University of Alberta

Design and Evaluation of Workwear for Protection
Against Steam and Hot Water

by

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ABSTRACT

People working in the western Canadian oil industry are often exposed to adverse working conditions, extreme environments and hazardous equipment. With a focus on functional clothing design, this study aimed at investigating, specifying and developing improved garment systems for workers in the oil industry. A seven-step functional apparel design process was applied as the conceptual framework and a multi-method approach was taken including analysis of photographic documentation, focus group research, precedent garment observations, interviews and wear trials. Full-scale fabric prototypes were developed by a local manufacturer and evaluated with oil industry workers, upon which recommendations were also provided. This study adds to existing literature within the design studies academy in the specialized area of functional apparel design while providing recommendations for practical merits for oil industry workers and safety supervisors, protective clothing manufacturers and standards development (*e.g.*, CGSB, ASTM).

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CHAPTER 1 INTRODUCTION

Background

Located in the north of Canada, the province of Alberta has long been known for its petroleum-centered industry producing conventional crude oil, bitumen from oil sands and condensate from natural gas. In fact, the Canadian oil sands bare the second largest hydrocarbon accumulation on earth with bitumen reserves of 1.7 trillion barrels, of which the three major areas are all in Alberta (Gingras & Rokosh, 2004; Leckie, 2008). Taking advantage of the abundant natural resources, the oil industry prospered in western Canada and greatly sustained and expanded the local economy across decades. According to Alberta Employment and Immigration (2012), in 2011 the mining and oil and gas extraction industry generated a total 19.2% of Alberta's Gross Domestic Product, while accounted for 7.2% employment rate within the province only, compared with that of 1.95% among all other industries in Canada (Statistics Canada, 2011). Over the past ten years, the number of people working in this industry surged from 96,100 in 2001 to 151,100 in 2011, 78.2% of whom are aged between 25-54 years (Alberta Employment and Immigration, 2012).

Although employment in the western Canadian oil industry seems to be positive and attractive, workers often face adverse working conditions, risky tasks and hazardous equipment. Many of these adversities, risks and hazards are common in routine work such as physical impact from machinery and falling objects, toxic chemicals, gases and combustible dust exposure, radiant heat and flash fire exposure from machinery and pipelines. However, other perils pertaining to this industry are a consequence of the extreme work environment, for instance, are often the result of winter conditions where temperatures can drop below -40°C with humidity close to zero. Flash fire has been the major concern within the oil industry due to high chances of gas leak from wellhead sites, compressor stations and refineries *etc.,* ignition of which may cause injuries and even death due to the impact of overpressure and skin burns from fire engulfment (Crown & Dale, 2005). More recently, statistics indicated that more than half of petroleum production in Alberta attributed to upgraded bitumen extraction from oil sands (National Energy Board, 2012), resulting in more extensive use of steam and hot water in oilfields and plants towards the production of heavy oil. Steam used is up to 375ºC and under extreme pressures of up to 13,500kPa; and industrial hot water is under significantly less pressure but is 80-90ºC, which is well above temperatures that result in partial thickness burns (Crown & Dale, 2005; Strickfaden *et al.*, 2010). Steam and hot water are part of routine work accomplished by workers, for example, steam and hot water runs through pipelines and contains in boiling tanks, and most of them are controlled by high pressured-valves located in different positions throughout the plants.

With the inherent adversities, risks and hazards within the oil industry it is crucial to foster a safety culture and awareness to ensure workers' safety within the workforce. One important factor being recognized is the use of personal protective equipment (PPE) as the last defense line. It is the closest objects termed the "portable environment" (Watkins, 1995) that workers interact with and will affect efficiency in their daily task performances. Currently popular items for oil industry PPE extend to and encompass gas detectors, wireless radios, helmets, protective goggles, gloves, boots, garments and more. Since the 1980s the oil and gas industry in North America begun to develop specific requirements and guidelines for PPE in their sectors, specifically to protect against flash fires (Crown & Dale, 2005). Standards have been developed for protective clothing and predominantly focus on the properties of fabrics, thermal protective performance of garments, and the testing methods used towards better understanding how a flash fire affects fabrics and garments (Canadian Petroleum Association, 1991; Canadian General Standard Board, 2000a, 2000b). Typical garments worn in the oil industry are overalls, coveralls, jackets and parkas that utilize flame resistant (FR) treated fibres, threads and/or fabric. These garments, fabrics and fibres are required to demonstrate certain properties regarding ignition, shrinkage, energy absorption *etc.* to protect wearers from severe burns and allow for several seconds to escape in an emergency.

Unfortunately, in some circumstances workers' garments failed to protect them; and in the oil industry the number of steam and hot water burn injuries have increased over the past decade, which indicates inadequate protection from these hazards. This however cannot only be purely due to the failure of fabric, and also may be due to broken seams, seam perforation or misuse of garments (*e.g.*, wear, laundering). Some of the things under-addressed in earlier requirements such as standards are that the integral design and use of the clothing system as a whole within the specific context. It is clear that many interrelated factors beyond fabric properties such as garment components, seam finishes, garment assembly contribute to the overall protection of the garment (Tan *et al.*, 1998). In addition, although thermally instrumented mannequins are widely used for research and commercial purposes to test an entire garment's thermal protective performance, little emphasis has been given to how real life use-scenarios and user activities can influence the garment performance and vice versa.

Initiated by local oil firms and an industry consortium, researchers at the University of Alberta embarked on an investigation to explore the working environment and workers' activities in western Canadian oil industry (Strickfaden *et al.*, 2010). A multi-method approach was taken including field observation, on-site interviews, photographing and videotaping to identify workers' routine tasks and to gain insights into workers' perception on current workwear. Although a variety of tasks were examined, the focus was on those involving steam and/or hot water exposure. Workers were observed while wearing additional garment and protective gloves when working on tasks that expose them to steam and hot water. During interviews with workers, they shared incidental accounts of steam and/or hot water exposure and expressed concerns about garment protection, fit and mobility in general. Six typical tasks that expose workers to steam and/or hot water were identified including:

- *Steam quality sampling*
- *Cleaning filters and sludge traps*
- *Loading and unloading hot water (connecting and disconnecting hoses) from boiler tank to truck and from truck to oil storage tanks*
- *Opening traps and high pressure steam valves*
- *Working very close to hot valves and pipes*
- *Spraying steam onto wellheads and valves*

A further investigation (Yu *et al.*, 2012b) was conducted where an in-depth analysis of photographs taken during research into these tasks was completed. Specifically, workers' body movements while on-the-job, their interactions within their work environments, and the details of how garments were worn were analyzed. The photo analysis revealed that sloppy use of the protective clothing and inadequate garment interfaces when workers performed dynamic motions and tasks exposing body parts especially the wrists, ankles, neck and lower face were significant. The potential concern for exposure to flash fire, steam and hot water hazards could be prevented or diminished by providing better designs and by recommending the correct use of PPE.

Statement of Problem

Current PPE used in the oil industry is designed to protect against hazards such as flash fire and radiant thermal exposures. However, due to an increase in workplace injuries reported in the last five years, including incidents of steam and hot water burns, further protection for workers is considered a priority. A great deal of research has been conducted on protective clothing and other PPE for firefighters, military personnel, and sports in terms of thermal comfort and protection (Bye & Hakala, 2005; Crown & Capjack, 2005; Smith *et al.*, 1997; Tan *et al.*, 1998), while little attention has been given to the garments worn in the oil industry addressing protection against steam and hot water. With the growing presence of workers in this industry and more frequent use of steam and hot water, the awareness was raised to design better garments with improved protection, comfort and fit for workers when performing tasks that involved steam and/or hot water.

The purpose of the research herein is to employ the functional apparel design process to design workwear for oil industry workers to protect against steam and hot water burns. A human ecological perspective is incorporated where workers' needs and expectations are at the center of the design process. A multiple method approach is taken including focus group interviews, observations, questionnaires and wear trials are used to gain a better understanding of workers relationships with their PPE, particularly their garments. Assessments of workers' environments, tasks and activities performed, and analysis of precedent designs available on the market are essential to developing the optimal design solution. In this way, a people-centred approach towards creating an improved garment system is taken.

Justification

The study highlighted in this thesis is work that builds on a larger project that aims to investigate and develop improved textiles, standards and garment systems for oil industry workers exposed to steam and hot water. With a focus on functional apparel design, the study herein addresses the process of garment design including wear trials for prototype evaluation. Although the textile and material development is out of the scope of this study, possible fabric options were selected and tested by a group of textile experts working on the broader project. To achieve the desired level of protection and comfort a semi-permeable fabric was recommended for the workwear (Murtaza, 2012). The goal was to develop a design that provided higher levels of protection compared with available FR garments. In addition, a comfortable and aesthetically appealing garment was also deemed important. To accomplish these goals a variety of methods are used during the design process; however, as people's perceptions are subjective these needs to be approached in a particular way.

