should have the same demands on them as the rest of the work wear, which is, to not put the user in danger. Accessories could be either be distributed centrally, or be personal. The recommendation for work wear accessories is then to put the demand on them that they are not flammable or meltable, that they do not have details or straps that can get stuck, that they are of proper size and that they are stored where they are not in the way of other users.
- Remove or add a piece of the clothing. This solution is often seen in hiking gear in order to give the same garment multiple functionality. The solution is however not used by the military as there is an increased risk of chafing from the zippers.
- Open or close slits in the clothing. This solution is seen in hiking gear, and to some extent, in military solutions. Slits can be either where they are naturally on the garments, such as the fly on military garments, or under armpits were heat is generated and needs to be ventilated away.
- Fold up sleeves or trouser legs in order to improve ventilation in the garments, to release heat. Folding of turtlenecks fall into this category.

- Alter the work wear, for example by cutting of legs or arms, or cutting away wristlets which may be unpleasant to some users.

At all occasions when the clothes are altered or folded, there is an increased hazard for the operators which they may or may not be aware of. The hazards fall into two categories:

- the alteration of the clothes can enable the clothes to get stuck in machinery or other equipment
- the alteration of the clothes can lead to exposed skin, which can in itself lead to an increased risk of damage, especially in Environment 2.

5.5. Evaluation of the Three Ideation Trails

The three main concept trails were evaluated both using the Pugh Matrix method, and by using a reference group at Company D. The Pugh matrix method relied on the information gained from the literature study in order to get the view of the future operators, whereas the reference group are users already working within the industry. To get an evaluation from both groups gives a better evaluation of the concepts compared to just one group.

5.5.1. Evaluated by Reference Group at Company D

The reference group of Company D consisted of operators who worked in the manufacturing, with a long experience of working in manufacturing industries. For the trousers, both groups were in favor of the new trousers, but saw no great difference between the suggestion and the trousers they already had. Two distinct opinions were held regarding the top layers; the operators already wearing a t-shirt and sweatshirt wanted to continue wearing a t-shirt and sweatshirt, and the operators wearing a shirt wanted to continue wearing a shirt. Their reasoning behind wanting to keep their clothes were similar despite wanting different clothes; the clothes already worn felt safer and more comfortable. The operators wearing a sweatshirt did however want to wear something which could be opened for ventilation. (observation and interview company D, 2013-04-22)

5.5.2. Pugh Matrix

The Pugh matrix was performed in two steps; with and without the softer values of identity and clothing expression. The criteria chosen in the Pugh matrix are from the bill of demands, summarizing the most important aspects of what is needed from work clothes. When the Pugh matrix was performed without the social acceptance of the clothes, all three new concepts had an equal end score, even though their strenghts and weaknesses were quite different, see appendix E and F. Notice that all three concepts are equal at this stage. The tight fitting clothes have a small edge compared to the other alternatives, but this is counteracted by the fact that it also has more minuses, therefore weakening the alternative.

When the social acceptance was entered into the criterion, concept B was the clearly winning concept. The benefits of having adaptable work clothes which are also acceptable by managers and the general public

The main track to follow in the next stages of development are therefore work clothes, and the adaptations to them which need to be made in order for them to be functional and protective. Elements from the other trails will be used as well, especially in the shaping of ventilations, and for getting a better fit in the work wear in regards to ease and movement.

6. *Prototyping of Work Wear Concept Trail*

The evaluation of the different concept trails showed that adapted work wear was the most promising concept to develop further. In order to find different solutions for fit, a number of prototypes were manufactured using commercial patterns as a starting point.

Numerous prototypes were created in order to find critical areas of improvement, and to find the limitations and possibilities of each prototype. Instead of just sketching the clothes, prototypes were created to try out the ideas in real life. The first prototype in each series of pants and shirts were carried out completely with all seams being properly seamed and felled, the garments steamed, and all details as buttons and collars finished, in order to see the impression of a final garment, which can be quite different compared to when the clothes are not properly finished. The final touches do take a lot of time however, which is why the intermediate prototypes were just finished sufficiently enough to find the fit of the garment, usually with felled seams but not with a collar or pockets.

6.1. *Trouser Prototype 1*

The first pant prototype tried out was a basic pair of jeans, using a ready-made pattern in order to have a basis to move forward from. The trousers are tightly fitting to the body. What can also be seen is that they are too low on the body, meaning that the belt has to struggle in order to keep them in place, and that the front of the trouser is constructed to be higher than the back, which can partly be attributed to the derrière of the wearer. However, the trouser is too low to protect the wearer from any sparks or other hazards in the work environment, especially when leaning.

6.2. *Trouser Prototype 2*

The pattern from the first pant prototype was modified in order to find a better protection level, to find the different solutions at the knee, and at the bottom of the foot. The trouser pattern was extended 10 cm in the waist in order to protect the wearers back from being seen, and from hazards. The result was a better fitting trouser. Even though the width of the trouser had not changed, the resulting trouser was more comfortable, as it had more allowance to shift around on the body. Even stiffer fabrics have some movement in them due to the bias of the fabric, which is more stretchy than the belt previously used to hold the belt up. Even though this high a trouser is unfashionably currently, it does a good job of protecting the wearer.

For pant 2, the trouser is cut at the knee. After the anthropometric measurements, it was discovered that the knee needed extra movement of on average 3.5 cm, see appendix B. This extra movement ease was created by having the front knee part being longer than the back knee part. The resulting knee part was then fastened to the cut of trouser leg in order to evaluate the actual fit and feel of the ideas for knee elongation that were the most important.

a) Scrunching the trouser up around the knee

b) Sewing small folds from a longer piece of fabric

c) Making a rounded edge on the back fabric, and longer front piece of fabric, creating a "bubble" for the knee
d) Sewing 2 larger folds which are sewn in place with top stitching

The most promising of these solutions were the 2 larger folds as it gives a smoother result, and is faster to make compared to the other solutions, making it more economical. As the folds are sewn in place, there is no risk of dust or other objects being stuck in the folds. The scrunching and smaller folds also have a tendency to create folds over the knee, making it slightly uncomfortable the rest of the time.

The same trousers also served as a basis for trying out the different closure methods at the end of the leg to make sure that they cannot drag at the floor, and that the risk of getting stuck at protruding objects is lowered and impeded. The most promising concepts from the ideation were tried out in physical form to see their effect. Apart from the prototypes 2e to 2h, other leg solutions were tried as well, in prototype 1 and 2, the leg could not drag onto the floor as the leg was too tight to reach the floor.

6.3. Trouser prototype 3

The third prototype tried used the same construction pattern as the second pair of trousers with one main modification; the buttoning. Using the same distances, a new buttoning was created with a sailor paint buttoning. The resulting fit from the sailor buttoning in itself was similar to the zipper solution, but it takes longer time to put on and to adjust compared to the zipper, and the trouser tends to shift around on the body to a greater extent than the zipper version does. Chosen material for pant 3 was pleather, a very thick nylon based fabric with no stretch. This fabric was chosen to evaluate the difference in movement for different kinds of materials. Results from the trial were surprising as the resulting trousers were very stiff even though the material itself was similarly pliable to the twill fabric, but still we see how hard it is to bend the knee and to move. This is attributed to the thickness of the fabric which affected the fit and movement possibilities the following ways:

A thicker material means that the actual garment will be smaller on the body, which makes it harder for the body to shift within the garment. A thicker material means that it is harder for the material to shift around on the body as it is less pliable, and larger creases need to made.

There were no adjustments for the knee in this instalment of the garment, meaning that exactly the same pattern was used as in Pant 3 apart from the buttoning solution. To not change the knee meant that the effect of the thicker fabric on movement possibilities was more clearly seen.

▶ *Figure 13: Trouser 1 seen from the front. Notice the strain on the fabric and the folds created from the strain from the fabric. The folds on the knees are caused by previous attempts at moving in the trousers, stretching the fabric.*

▲ *Figure 14: Trouser 1 seen from the back. Notice the strain on the fabric, especially on the upper thigh area*

◀ *Figure 15: Trouser 1 seen from the side. The leg is lifted as high as possible given the strain fromt the fabric. Notice the strain over the knee and buttocks as too little fabric is available.*

▶ *Figure 16: Trouser 2 seen from the front. There is less strain on the fabric using the higher waist, as more material is available for moving in. The knee is cut off to test different knee constructions but naturally the uncut knee is used as well.*

▲ *Figure 17: Trouser 2 seen from the back. There is less strain on the fabric using this construction.*

◀ *Figure 18: Trouser 2 seen from the side when the leg is raised as far as possible. There is still strain over the knee and buttocks, but the lower back is not exposed when the leg is lifted.*

▲ *Figure 19: Different knee solutions; from left to right: pleats sewn in place, circular add-in, folded pleats, original straight knee.*

▶ *Figure 20: Trouser 3 seen from the front. Notice the strains on the fabric and how it is creasing at the hips and knees, and the wrinkles at the lower part of the leg. Due to the stiffnes and thickness of the material it does not drape well over the body. As can be seen, a sailor type of buttoning is used.*

▲ *Figure 21: Trouser 3 seen from the back. Notice the strain on the fabric, especially on the upper thigh area and over the knees.*

◀ *Figure 22: Trouser 3 seen from the side. The leg is lifted as high as possible given the strain fromt the fabric, which is lower than for trouser 1 and 2. The creases at the knee are caused by the lifting action, and creates painful and stiff creases on the knee region. The construction is very limiting*

6.4. Shirt Prototype 1

Just as the trouser, the shirt was created from a commercially available pattern, to have a basis to work from. The pattern chosen was a fitted womens size with shaping at the waist. The shirt can be buttoned all the way up which prevents the user from being exposed to hazards as sparks and dusts. When the user moves, the garment distorts and prevents free range on part of the user. You can also see how the edges of the shirt front are pulled away from each other by the tension created by moving. The slits at the cuffs also allow material to get into the arms of the garment, even though the cuff in itself is tightly fitting. As the shirt is shorter, the stomach and back is exposed if the arms are stretched up. The tight fit makes it harder for the garment to slide down the body again meaning that the wearer needs to manually pull it down again. The tight fit at the arms can be seen which makes movement cumbersome. There is strain on the fabric as the shoulders are pulled to the back or the front. As you can see, the strain is a combination of the bodice of the shirt, and the shoulder and arm construction. There is simply not fabric enough for the arm to move freely. The fabric distance between the front of the shirt and the top of the shoulder is simply too short to allow free movement. Even if the arm is just elevated, the entire shirt is raised up on that side.

In the end, the fit of the shirt is fine as long as the person is simply standing, but as soon as they move or perform work, the shape of the garment prevents the movement, or exposes the wearer to hazards.

6.5. Shirt Prototype 2

The second shirt has the same body as the first shirt, but the arm construction is different to the first. As can be seen, the collar is a china type of collar to try a different styling, and to improve the prototyping time. The front closing is made with a wider hem to increase the protection of the user, and to protect from full gaps forming.

Both sleeves have a less prominent sleeve cap, two tucks symmetrically placed on each side of the centre line of the sleeve, and a sleeve construction where sparks can not reach the skin. The tucks are folded so that the crease is on the dorsal side of the centre of the sleeve, to promote objects to fall off from the pleat instead of getting stuck. The way to get these functions was however different between sleeve A and sleeve B. Both sleeves have the same measurements, except for the fastening to the cuff.

Compared to shirt 1, shirt 2 has a much greater movement of freedom. There is no strain on the fabric between the bodice and the arms. As we can see the movement is free when the arms are stretched forward, backward and up, which is a huge improvement compared to Shirt 1. Apart from giving a greater freedom of movement, the improved sleeves also did not raise the shirt itself when the arms were stretched upwards, meaning that stomach and back were not endangered. As we can also see in said figures, the arms are much wider than the sleeves in shirt 1. The wider fabric was added to increase the freedom of movement, but could put the person at risk for getting stuck on objects as there is excess fabric. As the arms are raised upwards, it can be noted that the cuffs strain on the wrists, meaning that the arms are slightly too short, or the cuff to narrow. Having the narrower cuff ensures that the sleeve will not glide up, and that no materials will get into the gap between the sleeve and the skin.

The pleats next to the cuff of sleeve are arranged so that one larger pleat can be opened upon removal of the garment.As the pleats are sewn into place, they fall into place when the garment is closed at the cuff. The sleeve cap of sleeve A has two pleats, arranged 3 cm from each other, and 1.5 cm from the centre line of the sleeve respectively.

The pleats next to the cuff of the sleeve are arranged on one side of the opening of the sleeve. As can be seen, the opening is created on the seam of the garment, with the pleats sewn in place on the inside and outside to create the opening. The sleeve cap of sleeve B has two pleats, arranged 6 cm from each other, and 3 cm from the centre line of the sleeve respectively.

Both sleeves had their strengths and weaknesses. The sleeve cap of sleeve A was superior, as it gave a better fit, and a better range of freedom. The sleeve cap of sleeve B also looked somewhat odd. The fastening to the cuff of sleeve B was however better at protecting the user, and easier to get to lie in place. Both sleeve cap solutions and cuff solutions are not traditional, and take equal time to sew.

▲ TL *Figure 23: Shirt 1 seen from the front. There is no strain on the fabric.*

▲ TR *Figure 24: Shirt 1 seen from the front with the shoulders pulled back. There is strain on the fabric as it pulls against the front of the torso. There is not enough fabric to reach fully back.*

◀ BL *Figure 25: Shirt 1 seen from the front. As the arms are pulled up the stomach and back are exposed.*

▶ BR *Figure 26: Shirt 1 seen from the front. After the arms are pulled down again after being raised, the stomach is still exposed as the fabric is stuck on itself and on the body.*

▲ TL *Figure 27: Shirt 1 seen from the back. There is no strain on the fabric.*

▲ TR *Figure 28: Shirt 1 seen from the back with shoulders pulled forward. There is strain on the fabric as it is pulled taut against the body. The full movement is prevented by lack of fabric.*

◄ BL *Figure 29: Shirt 1 seen from the side as the elbow is pulled up to 90 degrees. Multiple creases are created by the motion.*

► BR *Figure 30: Shirt 1 detail of the cuff. The skin is exposed at the cuff allowing materials to reach the skin.*

▲ TL *Figure 31: Shirt 2 seen from the front. There is no strain on the fabric*

▲ TR *Figure 32: Shirt 2 seen from the front with the shoulders pulled back. There is less strain on the fabric, and the full motion is allowed.*

▲ ML *Figure 33: Shirt 2 seen from the front. As the arms are pulled up the stomach is partially revealed, but to a smaller extent compared to shirt 1.*

▲ MR *Figure 34: Shirt 2 seen from the front. After the arms are pulled down again after being raised, the stomach is not exposed as the fabric can fall back down.*

◀ BL *Figure 35: Shirt 1 seen from the back.*

▲ TL *Figure 36: Shirt 1 seen from the back with shoulders pulled forward. There is strain on the fabric as it is pulled taut against the body. The full movement is prevented by lack of fabric.*

▲ TR *Figure 37: Shirt 1 seen from the side as the elbow is pulled up to 90 degrees. Multiple creases are created by the motion.*

▲ ML *Figure 38: Shirt 1 detail of the cuff. The skin is not exposed due to the folds.*

▲ MR *Figure 39: Shirt 3 detail of the cuff. The skin is not exposed due to the umbrella fold*

◀ BL *Figure 40: Close-up of the umbrella fold.*

7. *Final Results*

The final concept to take further was concept 2, work wear looking like adapted office clothes. After another round of ideation, the final product is that of adapted work wear. The following chapter describes the design and construction of the work wear, how it is intended to work, and what is meant to achieve.

There are however equally important results from the research which are worth mentioning.

1. During the product, a development methodology was developed for systematic development of work wear. The same methods can be used for similar environments and tasks, giving a framework for the development of clothes.
2. The bill of demands can be used both as a checklist for the investigated work environments, and as a checklist for other environments. The checklist in turn can be used both to develop new work wear, and for companies wanting to purchase new clothes for their operators and wanting to ensure that all relevant demands are met for the clothes.
3. The demonstration of the importance of the symbolic values even in work wear, and how what we wear affect who we are and what we do, as well as the possible paths we see before us.

These other results might be more interesting than the final prototype to some readers as they can be used outside of the project.