Comfort and fit are highly subjective perceptions and to explore these a variety of methods can be used. Some of the ideal ways to explore subjective perceptions are to conduct field research such as field observations, field trials and through ergonomic design that emphasizes the compatibility of product-human-environment and creates user-friendly products (Akbar-Khanzadeh *et al.*, 1995). However, existing literature shows that the majority of researchers prefer controlled environments, large number of participants and/or administration of survey or questionnaire when conducting garment trials (DeJonge *et al.*, 1983; Huck, 1991; Huck & Kim, 1997; Nielsen, 1986). The study herein, in contrast, recruits a smaller number of participants and dedicates more time to interaction with individuals to delve into their perceptions and attitudes around use of the new design in a real-life working environment and use-scenario. In addition, statistics indicate that male workers traditionally dominate the oil industry at 77% of total employment in 2011 (Alberta Employment and Immigration, 2012). Therefore, despite unisex styles being popular in new designs, male workers were recruited as participants for this study for the sake of consistency.

Significance

The study has significance on several general levels and four specific ones (see Figure 1-1). From a human ecological perspective it applies the functional apparel design process using a user-centred approach, it also presents possible design solutions, prototypes and design recommendations for practical merits for oil industry workers and PPE manufacturers. In addition, the wear trial evaluation allows participants, who are the end-users of the workwear, to be intensely involved in the design process and contribute to the design. Through various lenses of examining the use-scenarios and user activities, it is possible to get a deeper understanding of the design case and generate the optimal design that can provide better protection that is more acceptable to oil industry workers.

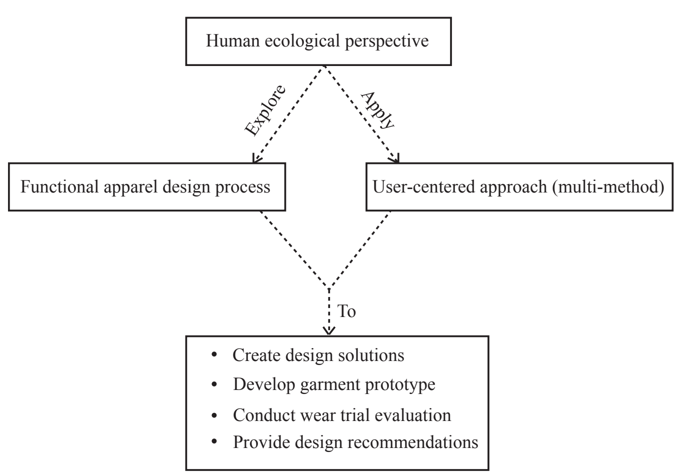


Figure 1-1 Significance of the study

Objectives

The objectives of this research are as follows:

1. To review reports on steam and hot water related injuries in the Canadian oil industry, and analyze how the protective clothing was involved and performed.
2. To apply the functional design process to create a mock-up and prototype for protection against steam and hot water with a local manufacturer, utilizing fabrics that were selected and recommended for workwear.
3. To evaluate prototypes with oil workers for functional fit, mobility, subjective comfort and acceptability through wear trials.
4. To provide recommendations for improved garment designs for protection against steam and hot water.

Summary

This chapter has outlined the background of the study herein and addresses some of the existing problems and the increasing demand for improved protective clothing in the oil industry. To achieve the objectives established a human ecological perspective is taken towards the design of a garment system that uses a user-centred design process and indicates great significances. In order to obtain a better understanding of the design problem, it is necessary to review related literature presented in Chapter 2.

CHAPTER 2 LITERATURE REVIEW

Based on the purpose and scope of this research this chapter reviews and addresses three main aspects of literature: 1) steam and hot water hazards, 2) functional fit and mobility in clothing design, 3) comfort and its role in protective clothing design. This literature review provides a background towards understanding work hazards and issues related to garment design that create a foundation for the research and design problem explored herein.

Steam and Hot Water Hazards

Assessment and prevention of environmental, equipment and material-related hazards in different workplaces have been taken care of at different levels including promoting safety culture, engineering control (*e.g.*, use of engineered equipment to reduce/eliminate hazardous exposure), administrative control (*e.g.*, safe work practices, supervision, on-site inspection), and PPE as the last line of defense for protection against specific hazards (OWIIPP, 2008; Yu *et al.*, 2012b). To identify and assess the steam and hot water hazards in the oil industry, background knowledge in occupational burn injuries is necessary.

Occupational burn injuries

Burn injuries are a typical occupational injury that can cause long-lasting physical, physiological and psychological scars to the sustainer or in some cases death, thus being a worldwide public health and safety concern (Lyngdorf, 1987; Mandelcorn, *et al.*, 2003; Song & Chua, 2005). The most common burns are from thermal, chemical, electrical and UV radiation hazards with elevation of the skin tissue temperature higher than 44°C within sufficient time of exposure; and when the temperature surpasses 72°C the epidermis and dermis will suffer from complete destruction virtually instantaneously (Stoll & Chianta, 1969). Based on different levels of damage and involvement of skin layers, burns are generally classified on a scale of first to sixth degrees (OWIIPP, 2008). For instance, water above 66°C can cause second-degree burns within three seconds, and third degree burns after six-second exposure, while the industrial hot water is up to 80-90°C (Fennel, 2009). A description of types of burn injuries is summarized in Table 2-1.

Table 2-1 Descriptions of types of burn injuries (adapted from OWIIPP, 2008)

Degree	**Affected Layer of Skin**	**Symptoms**	**Healing**
First-degree	Epidermal	Redness, swelling, white patches at site of injury	10 days with little scarring
Second-degree: superficial	Epidermal and upper portion of dermal layer	Red, moist, may blister, skin may peel; minimal nerve damage	If not infected, heals in 10 days; minimal nerve damage
Second-degree: Deep	Epidermal and dermal	Like second-degree: superficial but whiter appearance and less pain due to nerve damage	If not infected heals in 10 days; more nerve damage
Third-degree	Epidermal, dermal and subcutaneous tissue	Hard, leather-like scabs, purple fluid and no sensation or pain at burn site	Usually involves surgery to aid healing and prevent infection; can destroy blood vessels and nerves
Fourth-, fifth-, and sixth-degrees	Epidermal, dermal, subcutaneous and tissues under sub-cutaneous layer (*e.g.*, muscle, bone)		Surgery is required and long-term therapy; depending on degree, skin, muscle, or bone is permanently damaged or lost

According to a study of occupational burn characterization in Oregon from year 2001 to 2006 (Walters, 2009), the most common type of occupational burn was heat burn or scald, 31.9% of which resulting from fire, flame or smoke, and 63.3% from steam, vapors, or liquids. In comparison, work-related burn injury data of

Ontario, Canada from year 1998 to 2000, electrical burns counted for the highest of the burn mechanism (31%), followed by flame (22%) and scald (17%). Both the American and Canadian studies indicated a significantly higher ratio of burn injuries in male workers, with the results being disabling or even death.

Steam and hot water related hazards

In the western Canadian oil industry where steam and hot water are extensively used in bitumen extraction producing heavy oil, high-temperatures of up to 375°C with pressured heat sources are considered very hazardous (Strickfaden *et al.*, 2010; Yu *et al.*, 2012a; Yu *et al.*, 2012b). Some work activities involve steam and/or hot water (*e.g.*, steam sampling, operation on steam valves, connecting hoses to boiler tank) and require manipulation at a daily frequency, while some tasks without steam and/or hot water manipulation may still put workers under the risk of encountering steam accidents, as the steam can spread quickly in the ambient environment and is more dangerous when it is in a confined space inside the plant (*ibid*).

Controlled by the high-pressure steam valves, steam constrained within pipes can reach the pressure up to 13,500 kPa. In addition, when steam and/or hot water ruptures the pressure may drop when splashing out of the pipe while the hot condensate can reach above 100°C due to impurities, which, when high enough can cause steam burns on human skin (Crown & Dale, 2005). Also, Kirsner (1999a, 1999b) pointed out in his analyses of several steam accidents that hot steam leaked very quickly into a confined space and the resulting hot condensate had a higher heat transfer coefficient, making it a penetrating heat. When the steam percentage in the air exceeds the threshold of 12% by volume, the condensate temperature would rise above 45°C and could lead to skin burns (*ibid*).

However, unless the skin is uncovered or exposed, the energy of the heat transfers through layers of fibre and air gaps prior to reaching the human skin when protective clothing comes into play (Mah & Song, 2010). Complicated as the process is, Rossi *et al.* (2004) examined the effects of hot steam transferring through thermal protective clothing layers. They tested fabric layers covering on a moisture-releasing cylinder model to simulate human body, the results of which came in agreement with their bench-scale testing on flat fabric layer combinations (*ibid*). According to their results, steam coming from the environment and evaporating between the fabric layers both have possibilities to cause steam burns, against which impermeable fabrics provided better protection than semi-permeable ones, also influenced by fabrics' thermal insulation and thickness (*ibid*).

Industry injury reports

Recently, the government of Alberta documented a serious injury that occurred to an operator when using a steam jet to purge the fire heater coil. The outlet valve failed and the steam rupture propelled him into a truck's bumper nearby and he sustained a severe head injury and steam burn (Alberta Employment and Immigration, 2011). Moreover, the Canadian Petroleum Safety Council receives workplace injury reports that investigate incidents, after which safety alerts are sent to stakeholders on a regular basis. Some alerted examples of the steam and/or hot water burn incidents in the oil industry were given in Table 2-2 below.

In many circumstances, misconduct of the operating procedure, extreme environment and equipment failure were the major causes to the incidents; however, the failure of their workwear may also contribute to the consequences to some extent (Crown & Dale, 2005; Enform, 2004; 2006; 2011). On one hand, garments might fail if the fabrics are not steam and hot water resistant, or waterproof. On the other hand, the overall design, functional fit and seam finish of the garment ensemble could influence the task performance and level of protection (Yu *et al.*, 2012a).

Table 2-2 Incidents of steam and hot water burn injury in western oil Canadian industry

Date	Location	Incident Description	Injury Type
2004-05-20	Boiler shack	• Inside the boiler shack checking equipment • Valve failed releasing pressured steam between 148°C and 162°C • Engulfment and inhalation of steam	Fatality
2006-01-30	Wellsite	• Inside the rig substructure • Fell into steam-heated water	Second- and third-degree burns to the lower portions of both legs
Lost time (Issued in 2011)	Production tank	• Partially opened the valve • Valve broke and sprayed water at approximately 75°C • Slipped and fell leading to direct exposure	Burns to the lower body

Data source: Enform Safety Alert, retrieve from archive: http://www.enform.ca/safety_resources/safety_alerts/Safety_Alerts.aspx.

Anecdotal incidents of encountering steam and/or hot water exposure and resulting in partial burns have not been documented in the Enform archive, but had been mentioned by oil workers in focus group interviews in previous studies (Crown & Dale, 2005). On the whole, existing steam and hot water hazards and industry injury reports presented raise the increasing demand and awareness of improving current PPE and providing better protection.

Functional Fit and Mobility

Functional fit of clothing is an important issue regarding comfort and appearance. Five factors are involved in determining the fit of garments: 1) the grain of the fabric, 2) the construction lines, 3) the set of the garment, 4) the balance, and 5) the garment ease (Erwin *et al.*, 1979). Grain is the direction of yarns (lengthwise or crosswise) woven together to produce the fabric. The construction lines are created for desired shape of garment and should fit the body to be used in various positions. The set for a garment refers to the state of no wrinkles when the wearer stands still. The balance of a garment is achieved when it hangs away from the body identically for symmetrical design. The garment ease is usually the amount of extra fabric added beyond body measurement (Boorady, 2011). The majority of literature reviewed indicates that the concept of fit builds on a static standing position; whereas it is insufficient for functional clothing when certain range of body movement and dynamic motion is required, and factors such as heredity, gender, occupation and psychological factors will also need to be taken into consideration (Huck, 1988; Watkins, 1995; Ashdown, 2010; Boorady, 2011).

In a study to design protective coveralls, van Schoor (1989) introduces and defines the concept of "functional fit" by incorporating two factors: the body dimensions of the wearer in anatomical positions and the amount of ease necessary to perform the required movement and work activities. Through body measurements and assessments of the range of body movement required in the tasks, the proper amount of ease and its locations on the garment can then be determined to achieve optimal functional fit.

Ease for functional fit

Ease refers to the added dimensions beyond the actual measurement of human body on a pattern design that offers unoccupied space to accommodate human movement and ventilation (Ashdown, 1995; Adams & Keyserling, 1995; Huck *et al.*, 1997). Not only does the amount of ease matter, the locations of ease on the garment also affect fit in many ways. For example, the underarm and crotch areas are two locations that typically require extra ease for movements like reaching, climbing, squatting *etc.*; while the neck and wrist areas may need limited ease for proper closure and protection (Huck, 1991; Huck *et al.*, 1997; Watkins, 1995; Yu *et al.*, 2012a). According to the different amount and purposes of ease, three major types are categorized: wearing ease, style ease and functional ease (Boorady, 2011).

Wearing ease

Wearing ease is the minimum amount of ease on the garment that allows involuntary movement such as breathing or sitting (Watkins, 2010). Usually in a sizing system the wearing ease is standardized, and bigger for the outer-layer garment than underneath layers. This kind of ease is included in the basic block pattern design, for instance, in a woven garment block the wearing ease typically exceeds about 4-8cm of the bust/chest, waist and hip circumference measurements (Anand, 2011).

Style ease

Depending on the styles of the garments, different amounts of ease can be incorporated to achieve the effects of loose fitting, semi-fitted and fitted (van Schoor, 1989; Anand, 2011). Generally speaking, loose-fitting garments provide more ease, higher level of mobility and wider accommodation to potential wearers. However, for protective clothing too much ease especially when not controlled will make the garment bulky and inflexible, and can lower the level of protection as extra fabric can result in accidents such as being caught in the machinery and diminishing dexterity in fine manipulation (Huck, 1988; Huck *et al.*, 1997b; Coca *et al.*, 2010; Tremblay *et al.*, 1996). While if too fitted, strain and friction between layers may occur, and the restricted movement can affect dynamic movements and work performance (Watkins, 1995). A dilemma, therefore, exists between fitting a larger population (*e.g.*, different sizes, shapes), freedom of movement while at the same time providing a high level of fit and protection. As a consequence, adjustability and flexibility are expected and functional ease is one of the options.

Functional ease

In terms of functional clothing it is essential to fulfill function and protection. However, some restrictions may undermine or limit the fit of the garment: 1) heavy and stiff fabric not being able to stretch, 2) full coverage required in one-piece suits with no waist seam, and 3) multiple layers involved in the clothing system (Anand, 2011; Ashdown, 2010; Watkins, 1995).

The study herein employs the concept of functional ease to accommodate the challenge of producing a garment system that is functional and protective. One way of accomplishing this is adding extra stretch panels to the areas where movement is required such as reaching, climbing or bending (Watkins, 1995). For instance, underarm gussets and a crotch panel would provide ease without too much strain for workers such as firefighters (much like those working in the oil industry) who would stretch arms frequently and perform tasks in climbing or crawling positions (Coca *et al.*, 2010). Also, flexible adjustments are desirable to create "custom fit" for ease as well as safety (Anand, 2011). Custom fit could be created in terms of accessories such as drawstring, elastic, buckles can be added to the waist at the back or side seam to control the fullness and provide flexibility. Another example of functional ease is to use a pant hem and cuff with some form of adjustable closure (*e.g.*, tab with snap, hook and loop).

Mobility in garment fitting

As the most intimate and portable environment to the human body, clothing is highly interactive with body postures and movements. It has been tested and described by Havenith *et al.* (1990) that movement poses significant effects on clothing insulation. Also, from a functional design perspective body movements are intrinsically necessary for wearers to perform required tasks without being impeded by the clothing (Watkins, 1995). Usually, the level of mobility via certain range of body movements are a relative concept dependent on the purpose of the garment, and determined by the interactions of fabrics, garment design, sizing and garment fitting (Ashdown, 2008; van Schoor, 1989).

Body movements

To obtain an understanding of a body's dynamic action and function is essential to design and evaluate clothing that conforms to dynamic body motions (Ashdown, 2010; Huck, 1988). Movements start with a change in position to the anatomical position, which refers to the relaxed standing position with arms at sides and palms facing out (Watkins, 1995). According to kinesiology, body movement is classified into three planes: the sagittal plane (front and back), the frontal plane (left and right) and the transverse plane (top and bottom); additionally, motions are specifically described as flexion, extension, adduction, abduction, medial rotation, lateral rotation, pronation and supination (Adams & Keyserling, 1995; Huck, 1988).

Generally speaking, anterior movement in the frontal plane has a greater range than the posterior ones; and at certain joints the range of movement is more extensive in one or more directions. For example, the shoulder joint can perform flexion, extension and abduction, thus critical in clothing fit as many garments suspend from the shoulder, yet constant movement is required around this area in daily life and work (Ashdown, 2010).

Providing and improving mobility

To provide adequate mobility in clothing, common approaches include using fabric inherent stretch, adding garment ease and combination of garment design and construction (Watkins, 1995). In a study to design and evaluate flightsuits for airforce personnel, Tan *et al.* (1998) reviewed a double-knit fabric used in the 1970s in U.S. army, which was more flexible and soft but tended to snag. This fabric proved to be impractical to improve mobility. Usually woven fabrics are applied in workwear or protective clothing to achieve better stability and durability, whereas for protection and functional purposes, they often comprise several layers thus making the garment heavy, bulky and inflexible (Huck, 1988; 1991; Watkins, 1995; Coca *et al.*, 2008; 2010).

Since limited stretch is offered by the most woven fabrics, garment ease and design features are usually emphasized and incorporated to accommodate the need for movement when designing protective clothing. For example, in workwear pleats are often used on the back of garments to provide ease for extensive shoulder and arm movement (Watkins, 1995); additional functional ease can also be integrated through stretch panels, adjustable fullness and other design details as reviewed in the previous section. Another way to create better mobility is to shape the cut of the garment to the natural contour of the body. Curved elbow and knee designs are commonly seen in firefighter gear to conform to curved limbs in a relaxed position, as well as for glove design where curved fingers are used to reduce the bulk and strain of stiff fabrics in a bending position and maintain the dexterity when performing tasks (Anand, 2010; Tremblay *et al.*, 1996).