The final product consists of a shirt and a trouser. It is developed to fit both the physical and the symbolic functions of the operators. The work wear protects the users from hazards in the work environment as little skin is exposed. As the shirt can be opened, there is also a chance for the operators to ventilate if they risk getting overheated. In the figures, the female model is portrayed but both male and female models should be produced and made available to the operators.

Figure 41: The final prototype consisting of a trouser and a shirt

7.1. Shirt

The shirt has a relativelly tight fit around the body of the operator. Too large clothes risk getting stuck in machinery. The figures show the female model but similar construction can be made for the male model. The model is slim, but not so revealing as to make the wearers uncomfortable. At the same time, the model is not overly sexualized. The length of the shirt is longer than shirts normally are. The length is made longer in order to ensure that the shirt can be comfortably tucked into the trousers, and cover the stomach and lower back when the arms are reached up. The shirt can be buttoned or unbuttoned to allow ventilation of the operator, provided that this is safe in the specific work environment.

The arms are constructed with a loose fit to make sure that the wearer can move comfortably in the garment, easily reaching in all directions. Tight cuffs make sure that no hazards reach the skin of the user. Normally, there is a gap in the arm at the cuff, which has here been replaced with an umbrella fold. The arm can still be opened up when taking the shirt on or off but the arm is protected. When the work environment is safe enough, the cuff can even be folded up using this construction. The wrist will then be exposed to hazards in the work environment, but the risk is much lower than exposing the ankles and calves.

Construction wise, the front, side and back pieces were elongated to better protect the trunk of the user from getting exposed and thereby come in harms way. The sleeve cap was lowered making the slope less steep. The small folds were introduced at the sleeve cap. Both of these changes gives extra room for motion without changing the slimness of the body. As can be seen in the figure below, folds were also introduced at the sleeve as were tabs making up the umbrella fold.

The shirt is made in a sateen woven cotton-wool blend in this instance. The colour was chosen to show that one can indeed wear fashionable colours even in a manufacturing situation. The colour might be the company colour, or chosen freely by the employee.

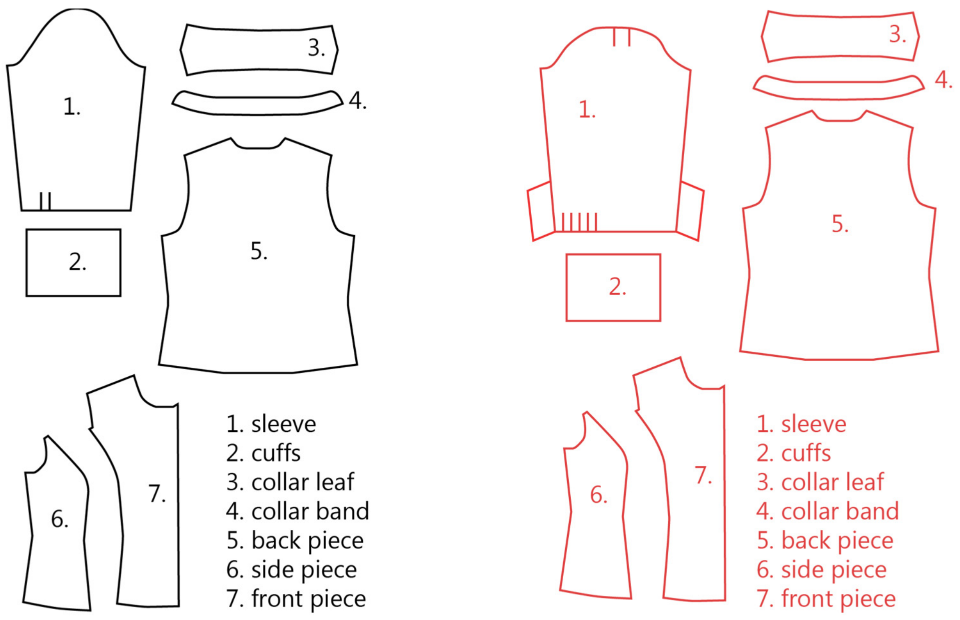


Figure 42: Shirt construction. The left sideeshows the traditional construction and the right side shows the developed construction.

▲ TL *Figure 43: Final shirt seen from the front. There is no strain on the fabric*

▲ TR *Figure 44: Final shirt seen from the front with the shoulders pulled back. There is little strain on the fabric, and the full motion is allowed.*

▲ ML *Figure 45: Final shirt seen from the front. As the arms are pulled up the stomach is not at all revealed even though the shoulders are fully extended*

▲ MR *Figure 46: Final shirt seen from the back. As the shoulders are being pulled forward, there is little strain on the fabric. Some creases are visible.*

◀ BL *Figure 47: Final shirt seen from the side.*

7.2. Trousers

The fit of the trousers is moderate to allow movement of the body, which is aided with the folds at the knee. The fit is still narrow enough to pass for normal trousers. There are fewer pockets than craftsman trousers normally have.

The trousers are also made without contrasting thread, one of the main distinguising traits for workman trousers. The contrasting thread has no other function than to show the sturdyness of the seams, and to clearly show what kind of trouser the user is wearing. The seams are made in the same colour as the trousers to better blend in with office clothes. The fabric chosen is a dark denim in this case, but could be made in any natural material. Dress pants are normally made in polyester, which is not suitable for this type of work environment. At the same time, the model of trouser is normally associated with twill or denim fabric.

The bottom of the trousers are sewn to the right height for the user. The only way to ensure that the trousers are the correct height, thereby preventing users from folding or otherwise altering the height of the trousers is to individually make them the right height for each user. This can easily be achieved by marking the right height and having the cleaner sewing them to the right height. The cost for shortening the legs is low, and can save money by decreasing the risk of operators getting injured.

The waist of the trousers is heightened compared to other trousers to ensure that the waist is protected from hazards. This change also improves the fit of the garments when moving. To make sure that the trouser fits snuggly around the back, button straps are used to adjust the width of the trouser. A belt can also be used, or a tool belt.

The width of the trouser is such that the diameter diagonally over the shoe is the same as the trousar diameter, thereby preventing them from falling down and drag on the floor, see image below. The effect is most clearly seen on the left leg in this image.

Figure 48: Preventing the trouser from reaching the floor

The construction of the trouser is more similar to a jean pattern than to craftsman trousers, therefore the figure showing the pattern construction compares to a jean pattern. The waist is slightly raised and there are folds at the knees for a freer movement.

▶ *Figure 49: Final trouser seen from the front. There is little strains on the fabric. There are wrinkles on the knees mainly caused by exesive movement during photography. Notice the high waist of the garment clearly protecting the stomach even during movement.*

▲ *Figure 50: Final trouser seen from the back. There is little strain on the fabric even though the fit is close to the body on the derriére.*

◀ *Figure 51: Trouser 3 seen from the side. The leg is lifted as high as possible given the strain fromt the fabric. As can be seen, the leg can be raised high without exessive strains on the fabric.*