Moreover, it is also pointed out that using separate garments (*e.g.*, jackets and pants) instead of a one-piece suit (*e.g.*, coveralls) can improve the level of mobility unless full coverage and seal is a must (Anand, 2010; Ashdown, 2010; Watkins, 1995). According to Ashdown (2010), the one-piece coverall does not increase dimensions with body movement (*e.g.*, bending, squatting) and will cause discomfort and impede performance and restrict movement especially at the crotch, shoulder and neck. Rather, a two piece overall and coat is recommended for improved movement, and better fit in terms of different body shapes (*i.e.*, people can wear a large pants for bigger lower torso while wearing a medium top).

Achieving functional fit in garment design

The optimal way to achieve fit in garment design regardless of cost is customization, yet it is impractical in mass production (Huck & Kim, 1997; Ashdown, 2010). Although local PPE manufacturers in Alberta provide services to customize name badge, pocket and reflective tape placement *etc.*, typically no personal fitting, sizing or tailoring is available. In terms of protective clothing where design is function and protection-oriented, researchers and designers usually conduct anthropometric studies and movement analysis of end-users to achieve the optimal functional fit.

Body measurement

The study of body measurements in relation to designed things is called anthropometrics. Anthropometrics provides the basics for fitting a garment (Watkins, 1995) and also for how people fit with the built environment (Kroemer & Grandjean, 1997; Panero & Zelnik, 1979). For the purpose of the research herein, anthropometrics refers to the relationship between people and garments. For fitting a garment, general anthropometric data includes height, weight, body mass, body fat composition and more, as well as purposefully selected ones such as bust/chest girth, waist girth, hip girth, crotch length *etc.* (ASTM F1731-08, 2008). With detailed body measurements a custom-fit garment for a wearer can be created by adjusting lengths and circumferences specifically. These body measurements are also useful in developing a standardized sizing system to accommodate the major population (Laing *et al.*, 1999), of which most garment sizing systems that currently exists are based on.

Comprehensive anthropometric studies are time, money and labor intensive, and these depend on the purpose of the research whether an anthropometric study is necessary. In a study of protective gloves design and evaluation, Tremblay *et al.* (1996) conducted an anthropometric survey of 380 agricultural workers for specific hand measurements, as the population they were studying had very different hand sizes to non-agriculture working population. In comparison, smaller scale anthropometric studies can also be carried out to achieve the most appropriate fit. To eliminate the effect by sizing and fit problems in designing protective coveralls for grass fire fighting, Huck and Kim (1997) took body measurement of all of their participants (ten in total) and customized the coverall patterns for each individual. Although extensive anthropometric studies are difficult to realize in the marketplace, small-scale anthropometric studies provides a viable method at the laboratory level to achieve the appropriate fitting of protective clothing.

Movement analysis

Movement analysis is essential to understand and identify how people perform on-the-job tasks while wearing garments. Quantitative method of movement analysis measure a body's range-of-motion (ROM), which refers to the possible amount of movement at each joint (Huck, 1988; Bellingar & Slocum, 1993; Watkins, 1995). Typical instruments that are used for ROM measurement are a goniometer and the Leighton Flexometer®. Static ROM can be measured at one fixed position (Adams

& Keyserling, 1995; Huck *et al.*, 1997) and dynamic ROM usually contains a process to complete at least two positions in consistency to simulate a task (Coca *et al.*, 2010). This is often used when comparing the ROM and time consumption to complete a specific movement or task between wearing light clothing and protective ensembles.

To gain insights into the use-scenario and users' attitudes while performing tasks, qualitative methods of movement analysis can also be implemented such as lab or field observations, photographic analysis, questionnaires, surveys, interviews and more (Boorady, 2010; Rosenblad, 1985). Lab observation are useful because conditions (*e.g.*, temperature, humidity) can be determined or isolated and well-documented actions with exercise protocol can be given; however, lab observations do not illustrate accurate real-life situation meaning that field observation and on-site interviews are an alternate method for understanding use-scenarios and users' attitudes. Bye and Hakala (2005) conducted research to develop sailing garments for women in which they did visual analysis of photographic documentation of women sailing on the crew to determine the type and range of motion for each participant, and identified corresponding garment needs to achieve the required movement.

Overall, accurate body measurements and movement analysis are necessary to determine optimal fit, and through various techniques of pattern manipulation (*e.g.*, adding ease, stretch panels, contoured cut) it is possible to achieve the desired outcome.

Comfort in Protective Clothing

Although comfort is a fundamental need and ubiquitous in the human world, it is difficult to derive a definition that can quantify the status of being comfortable. Paradoxically, people find it easier to express negative feelings or discomfort such as prickle, itch, hot and cold (Slater, 1986). Fuzek and Ammons (1977) refer to comfort as the sensation of having a satisfied feeling of well being without unpleasantness perceived during ordinary human dynamic and adjustable assessment. When determining and measuring levels of comfort in terms of textile and clothing, three interacted aspects—physiological, physical, psychological—are important to be taken into consideration (Slater, 1985).

Physiological aspect of comfort

Physiological comfort is present when the human body maintains the thermal equilibrium at normal body temperature with the least amount of bodily regulation (Choudhury *et al.*, 2010). Different body components such as skin, blood vessels and heart help to regulate body temperature, and the process of energy metabolism (*e.g.*, muscle contraction, blood circulation, breathing), which enables people to be alive and function normally. In this way physiological comfort can be quantitatively monitored and assessed through thermoregulation, sweat loss, heart rate and energy cost (Haisman, 1977).

Physiological comfort of textiles and clothing

In terms of textile materials and garment ensembles, physiological comfort can be reduced or difficult to maintain when the fabrics applied in garments are not breathable and limited ventilation exists, due to its interference with skin respiratory mechanism and the heat dissipation from skin to the environment (Fennel, 2009; Choudhury *et al.*, 2010). Besides, tasks require different levels of work intensity also affect the physiological comfort. Cheung *et al.* (2010) indicate that physiological strain with firefighting tasks are highly demanding and strenuous, and such activities lead to high levels of thermal and cardiorespiratory strain especially when extra PPE is worn, lowering firefighters' work tolerance and sacrificing physiological comfort.

Turpin-Legendre and Meyer (2003) compared the physiological and subjective strain of workers wearing two types of coveralls for asbestos abatement tasks (one was disposable, the other was ventilated) at a moderate workload and at a heat stress level. Fewer differences are indicated by quantified physiological measurement, while subjective ratings of participants (*e.g.*, clothing comfort, cooling, robustness) for the ventilated coverall was much higher than the other. Turpin-Legendre and Meyer's study results indicate that subjective perception of comfort might be affected by other factors besides the body responses to environment and physical workload.

Physical aspect of comfort

Physical aspect of comfort looks at how people connect with objects, materials and environments of which physical properties such as heat transfer and moisture movement between human body and environment are measured. Yet, measurements of physical aspects are merely a prediction of performance, particularly when laboratory or simulation testing is used. It is therefore considered more appropriate to assess physical aspects of comfort through actual trials completed by end-users (Slater, 1986).

Physical comfort of textiles and clothing

When describing the properties of a textile material, the parameters to rate physical aspects of comfort are heat conductivity, water-vapor resistance, air-permeability, moisture regain and more (Fuzek & Ammons, 1977). Furthermore, characteristics such as softness, stiffness, handle and drape are determined by sensory touch by human body (*ibid*). In a study to evaluate the functional performance of running wear, Yao *et al.* (2009) classified the physical properties of clothing into five categories: 1) structural characteristics (*e.g.*, weight per unit area, thickness), 2) thermal properties (*e.g.*, thermal insulation, water vapor permeability), 3) protection properties (*e.g.*, protection from UV radiation), 4) hand properties (*e.g.*, stiffness, softness) and 5) biomechanical properties (*e.g.*, elastic capability).

Besides physical properties and perceivable characteristics of textile materials and clothing, environmental temperature, moisture and wind speed do also influence human perceptions of comfort, as it will affect the sweat dissipation of human body and heat/vapor transfer between human and clothing (Xu *et al.*, 2012) A study on operating room (OR) attire characterized selected thermal properties of fabrics used in the hospital OR, and found out that not only physical properties of the fabrics influenced thermal comfort of OR staff, different temperature and air flow velocity perceived in different areas in the OR, and various level of mobility in their tasks also contributed to their overall thermal comfort (*ibid*).

Psychological aspect of comfort

Closely related to symbolic values of people such as self-esteem and group membership, psychological comfort emphasizes individual idiosyncrasies and vastly varies from person to person, and culture to culture (Rosenblad, 1985). Regarding textiles and clothing, although in many situations the psychological comfort of end-users does not involve the textile product directly, it can be observed with indicators such as people's patterns of decision-making, the frequency of purchase, styles of dress, *etc.* (Slater, 1986).