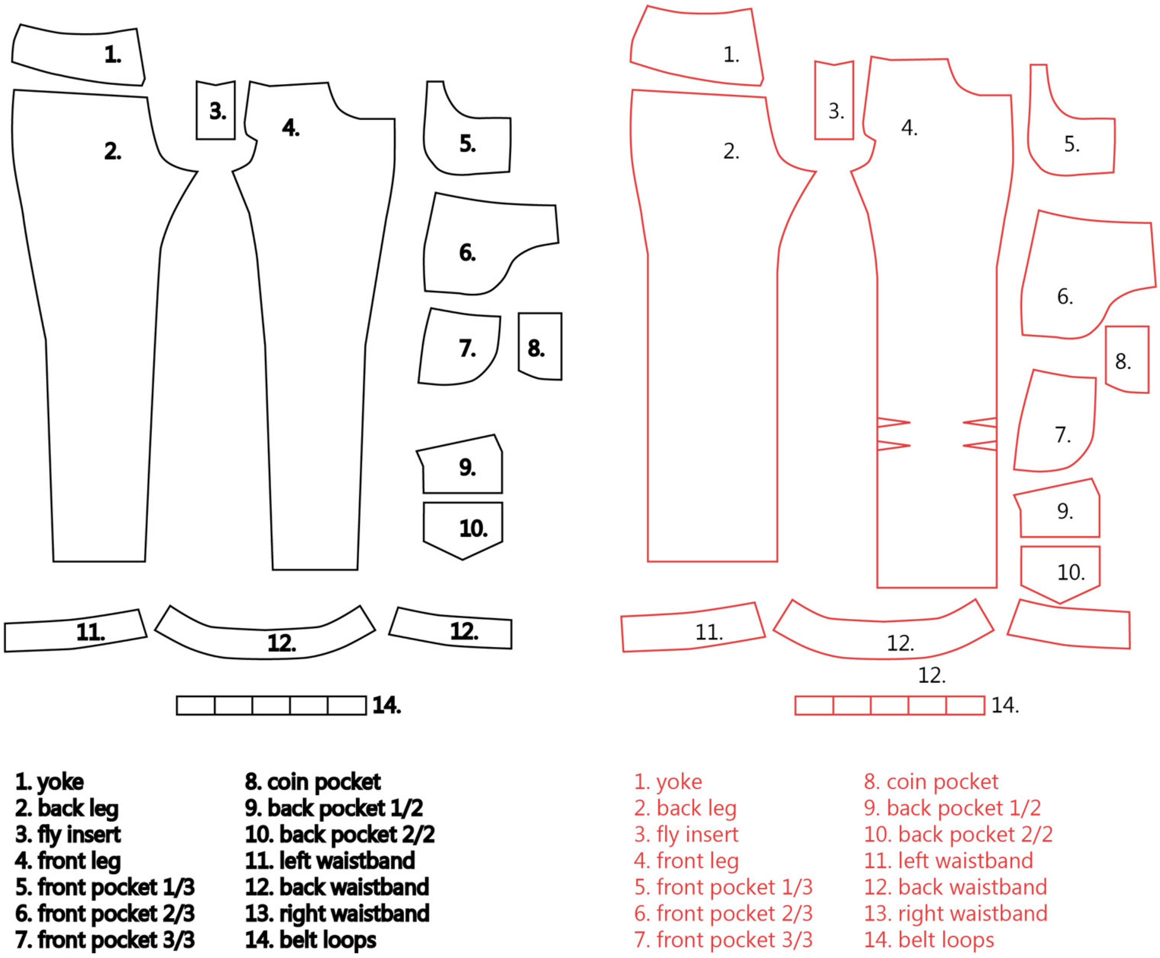


Figure 52: The construction of the trouser. The left side shows the original trouser. The right side shows the developed construction.

7.3. Sizing System

The chosen sizing system is the Swedish military system which takes height, weight and gender into account. I.e. there are clothes available for every combination of height, weight and gender. It should be noted that for the trousers, special maternity trousers should be manufactured as well, which are adapted to the larger belly of pregnant women working within the industry.

7.4. Compliance with Bill of Demands

The work wear are developed using the bill of demands as both an evaluator in the Pugh matrix, and as a basis for future work. As the work wear is developed using the bill of demands as a benchmark, the final product also complies with the bill of demands. It should be noted however, that the product is not suitable for environment 2 as environment 2 is too dangerous. In this environment, the developed work wear does not offer full protection. In environment 1 however, the clothes work well to protect the operators. For the work wear to be fully operational in environment 2, reinforcements on the clothes are needed on exposed areas, as well as a further look on the materials used.

7.5. Sustainability of the Developed Product

The construction of the shirt is slightly more complex compared to traditional shirts; the umbrella fold and the folds all take longer time to make than compared to not having these additions. The trouser also has folds at the knee meaning that it takes slightly longer to sew. Both shirt and trouser take up more material compared to their traditional counterparts meaning that they are slightly more expensive to use. The environmental impact and social usability during production remains the same. As for social usability during use, the suggested product could aid in removing social both within the workspace and surrounding the workspace.

8. Discussion

The master thesis started with the open question of what the clothes of the operator of the future could look like, narrowed down to the operators of the manufacturing factories for the year 2020. It developed into a search to find the new generation of work clothes to be used in a factory setting. This chapter supplies a discussion about the process, the end result, the relevance of the clothes for the operator of the year 2020 and future work.

8.1. Method and Execution

Looking back at the project, the methods chosen and the time plan functioned well. During the development of the clothes, buffer time had been allotted allowing for more interviews and observations to be booked in as the need arose, and when more information needed to be supplemented. At the same time, activities were carried out within the project which were, in the end, deemed to not be so relevant as to be brought into the report in their totality. This is especially true for material evaluations and technology. At the beginning of the project a cursory literature review was performed concurrently with the time planning. Even though at the time, it felt frustrating to not be allowed to jump into the project, making this time plan and the thorough plan of activities was crucial for the success of the project. Clothing is a huge area of research and spans from material to social impact and fashion. Therefore it could have been easy to get lost within any one of the different research areas and make that a master thesis in itself. By allotting the time to make a thorough plan, it was ensured that the project would stay on track throughout and to make sure that it would not become stressful towards the end.

A relatively large portion of the project was devoted to ideation of concepts and early prototypes of them. To make 3D sketches of concepts and translate them to the human body, especially when the body moves, is notoriously hard. More experienced pattern constructors and tailors could likely have just performed the sketches and thereby evaluated fit and function, whereas I had the need to do physical versions of the sketches in order to evaluate them. The process of pattern construction and prototyping is time consuming but rewarding. Therefore I think the time was worthwhile and greatly contributing to the finished product.

One issue with the project throughout was that the end product was intended for the year 2020, and for a part of the population who are to be attracted to working in factories, not the ones currently actually working there. The interviewees and observations were selected to compensate for the this, by choosing to interview younger employees and people outside of the factories, together with managers. The problem with finding the right sample was compensated for using the literature study as well. In order for the results to be fully valid, the resulting work wear would have to be professionally manufactured for all sizes and tried in the factory setting for a longer time period to see how they withstand washing, and how they are received after a longer time of usage when the operators get used to them.

8.2. Project Discussion

Even though the project was carried out within a larger Vinnova project, it was still largely performed as a solo effort with the aid of the supervisor and examiner. Working without a company had both drawbacks and advantages. Working alone is much quicker than coordinating with a larger company and different stakeholders. At the same time, it allowed me to look objectively at all the different available work wear and contact different manufacturers, thereby being given more free reins. Instead of just looking at the current clothes and developing them further, it allowed me to go in from the other direction and develop what is actually needed. Being able to do the manufacturing of prototypes myself also added to the quick work pace and evaluation of concepts. However, working alone also meant that all contacts and all the work needed to be done by myself. Had the project been carried out with a company, other contacts would have been made, further away from my own network of contacts.

8.3. Result Discussion

There are three main results from this project, which can be used in future projects:

1. a work methodology for the systematic development of clothes showing what methods to use and how to use them in this context. By following the same steps, clothes could be developed for any environment. The methodology resulted in a general bill of demands suitable for the development of any type of clothes. It is written in such a way that it can be used as a check-list for picking the most suitable available clothes already on the market.
2. a theoretical background to why clothes and what we wear is so important not only seen from a functional viewpoint but also on how they affect how we behave, think and act.
3. a finished concept and prototype to be used in the factory of the future. In fact, the clothes could be used already today in Environment 1. The finished concept could be sent to a pattern maker and then to the factory to be produced on a large scale.

Which one of these results that is the most interesting depends on the reader of the report. The results can be used separately but put together I believe they show that the results are solid. From an industrial design point of view, the actual finished prototypes and concepts are the most important results, but from the viewpoint of clothes manufacturer, the work methodology and bill of demands are more important. And from the viewpoint of someone wanting to change the future of the Swedish industry, the discussion on clothes and what we wear is probably the most important. The same kind of discussion could be used for the work environment as a whole, i.e. how we as humans function in different situations depending on the impact from the surroundings.

8.4. Acceptance of the Developed Clothes

The clothes were only partially accepted by the current work wear users in the designated work environments. As wearers of tshirts and wearers of shirts both claimed that the clothes they already wore were the most comfortable, it is clear that both types of clothes can be worn comfortably during heavy work. The psychological resistance against the shirt can be attributed to implications of the work wear and what they would mean to the user. Even though the users resist the clothes now, that argument strengthens the idea of putting the operators closer to the managers from a clothing perspective. And the resistance against the clothes is likely temporary, given that they work in a satisfactory way. Fashion changes quickly, along with our notion about what is acceptable or not.