Psychological comfort of textiles and clothing

A good design must be functional as well as aesthetically and culturally acceptable for wearers or it will be rejected on the grounds for appearance or other psychological factors leading to discomfort (Black *et al.*, 2005). Research has supported this statement in cases such as low acceptability of special-looking garment designed for disabled people, where they actually would like to look normal instead of being identified as different through their clothing (Rosenblad, 1985; Thorén, 1996). Also, the need for identification and recognition and awareness of safety also influences the psychological comfort. When designing a flightsuit for military personnel, Tan *et al.* (1996) conducted a focus group interview where it was noted that participants felt more comfortable in the military-looking colors and styles. DeJonge *et al.* (1983) developed a questionnaire to investigate relationships of attitudes, practices and preferences of protective clothing worn by people working with pesticide. In DeJonge's research it was determined that participants who held high beliefs in protection would be move attentive to using PPE for pesticide protection. Similar results were indicated in the research of Perkins *et al.* (1992) where farmers remarked a more secure feeling about using pesticides when wearing protective coveralls.

Psychological scaling

To understand the process of how comfort is perceived and assessed subjectively, psychological scaling is often used based on human perceptions (Hollies, 1977). Hollies *et al.* (1979) continued to explore human perception analysis to clothing comfort, utilizing various psychological scaling to rate the wearers' comfort in different microclimate and clothing. Huck *et al.* (1997) developed a more comprehensive method that built on Hollies *et al.*'s scaling system that evaluates the wear acceptability of coverall for grass fire fighting. Extensive factors are measured, such as general comfort, flexibility, ease to don or doff, freedom of movement of specific body parts. Dynamic movement exercise are also measured such as walking, jumping, bending. Each factor is evaluated by a 9-point scale, 9 representing "comfortable" or "easy to do", while 1 representing "uncomfortable" or "hard to do". Wear acceptability scales can also be developed including factors such as likes/dislikes in design features, handle, quality, with scales from most to least (Tan *et al.*, 1998).

Summary

Based on the injury reports and literature reviewed in this chapter, it is clear that steam and hot water hazards are dangerous yet there is no PPE that protects workers in the oil industry from this hazard. It is deemed that workwear, particularly garments are an important component of workers' PPE, and that these can be improved with better fit, higher level of mobility and enhanced comfort to provide better protection while accommodating wearers' task performance. Even so, the design of garments to protect from steam and hot water is under addressed and currently not explored in existing literature. What is found in current literature is information about how to design PPE that meets or exceeds the needs of workers wearing such garments. The study herein, including the design and evaluation of garments to protect from steam and hot water, is built upon the literature reviewed in this chapter. Furthermore, the functional apparel design process is purposefully employed towards developing this, which is described in the next chapter.

CHAPTER 3 DESIGN PROCESS AND METHODS

It is a widely held belief that modern design problems are more complicated than traditional ones that can be dealt with linear thinking or design-by-drawing. Unlike the conventional way of designing within the designers mind, evolving techniques and design methods strive to externalize the design process and make it more open and manageable at a systematic level (Jones, 1970; van Schoor, 1989).

Design process models

According to Jones (1970), the differences between design methods can be viewed from three perspectives: creativity, rationality and strategy-control over the design process. The creativity perspective describes designing as working within a "black box", out of which the creative solutions come from within with all possible input. In the "black box" method, the design process is described as unseen and mysterious. As for the perspective of rationality, each step in the process is explicable and rationalized by the designer, who is considered a "glass box". The characteristics of the "glass box" method are that objectives, variables and criteria are established at first, analysis is completed in advance and evaluation is extensively logical then experimental, and strategies are decided in a sequential order. Both the "black box" and "glass box" way of design are deemed to enhance the chances of seeking optimal design solutions; however, weaknesses are that unknown knowledge remains to the designer for which he or she cannot simply rely on intuitive ideas or computerized logical analysis. Hence the final perspective of strategy-control is introduced where designers use external criteria and results of partial research to find short cuts in unknown domains, and further control and evaluate the design. Creativity, rationality and strategy-control perspectives adequately describe the design process but do not give specific details about how to respond to complex design problems. For the purpose of this study, three additional models are looked to in order to aid in engaging in the design process. These are identified in the following sections.

Apparel design model

Lamb and Kallal (1992) proposed a conceptual framework or model for apparel design that could be applied to both fashion design and functional apparel design. Functional, expressive, and aesthetic (FEA) considerations are combined to create a consumer needs model as the core of the framework (see Figure 3-1).

Figure 3-1 FEA consumer needs model (Lamb & Kallal, 1992)

Interrelated in different ways for various end-users, these considerations were put together to assess the relative importance of the three factors. Based and centered on the FEA model, six steps are included in the design process: problem identification, preliminary ideas, design refinement, prototype development, evaluation and implementation. Before the final stage, each stage involves close interactions with the FEA model. For instance, at the design refinement stage, priorities are established based on FEA considerations where functional needs may predominate aesthetic needs or vice versa. In a more recent study, Bye and Hakala

(2005) successfully applied this design process to develop sailing apparel for women in which various techniques such as interviews and movement analysis are implemented to identify the end-users' functional, expressive and aesthetic needs. Other applications are also found in development of innovative smart clothing and apparel for elderly people and the disabled and more (McCann *et al.*, 2005; Strickfaden *et al.*, 2011; Watkins, 1995).

User-centred design process

In the FEA model, the concept of users' needs are already integrated and emphasized for apparel design, yet not extrinsically titled and extended into other product development. In fact before initiating any product design, it is of critical importance to understand the characteristics of those who will be the end-users of the product being designed, from which derived the user-centered design process (Jordan, 1998). The starting point of this design process model is the user and the use-scenario, in contrast to the conventional driving urge of a market need. Moreover, the user-centred design process concents on the use-value of the product rather than the exchange-value on the market (Rosenblad, 1985).

According to Rosenbald (1985), the user-centred design process is complementary to traditional design methods, and greatly benefits products for which functional properties are more important. She identified the use-demands as functional and symbolic values; of which similar concepts are reflected in the FEA model. Nine steps are included in the user-centred design process including: identification of problem area, problem analysis, formulation of objective, formulation of use-demands and use-situation, data processing and analysis, specification of the use-demands, development of ideas and technical solutions, evaluation and modification of prototype, evaluation of the final solution.

Functional apparel design process

The user-centred design process sheds light on the strategy-control product development process on a user-oriented basis, and combined with the FEA model, it becomes a better fit for a more holistic and comprehensive functional apparel design process that is suited to the human ecological perspective. However they are not formulated in a systematic and operational way that designers can easily follow at each step in the process. Orlando (1979) brought out her design process model, the "functional apparel design process" as an externalized, more holistic and self-organizing system approach to development of special purpose apparel.

This seven-step model presented a similar framework to the FEA and user-centred models including: a general request for the design, exploration of the design situation, perceiving the problem structure, development of design criteria and establishment of interaction matrix, prototype development and the final step, evaluation. At each step techniques are recommended and combined to achieve the partial objective. One of the important development in this process is the incorporation of design criteria and interaction matrix as an integrated step in the process. All the specifications in the design criteria are listed, ranked, and weighed in order to set priorities in garment design, upon which the interaction matrix of the design criteria can be established to demonstrate how those specifications might conflict with each other (Watkins, 1995). Van Schoor (1989) adapted Orlando's model and approach into a flow diagram with all techniques indicated at the corresponding step, making it more clear and operational. This adapted model was also applied in the research of Tan *et al.* (1998) and Huck *et al.* (1997) for the design of flightsuits and coveralls for grass fire fighting respectively.

The functional apparel design process presents a strong research focus, being descriptive and having a high level of interpretation. Although the final mass production stage is missing, in comparison to the complete product design process on the market (Stone, 2010), it provides a more holistic perspective and operational procedure for conducting a research-oriented design process with the possibility to refine designs and produce it towards a marketable standard.

Multi-method approach

According to Jordan (1998), two categories of methods are employed in the user-centred design process, namely non-empirical and empirical methods. Non-empirical methods do not involve participants, such as "task analysis" in which structured checks are made for predictions how difficult or easy a task would be; "expert appraisals" in which educated and trained experts make informed decisions and opinions about the product (pp.51). However, in many situations users participate highly and add significant value to the design process via empirical methods. Jordan (2000) identified several empirical methods that are frequently employed in the user-centred design process. Advantages and disadvantages of each method are also demonstrated based on time and effort relative to financial cost, size of sample population, skills and expertise required by designers and/or researchers, necessary facility and equipment, and more. A comparison of different empirical methods recommended by Jordan are summarized in Table 3-1.