8.5. Future Work

One of the main identified issues with clothes at large is their large consumption of water during washing. Over time, the technology of both washing and of fabric should improve. As materials develop which do not wick in oils, these could be used instead to allow a longer washing interval. Another current problem with work clothes is the fibre origin and production. Different materials were investigated, such as hemp, nettle, ramie and tencel. All of these are natural materials which can be produced with minimal environmental impact, and they have better properties than cotton. As of yet however, the production of these materials is negligible on an industrial scale, meaning that it is impossible to evaluate the cost or actual production impact of the fibres. Over time, as the production scale of both organic cotton and the aforementioned fibres increase, a better comparison can be made between the different materials in order to choose the best ones.

The other identified issue to be resolved in the future, and which was also part of the Vinnova project, was the role of technological aids and cognitive aids in the future. To say today which kind of technology which is going to be used in the year 2020 as a cognitive aid is impossible. The developed clothes are compatible with different kinds of devices, but exactly how they are to be integrated is for the future to tell. Pocket placement, energy source placement and device placement all depend on the kinds of devices which are to be used.

8.6. Source Material

As can be seen in the references, many of the literature sources are old, ranging as early as from the 1970s. Especially the material for work wear is old. The reason is that no other material could be found, not only in Sweden, but in the world as a whole, during the literature search. The material is still valid; the design of the clothes described in the literature was almost identical to the clothes seen in the factories with classic craftsman trousers and a sweatshirt. Likely the material described in the early research led to the clothes currently worn. The research performed in this work builds on that previous material, taking work wear one step further. To ensure that the literature research was valid, it was combined with newer literature studies, law and regulations searches, and interviews.

8.7. Are the Clothes Futuristic Enough?

Humans have been clothing themselves for millennia, and there are just so many things you can do with fabric and still be functional. The title Clothes for the Operator of the Future brings to mind futuristic images of high-tech materials and integrated technology. What was found for this project was that these kinds of solutions are simply not realistic from a cost perspective, and from the maturity level of the materials both now and in the future. For the project to be worthwhile, the concept trails need to be at realistic. The clothes are however vastly different from the work wear currently used, and the intention behind them is different compared to the current work wear. Therefore the clothes are intended for the future, without being "futuristic".

9. Conclusions

The ultimate goal of the project was to investigate the opportunities and demands for clothes of the operator of the future in common manufacturing industries in Sweden, for the year 2020. Instead of simply looking at the current work clothes and developing them yet further a solution was found approaching from the other direction; looking at the actual needs and developing for them.

By investigating a number of different principal concepts with extreme prerequisites, solutions could be found which would not have emerged if just a general solutions was searched for. By then adapting the results and harmonizing them with the found requirements, a final concept could be found which has better functions and construction compared to just aiming straight at the final concept without taking detours.

The proposed work wear can be used by operators and managers alike. By using the proposed methodology and the bill of demands, clothes can be developed which fit in other work environments as well. The developed fit and ease of the garments can be achieved using different kinds of materials. As of today, the most common material for clothes production is cotton, which is still suggested from the literature findings. However, as other materials become more readily available and economically viable, it is suggested that the clothes production should utilize other materials, and to recycle the clothes to a larger extent.

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11. Oral References and Observation Dates

11.1. Interviews

Agnar Hansson, Holmens Laundry (2013-03-15)

Anna Forsström, Welder Apprentice (2013-02-05)

Anna Valtersson, Textile Engineer at Smart Textiles (2013-02-26)

Daniel Söderberg, Osteopath (2013-04-02)

Fredrik Gunnarsson, Welder and Engineer (2013-02-12)

Johan Heinerud, Materials and Textile Expert (2013-02-08)

Mattis Karlsson, Former Military (2013-03-21)

Ted Göthberg, Welder and Machine Operator (2013-02-15)

11.2. Company Interviews and Operators

The condition for being allowed to visit the different companies were that the managers did not want to be named, or that their companies were named or clearly identifiable.

Observation and interview with operators and manager responsible for work wear at Company A (2013-02-07)

Observation and interview with operates and manager at Company B (2013-02-07)

Observation and interview with operaterators and manager at Company C (2013-02-27)

Observation and interview with operaterators and manager responsible for work wear at Company D (2013-04-27)

Interview with manager responsible for work wear at Company E (2013-04-27)

Interview with operations manager (2013-03-10)

12. List of Tables

13. *List if Figures*

Unless otherwise stated, all figures are made by me and all photograps are taken by photographer Jan-Olof Yxell.

14. Appendixes

Appendix A: Clothes Types

The clothes presented in this Appendix were identified during the project.

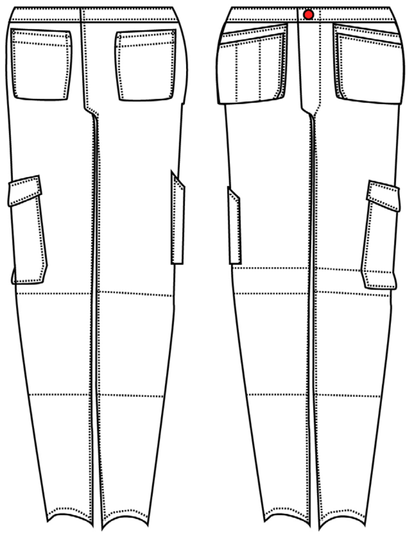


Figure 53: Craftsman trouser

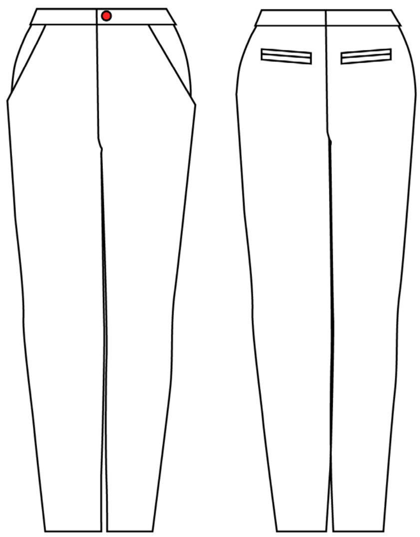


Figure 55: Chino, slacks, khakis

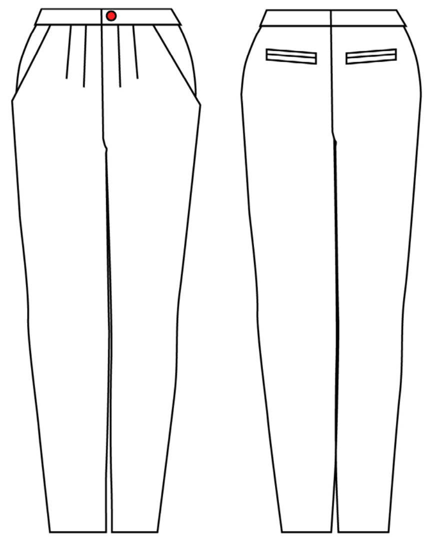


Figure 57: Chino, slacks, khakis, with front pleats

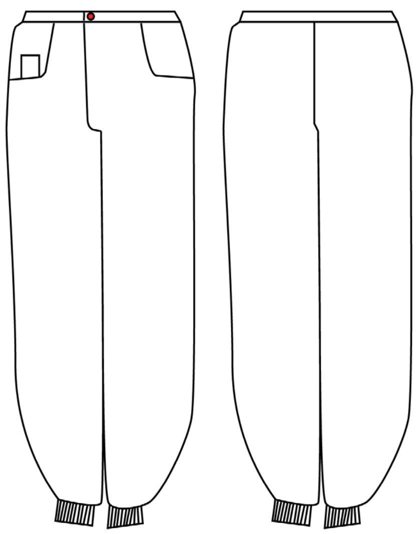


Figure 54: Loose jeans pant

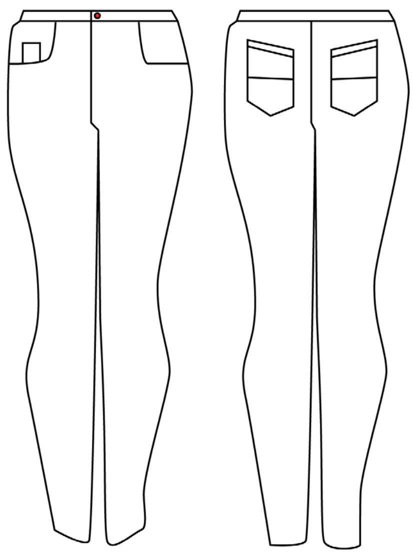


Figure 56: Tight jeans

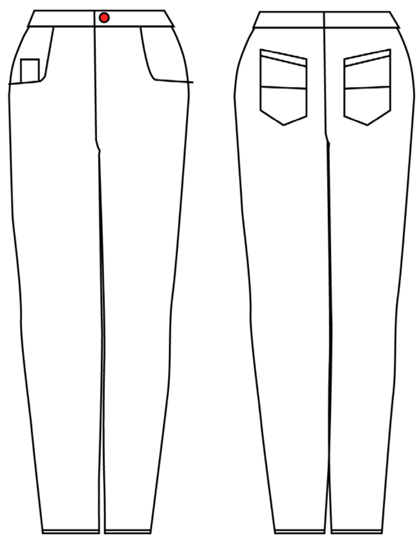


Figure 58: Jeans

Appendix B: Anthropometric Measurements

1. Coracoid width: standing straight
2. Coracoud width: pulling shoulders back
3. Coracoid width: difference
4. Acromion width: standing straight
5. Acromion width: pulling shoulders forward
6. Acromion width: difference
7. Distance patellar tendon to quadriceps: knee straight
8. Distance patellar tendon to quadriceps: knee bent 90 degrees
9. Distance patellar tendon to quadriceps: difference
10. Distance joint capsule of elbow to ulna radial notch: elbow straight
11. Distance joint capsule of elbow to ulna radial notch: elbow bent 90 degrees
12. Distance joint capsule of elbow to ulna radial notch: difference
13. Barefoot distance around ankle measured from talar dome to heel plate
14. Corrected distance around ankle: working shoe added
15. Height when standing straight
16. Trouser circumferance

Table 9. Anthropometric Measurements – Analysis and Impact on Work Wear

	Men				Women			
	5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
1	169,1	183,5	194,8	8,6	159,2	167,0	172,9	5,4
2	40,6	42,0	44,9	1,7	36,6	38,5	39,0	1,1
3	8,1	9,0	11,0	1,1	7,6	9,0	10,0	1,0
4	11,0	13,0	14,5	1,2	10,1	12,0	14,5	1,8
5	2,0	4,0	5,0	1,0	2,0	3,0	5,5	1,2
6	4,6	6,0	7,0	0,9	5,0	6,0	7,0	0,8
7	7,6	8,0	9,5	0,8	7,0	7,5	9,0	0,9
8	2,0	2,0	4,0	0,8	1,0	2,0	2,9	0,8
9	40,6	42,5	47,3	2,6	33,6	37,0	40,0	2,4
10	42,0	45,0	51,8	3,5	35,6	41,0	43,5	2,8
11	1,0	2,5	4,5	1,3	2,0	3,0	4,0	0,9
12	40,6	44,0	52,5	4,7	38,6	40,5	44,5	2,3
13	44,2	50,5	60,5	6,2	42,0	47,0	53,9	4,0
14	3,1	6,0	10,0	2,5	2,6	5,5	11,8	3,4
15	33,0	35,0	38,0	1,8	30,0	31,5	33,5	1,2
16	47,5	50,4	54,7	2,6	43,2	45,4	48,2	1,7

Appendix C: Water and Energy Usage for Maintenance and Washing

Calculations for Laundry of Work Wear
The assumption is made that the washing frequency and duration remain independent of type of materials chosen for the clothes. The calculations are based on the figures from the industrial washing machine W41100H from Electrolux with a 110 kg capacity. The product has the following capacities:
http://laundrysystems.electrolux.se/node188.aspx?pdfid=21489
Machine can take 110 kgs per wash
Energy usage of machine per wash : 5,3 kW or 16A
Water used (renewable) per wash : 713 l
Duration of laundry: 50 minutes

Trousers
Let us assume that the pants are washed once a week.
Weight per garment: 1 kg
110 kg total weight ==> 110 trousers can be washed at the same time
Energy usage for trousers per week: 48,18 W
Water usage for trousers per week: 6,48 litres

T-shirt
Let us assume that the t-shirt is washed every second day, on average 3 times per work week (on the Monday, Wednesday and the Friday)
Weight per garment: 350 g
110 kg total weight ==> 314 tshirts can be washed at the same time
Energy usage per garment and wash: 16,88 W
Water usage per garment and wash: 2,27 litres
This is done three times per week, therefore total usage per week
Energy usage total for tshirt: 50,64
Water usage total for tshirt: 6,81 litres

Sweatshirt
Let us assume that the sweatshirt is washed three times per work week (on the Monday, Wednesday and the Friday)
Weight per garment: 800 g
110 kg total weight ==> 137,5 sweatshirts can be washed at the same time
Energy usage per garment and wash: 38,54 W
Water usage per garment and wash: 5,19 litres
This is done three times per week, therefore total usage per week is:
Energy usage total for sweatshirt: 115,62 W
Water usage total for sweatshirt: 15,57litres

TOTAL EFFECT FROM LAUNDRY PER WEEK PER USER
Energy used: 217,44 W
Water used: 28,3 litres

Appendix D: Constitution of Work Wear

Workman trousers consist of:

- Fabric: the body is covered in cotton. The material is commonly twill woven cotton
- Thread: made out of cotton or polyester
- Colourants and dyes: for both fabric and thread: commonly synthetic indigo for jeans
- Metallic zipper: usually steel
- Jean button or snap button: commonly made of steel or alloy metals. Neither source nor material can be confirmed
- Rivets: commonly made from copper
- Flame retardants: commonly from bromides

A t-shirt or tank top is normally paired with the trousers. Even when the materials are not treated with flame retardants, they are normally of an organic origin. The organic materials can burn, but they do not melt as plastics do, meaning that the consequences of sparks are less for organic materials than for plastic materials which can stick to the skin.

- Fabric: cotton
- Polyester thread
- Colourants and dyes: for both fabric and thread

A sweatshirt is commonly used as the outer layer except for welders where the overall cover the entire body.

- Fabric: cotton fabric created by knitting. Most of the garment is made in knit stitch which creates a flat surface on the right side of the fabric, and an uneven surface on the inside, which increases the insulation of the garment. The elastic parts of the sweatshirt on the wrists and neck is created by the knitting process of the material as the ribbing can expand and shrink again (Natter, 1983).
- Polyester thread or cotton thread: different brands use cotton and different use polyester threads.
- Colourants and dyes: for both fabric and thread

An alternative to the sweatshirt is the shirt. This has the same constituents as the sweatshirt, with the addition of buttons.

- Fabric: twill woven cotton
- Buttons are made from a wide range of material, from natural materials as bone or shell to metals, glass and plastics. The cheapest alternative is however polyester which is dye-casted. As other materials are more expensive, it can be assumed that polyester is the most commonly used plastic in buttons. (http://www.madehow.com/Volume-2/Button.html)
- Snap buttons

Appendix E: Pugh Matrix without Social Acceptance

	Pugh matrix: not weighed			
	Alternative			
Criterion	**Reference**	**Tight fitting**	**Office Wear**	**Temperature adaptation**
Carry tools in clothes	0	-1	-1	0
Allow full movement	0	1	-1	1
Not get stuck in machinery or on the user	0	1	0	-1
Effects of wrongful adaptation	0	1	0	0
Right temperature	0	-1	0	1
Allow the users to perform work tasks	0	0	1	0
Work wear compatible with PPE	0	0	0	0
Decrease barrier between operators and managers	0	0	1	0
Users have physical comfort in the clothes	0	1	1	0
Production of clothes take minimal time	0	0	-1	-1
Little abrasion	0	-1	0	1
Little chafing	0	1	0	-1
Bloodflow not restricted	0	-1	0	0
Count +1	0	5	3	3
Count 0	13	4	7	7
Count -1	0	4	3	3
Net value	0	1	0	0
Ranking	2	1	2	2
Further development?	No	Yes	Yes	Yes