Naturally, each method is effective and advantageous in different ways while conducting user-centered research. On the most part methods relate to the complexity of people, their use-scenario or environment and overall product interactions. The study herein aims towards developing workwear for protection

Table 3-1 Comparison of different empirical methods used in design process (based on Jordan, 1998)

Method	Description	Advantages	Disadvantages
Focus group	A group of people gathered together to discuss a particular issue	• Flexible for any stage in the design process • Issues can be raised to investigator in person • Stimulation among participants from one another	• Individual participant can be dominating
Field observation	Watching people in the environment in which they would normally experience a product	• Analysis of a product's usability under "natural" circumstances	• Ethical difficulties (e.g., observation without informing participants) • Affected by environment and context of use • Usually for end-product
Questionnaires	List of fixed-response and open-ended questions to users	• Cheap and effective • Large population • Versatile in any stage of the design process • Anonymous and free of investigator's effect	• Time-consuming in formulation of questions • Low response rate • No control whether sample is representative
Incident/ Experience diaries	Mini-questionnaires issued to users to make a note of their use experience	• Time and effort saving • Can be sent to as many users as necessary • No lab, video or audio facilities required	• No guarantee how users will complete it • User may lack technical vocabulary to accurately describe the experience
Interviews	The investigator complies a series of questions that are then pose directly to participants in a face-to-face situation or over the telephone	• Versatile in any stage of the design process • Less likelihood of misinterpreting • More interactive	• High administration costs • Effect of investigator's presence
Controlled experiments	Formally designed investigation with comparatively tight controls and balances	• Identify small effect undetectable to other methods • Useful for inferential tests for statistical significance	• Artificial environment • No guarantee for real-life use interaction and experience

against steam and hot water, exploration and identification of use-scenarios and user activities (*e.g.*, work tasks), and the users' attitudes and perceptions about the workwear in the oilfield and plant are essential to developing a new design. Therefore incorporation of various empirical methods is an effective way of better understanding the needs, wants and expectations of end users. As a consequence, a multi-method approach is employed for the study herein where a combination of selected empirical methods is performed at different stages of the design process. The process used herein is a combination of the aforementioned design process models and includes empirical methods including field observation, on-site interviews, photograph analysis, precedent research and field trials. For example, when characterizing the design problem, observation of the use-scenario and work environment takes place and for evaluation of the design concept (mock-up, prototype) focus group research and wear trials are completed.

Ethical issues

The multi-method approach used in the study herein is intensively user-centred and involves human participants (*e.g.*, oil industry workers, operators, safety supervisors, manufacturing facilities). According to the Research Ethic Board of University of Alberta, ethic approval is required for any human participation and involvement in research activities. For this study, approval was granted, which includes obtaining consent from all involved participants including an oil industry consortium and individual companies where field observation and wear trials take place. To keep participants' personal information confidential, all raw data and documentation is kept anonymous and accessible only within the research group. Photographs do not present any identifiable information such as faces and name badges. Presentation and publications in any forms resulting from the study does not disclose participants' identification. Upon ethic approval, the procedure of recruiting participants and conducting research proceeded.

Framework

Consistent with a human ecological approach, the functional apparel design process employed in the project herein allows the designer to form a more holistic view on the complexity of interactions between the use-scenario, garment and the user (Orlando, 1979; Watkins, 1995; Yu *et al.*, 2012b). At each step of the design process, input objectives are specifically established and a variety of techniques and methods are purposefully selected and combined as the multi-method approach (see Figure 3-2). Previous research accomplished in the broader project relating to protection from steam and hot water provided the context and background for the study herein. The work described in this thesis launches from a basic understanding of the use-scenario to develop an in-depth analysis of the design problem and continues towards the development and evaluation of a prorotype. The entire process is further elaborated in Figure 3-2.

Limitations and Delimitations

Limitations

The limitations of this study are linked to the various methods and stages of the design process. Although the functional apparel design process is comparatively holistic in nature, it is not possible to create a completely holistic process. Even so, a more comprehensive multi-method approach is taken in order to address some limitations. That is, the multi-method approach allows for triangulation of data by looking at the design problem from multiple points of view. The focus group interview and field observations are used to identify the user needs and use-scenario,

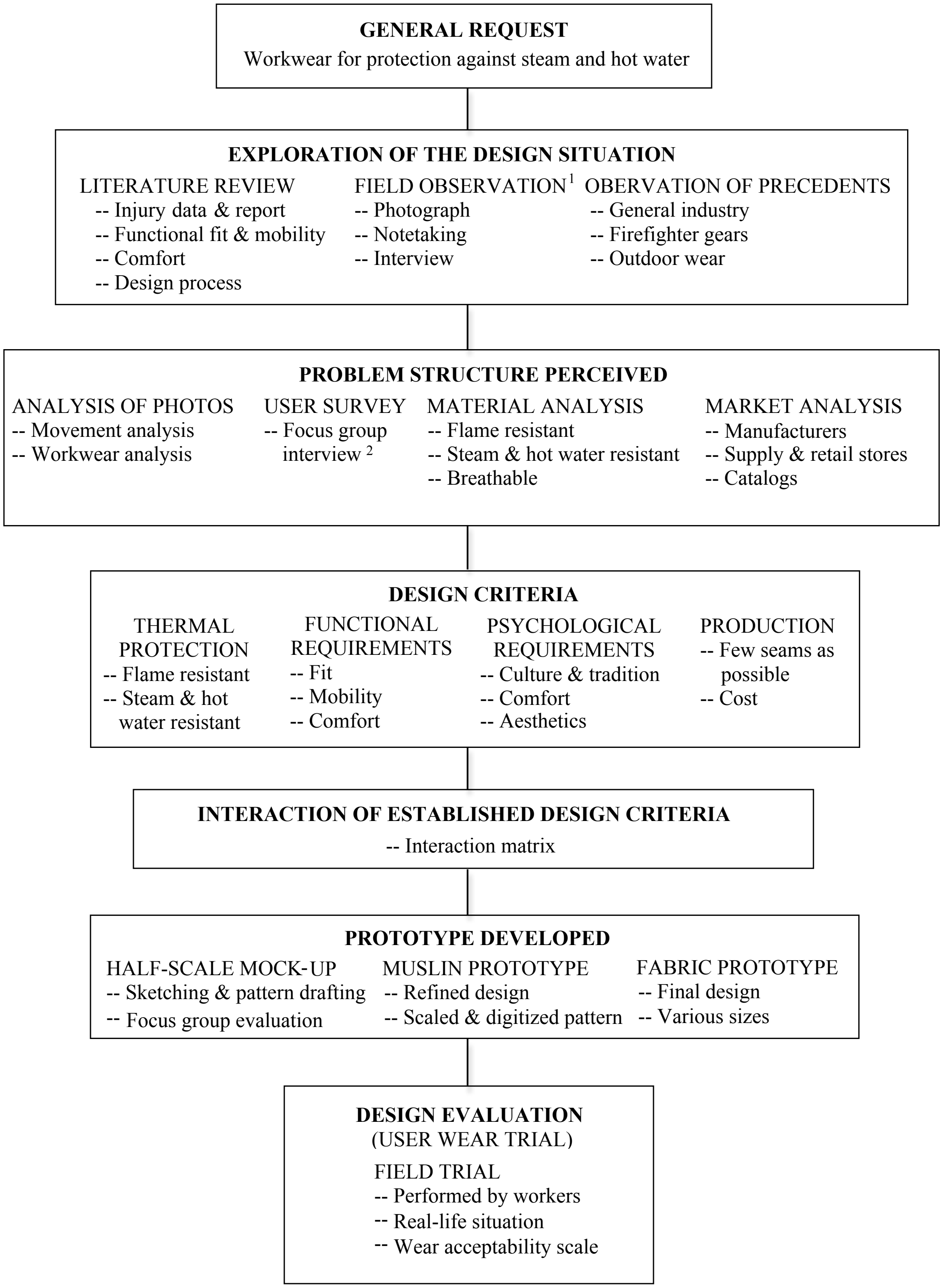


Figure 3-2 The functional apparel design process for workwear for protection against steam and hot water

while wear trial is used to understand how the new prototype addresses the workers' needs and satisfies or fails their expectations. In addition, analysis of photographs can be limited by number of photos taken, and the content captured on each of them. To compensate for photo content, more than one researcher took photos from different positions with continuous shooting. When doing precedent research, limitations are related to the number of garments that are available on the market that can be assessed. In regards to textile and seam testing it can be limited by the testing apparatus and the number of selected samples. In addition, the ideation of design sketches and mock-up development is affected by the researcher and limitation relates to her expertise and skills.

Furthermore, the limitation of this research related to the evaluation stage of the prototype is the small number of participants and the time and high cost of production needed in developing a garment system prototype. This was also relative to the number of prototypes that could be created and distributed to participants (one set was needed for each participant). The participants' individual working style and experiences, and attitudes and aesthetic standards may not be generalized to a broader group of end-users. Also, only males were recruited in this research, and admittedly female workers may have more variety in body shapes and more deviation in circumferential dimensions (*e.g.*, chest, waist, hip), therefore the evaluation results do not represent both genders.

Moreover, by the time of the prototype production, no innovative fabric design solutions had been achieved to the level of manufacture within this project, and only one similar fabric that met the protection requirements was available for prototype development. Therefore the complete garment system produced as a prototype is not a marketable product.

Delimitations

The research herein was conducted within western Canadian provinces and the workwear design may be limited to the western Canadian Oil industry. The material used to produce the garment was a combination of tri-laminate fabric, single-layered, knitted rib and Nomex® mesh, and only for the purpose for the prototype evaluation. Moreover, the wear trial in the field took place in the winter season and results may not be indicative towards other time periods.

Assumptions

1. The fabrics involved in this study are representative of what can be used for protective workwear and can be applied in the industry.
2. In the wear trial, the participants provided valid information regarding functional fit, mobility and comfort of the prototype.