Appendix F: Pugh Matrix with Social Acceptance

	Pugh matrix: not weighed			
	Alternative			
Criterion	Reference	Tight fitting	Office Wear	Temperature ad-
Carry tools in clothes	0	-1	-1	0
Allow full movement	0	1	-1	1
Not get stuck in machinery or on the user	0	1	0	-1
Effects of wrongful adaptation	0	1	0	0
Right temperature	0	-1	0	1
Allow the users to perform work tasks	0	0	1	0
Work wear compatible with PPE	0	0	0	0
Decrease barrier between operators and managers	0	0	1	0
Users have physical comfort in the clothes	0	1	1	0
Production of clothes take minimal time	0	0	-1	-1
Little abrasion	0	-1	0	1
Little chafing	0	1	0	-1
Bloodflow not restricted	0	-1	0	0
Acceptance by operators	0	-1	1	-1
Acceptance by managers	0	-1	1	0
Acceptance by the general public	0	-1	1	-1
Count +1	0	5	6	3
Count 0	16	4	7	8
Count -1	0	7	3	5
Net value	0	-2	3	-2
Ranking				
Further development?	No	No	Yes	No

Appendix G: Interview Form Factories

Interview form for visits at the different manufacturing companies. The interviews were semi-structured meaning that the questions in the form should be replied to during the interview session, but not necessarily in that order.

Introduction to the project
Vinnova and the Operator of the Project
The Future of Swedish factories
Clothes for manufacturing industries

How many are employed at the company?

What is the main area of operations in the factory? What kind of tasks do the operators perform?

What kind of clothes do the operators wear? Do they have any options to choose between? What opinions do the operators have of their clothes? Can the operators wear their private clothes? Are the work wear personal or do they grab any clean clothes? Have any strains, abrasions and bruises been reported?

What kind of information devices do the operators carry with them? What kind of information do the operators need during the work day? Is this information displayed where they work or do they need to carry it with them?

What kind of tools do the operators need to carry with them? Do all operators need to carry the same things?

Do operators commonly drop things on the floor?

What kind of injuries do people suffer? What are the most common injuries? What are the most harmful injuries? What do people complain about? How heavy is the load on the operators?

What other hazards are there in the work environment? What kinds of dirts are in the work environments? Are there oils, chemicals, sparts and dusts which are detrimental to the health of the operators?

What moving parts are there in the factory? Can the operators get stuck in the moving parts? Can operators get caught on other objects?

What temperature is prevalent in the factory? Does it change over the year? Are there any drafts? Is the break rooms the same temperatures as in the rest of the factory? Is indoors and outdoors work mixed.

How are the clothes maintained? Who mends the clothes? How and where are the clothes washed? What is the washing interval?

How well do the work wear protect the operators? Are the operators fully protected from any hazard in the work environment?

Are all pockets and straps used? Could the pocket placement or shape be changed? Are the knee pads used? Do they work well?

Appendix H: Observation From Factories

Observation sheet for the visits to the different work environments. The observations supplement the interviews made, and aid in recording information which is not given by the interviewer, or gives a contrast to what the interviewee has stated.

Do people drop things? What and when?

What type of movements to the operators perform? What kind of load to the operators have? What kind of work do the operators perform?

What alterations have the operators made to their work wear? Have they folded up their trouser legs? Do they wear any personal items or clothes? Is this allowed at this work place? How do the operators adjust their clothes?

What combination of work wear do the operators wear?

Are any operators observed which are injured or subjected to hazards?

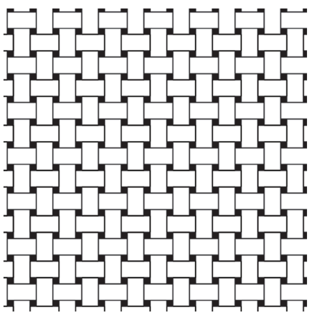
What kind of communication do people have? What kind of information tools do they have?

Appendix I: Turning Fabric Into Cloth

There are two main different ways in which fibres can be turned into cloth; through weaving, or through knitting. The end results are quite differnt and the materials behave differently because of this.

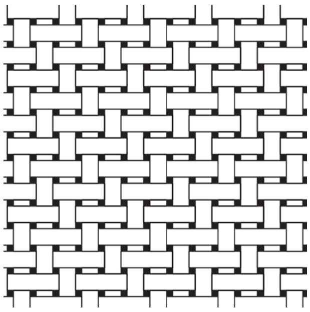
Weaving is a method in which lateral one or several threads are woven into several longitudinal threads. The longitudinal threads make up the warp of the fabric, and give the width of the fabric bolt. The lateral threads are the weft of the fabric and the way in which the weft is woven into the warp affect what the fabric looks like. Unless the contained fibres are stretchy, the resulting cloth is stiff in the lateral and longitudinal direction. The threads are straight meaning that they cannot stretch more. The fabric can however stretch more in the diagonal direction which is called the bias.

Some of the most common weave types are the plain weave, twill weave, and the sateen weave. The expression of these fabrics are quite different, even when the used fibres are the same.



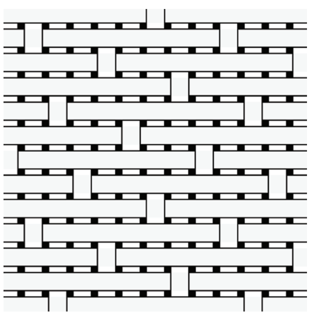
The plain weave is a common weave in cloth for shirts and bed linnen. It is created by the warp going one-over-one-under in the entire cloth . It is the strongest cloth as the maximum overlap between the warp and weft is reached.

Figure 59: Plain weave



The twill weaving, often seen in rugged clothes and jeans is created by the weft skipping two or more threads in the warp when weaving. The fabric is distinguished by a diagonal pattern appearing due to the weaving method.

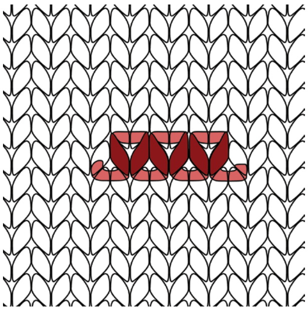
Figure 60: Twill weave



Sateen is created by floating the weft on top of the warp, meaning that the two directions are seldom crossed. By weaving the fabric this way, the thread is showcased for a longer time without being interrupted which gives a greater shine to the fabric making it feel luxurious.

Figure 61: Sateen weave

Knitting is a method in which a single yarn is used at a time. Several yarns can however be used in a whole cloth to make patterns and colour changes but just a singular is worked at a time. The cloth is created by consecutive loops being made by turning the yarn through the loops of the previous row while at the same time making loops for the next row. As there are several ways of creating the loops, and turning the loops into each other, there are also several looks and functions of knitted fabric. The most commonly seen stitches in both civilian clothes and work wear are knit stitch and rib stitch. The most common resulting fabrics are knit or ribbed, the knit using just one type of stitch and the ribbing two different kinds placed in rows as to create extra flexibility and stretch. (Natter, 1985)



This fabric is knit, the red showing how the yarn is looped in a single row. Notice how the looping of the yarn extends to the row above and below. As can be seen, the yarn is wound back and forth, enabling it to be stretched out in the different directions. The type of yarn and the tightness of the knitting, determines how stretchy the fabric is, and what it can be used for.

Figure 62: Knit Fabric

This fabric is ribbed, the red showing how the yarn is looped in a single row. Notice how the yarn extends to the row above and below. During knitting, the knit (seen as a v-shaped form in the figure) builds a ridge whereas the purl (seen as the rounded shapes between the v's) forms a valley. When the ridges and valleys are put next to each other, the fabric can contract meaning that given the same amount of stitches on a row, the finished ribbed fabric will be narrower compared to the knit. The height of the fabric is still the same. When comparing the visual effect of knit and ribbed, the knit appears smoother than the ribbed.