Summary

This chapter has reviewed a generic design process and three different design process models that are combined towards the creation of this design project and the research used towards understanding end users and use-scenarios. Furthermore, a variety of empirical methods have been examined in order to engage in a more holistic design process that addresses the complexity of the design problem. Based on the inherent nature of functional apparel design and the objectives of this study, the seven-step functional apparel design process adapted from Orlando (1979) is applied to guide the development of the workwear for protection against steam and hot water. A multi-method approach with chosen empirical methods is taken throughout the design process to explore the complexities of design problem towards the prototype development and evaluation.

CHAPTER 4 CHARACTERIZATION OF THE DESIGN PROBLEM

The full scope of the design process shown in Figure 3-2 consists of seven steps, while the first to fifth steps focus mainly on exploring and identifying the design problem and are completed at an earlier stage. The last two steps are towards developing and evaluating the prototype, which happens later. Hence in this chapter the process of characterization of design problem is addressed separately.

General Request

To initiate the research, a general request was made by local oil companies in Alberta to develop improved material and garments for oil industry workers, especially for protection from steam and hot water. The preliminary objectives were to establish requirements and guidelines regarding protective textiles and materials. Due to the lack of appropriate garment design available on the market and the progress of the research on the broader project, an extended goal was raised which was the request for the development of a garment systems that incorporated a better design and improved textiles. As part of the broader project, the specific request for this study was identified as to develop “workwear for protection against steam and hot water”.

Exploration of the Design Situation

The second step was to explore the design situation, which was to enable the researcher to look at the design situation in a broader scope thoroughly without restricting any possibilities for the design solution. Extensive literature was investigated in general terms and specific aspects, and observation of field activities and precedent garments were also carried out for a visual and tangible understanding of the real design situation.

Literature review

At the onset, general terms such as protective and functional clothing and design process models were used for literature searchers. Protective and functional clothing for various occupations and end-user groups were reviewed regarding thermal, bio-chemical and physical impact protection and function. Techniques and approaches that were applied, emphasized and examined included for example, testing of fabric properties, interviews, observation, movement analysis, and wear trials. Design process for different design domains were included and compared to select the suitable ones. And many sources related to protective and functional clothing were also examined.

A more specific and structured literature review was conducted in parallel with the next phase "Problem Structure Perceived", which were previously presented in chapter 2. Industry injury data has been accessed through Canadian Petroleum Safety Council and Alberta Government database to identify specific hazards. The major part of the literature fell into the design aspects for which functional fit, mobility and comfort issues were thoroughly reviewed. A generic design process model and three specialized design process models for apparel design were also reviewed in order to determine the conceptual framework for conducting the research.

Field observation[1]

At this stage, a broader scope of the use-scenario was explored including the natural and constructed working environment as well as the workers' work activities, behaviors and attitudes. To achieve this, field observations with photographs and

[1] The field observation had been completed by other research team members before this study began. This research was published as Strickfaden *et al.* (2010).

note-taking and on-site interviews had been done prior to any design ideas were generated.

Four worksites (two plants, two in the oilfield) in two provinces in western Canada were visited and observed. Nearly five hundred photographs were taken in field/plant environment, and routine and specific tasks that involved steam and hot water. In the field researchers encountered extreme temperature of below -30°C when workers were observed to perform tasks of frequent transition from truck to working station, manipulation on steam valves, and spraying steam onto wellheads *etc.* in layers of protective gears. It was warmer inside the plant but the vision was reduced by complicated pipeline and equipment setting at different heights, with steam immersed in the atmosphere.

Different workwear is worn for various tasks such as coveralls, parkas and raincoat-like ensembles (*e.g.*, long coat with bib pants) were worn over typical PPE (*i.e.*, coveralls) for short time durations when steam and hot water was involved in the task. On-site interviews were carried out with 13 participants to gain insights into workers' perception about their current workwear and demands for improvement.

Observation of precedents

The process of incorporation of prior designs into a new design is called precedent-based design (Boling & Smith, 2008). With the use scenario and user demands in mind, it is necessary to investigate what is already available on the market for transferable design features and innovative ideas. In this phase of the design process, observations of garment precedents were carried out upon ethical approval in four local retail stores and a firefighter gear collection through contact with Faculty of Physical Education and Recreation at the University of Alberta (Yu *et al.*, 2011; Yu *et al.*, 2012b). An operational observation sheet was developed to collect data such as fibre content, garment measurement, closure detail (see Appendix A).

In total, fifteen garments were collected and documented because of unique or representative features and designed-in details that fit into the criteria for creation of a garment system that protects from steam and hot water, including nine industry workwear, four outdoor wear and two sets of firefighter gear. Over three hundred photographs were taken to document the garments, including front and back views, collar types, sleeve types, cuff designs, pockets, waist finishes, leg details, and closure systems. Further analyses were conducted with an emphasis on cuff design, adjustable features and closure systems, which would influence garment interfaces and functional fit. For example, one of the features of particular interest was the incorporation of the interior cuffs that are hidden inside the sleeve of firefighter coats that provided an added layer and are interfaced with gloves, which potentially protects the wrist and arm from steam or hot water flowing inside the sleeve.

Problem Structure Perceived

To further identify critical factors that are part of the design problem, several strategies were incorporated in the third phase including movement analysis of use-scenario and user activities, focus group to identify user needs and expectations, and textile analysis to determine fabric options. Assessment of movement was achieved through examining photographs taken during field research in the observational phase; and focus group interviews were conducted in different phases, a preliminary one to identify needs and a later one to evaluate design (see Chapter 4); moreover, fabrics were selected and tested by a group of textile researchers working on this project.

Analysis of photos

Analysis of photographs obtained from field observation was implemented to examine workers use of workwear when performing different tasks, and to visually analyze the range of movement in daily work. As defined in Chapter 1, two levels of garments are identified for the oil plant and field workers (see Table 4-1). Current garments that are worn for protection from steam and hot water protection observed in the photographs was coined as "slicker", which was a rainwear-like coat and bibbed pants made from an impermeable fabric to prevent moisture penetration. The "slicker" is seam-sealed and water proofed but has not demonstrated satisfactory performance in terms of hot steam protection nor is it thermally comfortable (Crown & Dale, 2005). One of the major problems with the "slicker" is that it becomes fragile in cold temperatures being vulnerable to cracking and tearing. In addition to this, workers had to take off their work boots in order to put the pants on, which exposed them to cold temperatures when standing outdoors or on a floor made of concrete.

Table 4-1 Descriptions of Level 1 and Level 2 garments in the oil industry

Garment	Examples	Wear situation	Wear duration	Observed use
Level 1	Cotton shirt, FR shirt, FR pants, FR coverall compatible with PPE such as steel-toed boots, goggles, hardhat	Daily work	Throughout work shift	• Cotton/FR Shirt and pants worn underneath FR coverall • Convertible collars not done up to cover neck • Cuff/Pant hem not properly fastened
Level 2	Slicker compatible with PPE such as steel-toed boots, goggles/face shields, ear muffs, hardhat	Steam and hot water exposure	Short time duration (e.g., 10 min)	• Long coat bottom gaping open when walking • Difficult in donning/doffing over the coverall

In addition to observing garment use and the use-scenario, various tasks that workers performed are observed in the field photographs. The workers' activities and movements ranged from ordinary standing and sitting positions, to stretching arms overhead and bending over, and sometimes climbing and crawling postures were performed to complete valve manipulation or equipment maintenance. A series of stick figures are drawn to illustrate typical tasks performed by oil industry workers, shown in Figure 4-1. Many of these working positions use movements that are necessary especially at places such as the back, shoulder, waist, crotch and underarm on the garment; in the meantime, adequate interface to cover all body parts are important in case of an exposure to steam or hot water.

Focus group interview[2]

This focus group interview had been conducted at an earlier stage prior to any further investigation and the results shed light on the attitudes of workers towards their current protective clothing and their needs for a better garment system, which enabled the researcher to perceive the design problem from the users' perspective. Three participants from the oil industry took part and guiding questions were provided.

[2] This focus group interview was completed in preliminary research and partial transcript provided to the researcher by the principal investigator of the broader project.