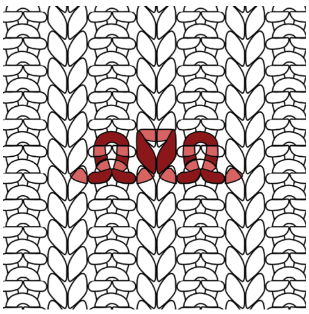


Figure 63: Ribbed Fabric

Appendix J: ICT Devices; Possibilities and Challenges

Three different ways of having access to ICT devices has been recognized in the project. The different access points give different degrees of access to the devices on part of the users. Under the different headings, the characteristics of the different usages of the ICT devices are outlined using optimal conditions. By using optimal conditions for all three ICT devices, I believe that the comparison between the three suggestions is the most fair, and show the full potential of the devices. For all three methods of access, there are some conditions and assumptions that need to be fulfilled, but they are fulfilled in different ways by the devices.

- The ICT Device is electronic and supplied by an energy source. The carried devices are run on batteries.
  - Electronics and plastics are often susceptible to heat and sparks
  - Electronics are sensitive to humidity and water
  - Electronics are sensitive to chemicals
  - Batteries need to be replaced
- The ICT devices must allow sanitation
- Each user should have immediate access to the ICT device when it is needed
- The ICT Device must not impair the ability to work on part of the user
- The ICT Device will likely take the shape of a screen with information shown
- The ICT Device will likely allow information to be broadcasted as well as searched for
- The ICT Device must withstand the factory environment 1 and 2
- The ICT Device must withstand bumps and rough handling
- The ICT Device should allow all users
- The carried devices use wireless network connection
- The stationary device use cable network connection
- If the ICT Device malfunctions or breaks down, the individual cannot resume work unless the device is fixed or exchanged.

The first access method, Device Access 1 (DA1), relies on the clothes themselves acting as an ICT Device. The technology can be completely integrated into the cloth, effectively having the fabric acting as a screen which is interacted with. Examples of how this could be manifested is through LEDs in the fabric or OLED screens. This means completely integrated electronics. The devices cannot be removed during wash or usage. Batteries can be fully integrated, or be removable during wash. This means both a risk to the electronics due to the water and detergents, but also that they are roughly handled both by washers and by the washing/drying machines. Both washing and drying means spinning of the clothes against the machine walls, extreme changes in temperature, and a high degree of water and steam. Ironing or pressing of the clothes adds extra load on the devices. If the device malfunctions, the entire garment needs to be sent to the repairer, or be replaced before the work continues.

In order for weekly clothes changes, each user needs at the very least 2 pairs of trousers, 11 top inner layers, and 7 top outer layers. There are three possible placements of the cognitive on the clothes; on the trousers, on the top inner layers or the top outer layers. The placement of the device should preferably be such that the device can be viewed without both hands needed to manipulate it. The number of cognitive support devices each operator needs, if they are fully integrated into the clothes is as follows:

Trousers: two devices, one in each pair of trousers. Devices placed so that they are visible on the trousers leg to the user at all time, and not being obscured by other equipment or clothes layer.

Top outer layer and top inner layer: 11+7 devices, one in each piece of top clothing. As the outer layer needs be allowed to be removed for increased control over the operators own temperature climate, and the outer layer obscuring the inner layer from view, the devices needs to be placed on both outer and inner layer of the clothing. Placement of the device could be on the wrist for easy access for the top outer layer, and on the top inner layer, on the front of the garment or on the shoulder.

The second access method, Device Access 2 (DA2) has ICT devices which are compatible with the clothes, but that are removable. Examples of this type of device are smart phones and RFID/Barcode readers. The devices can be compatible either by the clothes permitting the devices to be fastened onto the clothes by elastic bands or clips, or by the clothes being adapted to carrying the devices by providing pockets, zippers, buttons and other fasteners onto which the device can be placed or attached. The device can easily be exchanged on malfunction and work can quickly resume.

If instead the device was separate but compatible to use with the work clothes, only one device would be needed per user. Exactly the same technology used for the cognitive device could be used in a bracelet, or allow for individual placement of the device depending on how the user wants to place it. The device could for example be placed on the belt of the user, around the wrist, or where the user wishes them to be.

The third access method, Device Access 3 (DA3) has ICT devices which are placed outside of the users. The placement can be in the form of consoles or near the work stations. As the devices are not carried by the users, they can be placed such that the risk of bumps is minimal. They can also be placed so that the likelihood of sparks, chemicals and oils reaching the device is small. Another effect of them being stationary is the decreased risk of losing connection to the system. The device likely takes longer time to replace as it is stationary and integrated into the building for network connection and electricity.

The demands put on the ICT devices vary per factory and on the placement of the ICT device. DA1 needs to withstand much more than both DA2 and DA3 simply because they are built into the clothes. Even if they were able to withstand the extra load of washing and drying, the breakdown of either garment or device still means that both garment and device needs to be replaced, which is not the case in DA2 and DA3.

Table 10. Fulfillment of the demands and assumptions put on the ICT Devices. Non-fulfillment is marked " ", partial fulfillment with "(×)", complete fulfillment with an "×" unknown result with "?

	Demand			
Washing	Having to withstand washing	×		
	Having to withstand drying	×		
	Having to withstand ironing or pressing	×		
	Having to withstand sanitization	×	×	×
	Device sanitized separatelly		×	×
Access to device	Constant access to the device	×	×	(×)
	Immediate access to the device near the work stations			
	Possibility for user to change position of device		×	?
Power	Device powered by batteries	×	×	
	Device powered the electricity grid			×
Network Connection	Wireless	×	×	
	Cable			×
Effect of malfunction	The device can quickly be replaced and the work resume	(×)	×	?
	If the device cannot be repaired, the work wear needs to be replaced	×		×
Recirculation	Technological and organic life cycle mixed in product	×		
	Technological and organic life cycle strenuously separated	×		
	Technological and organic objects easily separated		×	×
Number of devices	Number of devices per person: less than 1			×
	Number of devices per person: 1		×	
	Number of devices per person: more than 1	×		
Usefulness for users	Large screen easily legible	(×)	(×)	×
	Sufficiently large buttons to interact with device	×	×	×
	Sufficiently large buttons to interact with device when wearing gloves			×
Factory 1	Having to withstand bumps		×	×
Factory 2	Having to withstand weld sparks		(×)	×
	Having to withstand oils		(×)	×
	Having to withstand chemicals		(×)	×
	Having to withstand bumps		(×)	×
	Having to withstand weight put on device by bending and crawling	×	(×)	

There are many similarities between DA1 and DA2, and between DA2 and DA3. There are few similarities between DA1 and DA3 which DA2 does not share. Therefore DA1 and DA2 will be compared with each other, and DA2 and DA3 will be compared to each other.

Comparison between DA1 and DA2:

- The technical and organic life cycles can be kept separate in DA2, allowing easier recycling, and minimizing the risk of contamination of each life cycle.
- The laundry does not have to take sensitive electronics into consideration in DA2 when deciding on laundry method, meaning greater freedom in deciding the best laundry method for each type of contamination and degree of dirt.
- Fewer devices per person is needed using DA2 than DA1 meaning a decrease in cost for the company, and fewer natural resources used up on Earth, which also means less recycling neededs
- Each user could decide their own placement of DA2 whereas it is pre-decided using DA1, allowing for some personal freedom, and greater comfort for each user

Comparison between DA2 and DA3:

- DA3 has a greater potential to be protected from hazards in the environment than DA2, as it is stationary. Being stationary allows a greater size and a greater weight compared to devices aimed at being brought along by the user.
- DA2 gives the user a greater degree of freedom of usage as the devices are carried by the user, i.e. the users can themselves choose where and how the ICT device should be used.
- DA3 has the potential to be used by more users than DA2. If the device does not need to be used at all times, each user can use it when needed, and otherwise let other users use it.
- The recycling and sanitation of DA2 and DA3 is similar, however greater care might be taken of DA2 as it is perceived as more personal.

As this thesis project is aimed at finding the work wear of 2020, it is yet too early to say exactly in what shape or form that device should have. To put out exact measurements today for placements or pocket sizes is arrogant as those things will change over time. What can be said however is that the work wear should allow ICT devices to be carried with the user, or allow users to use stationary ICT devices. The front pockets of the trousers should be made such that a ICT device can be carried with the user and be easily accessible. As for the top layers, identified placements for ICT devices are on the sleeves where either pockets could be placed, or place made for a bracelet holding the ICT device. The last two placements are somewhat contradictory; a pocket allows for placing of DA2, but is in the way for DA1 which is integrated into the fabric of the clothes.