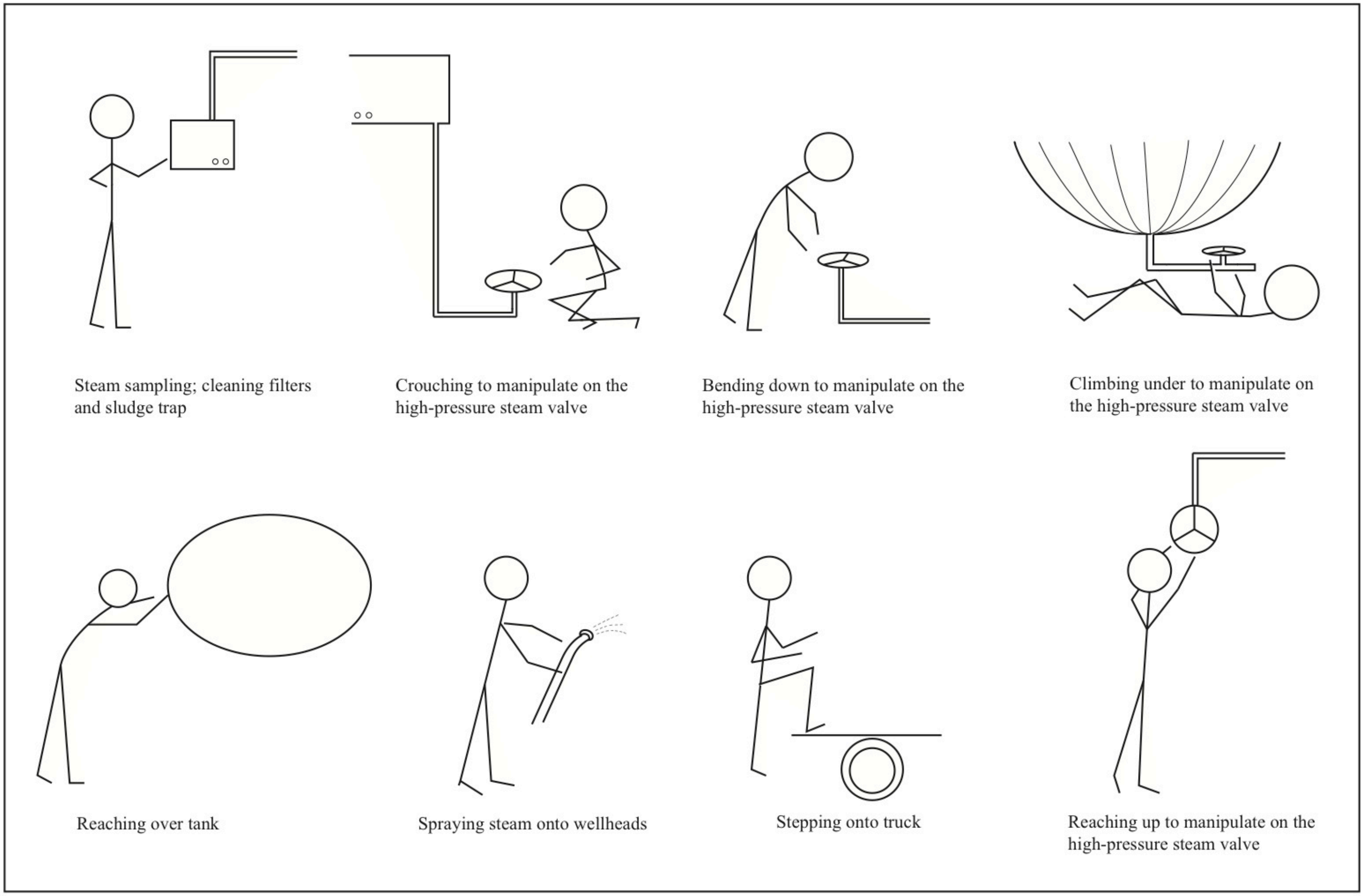


Figure 4-1 Movements of typical tasks of oil industry workers in stick figures

The main job and tasks that participants performed in their work included sampling high temperature steam and water, checking equipment for maintenance, loading and unloading hot water, *etc.*, for which they had all experienced steam or hot condensate burns. Anecdotal incidents were shared and the performance of their protective clothing was discussed. Main topics around likes and dislikes about their current protective clothing revealed that breathable (*i.e.*, semi-permeable fabric), light weight and quick drying fabrics were preferred, and pockets to carry necessary things and loops to hold microphones and radios were also appreciated as design features. What was mentioned as demerits for the "slicker" were that the heat dissipation interferes with heat and stiffness in cold affects the garment. As well, the ill-fitting nature of the "slicker" and poor design of the closures such as on collar, pant hem and cuffs were also identified.

Based on the analysis of photos and the focus group, guidelines towards a Level 2 garment system design were developed including four aspects as follows (Yu *et al.*, 2012a). These guidelines become the foundation for creating the design of the garment system.

1) *Clothing configurations*. The Level 2 garment system will need to cover torso and limbs completely, either in a one-piece coverall or two-piece suit with sufficient interface.
2) *Clothing components*. The Level 2 garment system will include a full stand-up collar that can cover the neck, front closure with overlap, full-length sleeve and functional pockets for wireless radios, tools and phones *etc.*
3) *Garment interfaces*. The upper and lower torso will be interfaced properly and adequately if it is not a one-piece garment. The sleeve design will need to be interfaced with gloves, and pants hem need to be interfaced with boots properly.

4) *Closure system*. The neckline, front, sleeve (or cuff) and hem will have a proper form of closure (*e.g.*, adjustable hook and loop, snap, zipper) to ensure adequate protection for areas such as neck, chest, wrist and ankles that are identified most risky.

Material analysis and Market Analysis

Further, a material analysis was conducted by a group of textile researchers and engineers at the University of Alberta who were involved in the broader project. Several manufacturers supplied selected semi-permeable, permeable and impermeable fabrics for testing at the Protective Clothing and Equipment Research Facility in the department of Human Ecology. The effects of fabric characteristics were tested on bench-scale pressurized steam testing equipment that measures energy absorption and time to reach the onset of second- and third-degree burns. Independent variables including mass, thickness, density and evaporative resistance were systematically tested (Jalbani *et al.*, 2012; Murtaza, 2012). It was concluded that impermeable fabric performed well but was not breathable, thus a desirable fabric system should have at least a semi-permeable barrier to combine comfort with steam and hot water protection. Moreover, Murtaza's research indicated that a multi-layered fabric system would be preferred because it could have an exterior fabric that repelled water with an insulation layer that would absorb energy. These fabrics would ideally be laminated together to create a fabric system that would perform at a higher level.

Fabric manufacturers and suppliers were contacted and product catalogs were reviewed to find optimal fabrics that could be applied in the prototype production. A local protective clothing manufacturer in Edmonton area indicated that they had similar fabrics available and agreed to provide them to this study, and guaranteed the prototype production for the next phase of the design process. The tri-laminate fabric system consists of a plain-weave Nomex® face fabric, a knit fleece fabric as the bottom layer, and a polyurethane (PU) membrane in between (see Technical Data Sheet in Appendix B). After conditioned in the laboratory at a relative humidity of 65% and temperature of 20°C for 24 hours as required in CAN/CGSB-4.2 NO.2-M88 (CGSB, 1988), fabric mass was determined according to CAN/CGSB-4.2 NO.5.1-M90 (CGSB, 2004), for which 10 fabric samples of 20 cm^2 were cut and weighed by electronic scale, then mass was calculated in grams per unit area, resulting in 479.8 g/m^2. Thickness was also measured according to CAN/CGSB-4.2 NO.37-2002 resulting in 2.6 mm (CGSB, 2002). Textile researchers conducted further steam testing on this fabric and it was clear that the fabric protected from second-degree burns. Although no further properties of the fabric were tested, the fabric system composition, weight and thickness, and steam testing results all indicated similarities to fabrics that demonstrated best performance in the previous steam testing. Textile researchers and technologists at the Protective Clothing and Equipment Research Facility continue to work on understanding and creating fabrics that protect from steam and hot water.

Establishment of Design Criteria and Interaction Matrix

Design criteria for Level 2 garment

Based on collected data and recommended design guidelines, in this phase the design criteria were established from a more comprehensive perspective. Four principal criteria were included: thermal protection, functional requirements, psychological requirements and production feasibility. Each criterion related to design specifications that are listed in Table 4-2.

Table 4-2 Design criteria and specifications for Level 2 Garment

THERMAL PROTECTION

- Garment system should cover torso completely (including neck, excluding face)
- Garment system should cover limbs completely (including wrists & ankles)
- Fabric and material utilized should be flame, steam and hot water resistant
- Garment system should function in different thermal conditions

FUNCTIONAL REQUIREMENTS

FIT

- Garment system should control fullness and be adjustable at waist, wrist and ankle to provide better fit
- Garment system (pants) should fit at crotch to accommodate body movement
- Garment system should provide adjustable closures for easy donning & doffing
- Garment system should be available at a range of sizes
- Level 2 Garment system should fit over the Level 1 garment when layering
- Garment system should provide functional pockets for tools, equipment and other accessories

MOBILITY

- Garment system should allow for body movement by analysis of movement (including stretching, bending, squatting etc.)
- Garment system should avoid excess fabric from being caught in machinery and impeding work performance
- Any tool, equipment and other accessories placed in pockets should minimize the interference of wearer's mobility

COMFORT

- Garment system should remain thermally comfortable for wearer at places where heat dissipation is high (i.e., underarm, back)
- The collar should not chafe neck, chin and lower face
- The seams and seam finishes should not diminish comfort

PSYCHOLOGICAL REQUIREMENTS

- Garment system should conform to the work culture and industry workwear
- The color of the garment system should be acceptable for oil-industry workers
- Garment system should make wearers feel comfortable and secure when wearing
- Garment system should be aesthetically appealing

PRODUCTION

- Garment system should have as few seams as possible to reduce garment protection failure
- The range of sizes and cost should be feasible for mass production
- Garment system should have reinforcements and be durable for wear and laundering
- Garment system should be compatible with other PPE (gloves, boots, hardhats)

The garment needs for thermal protection are safety-oriented and prioritizes use-scenario and task requirements. In addition, the garment system needs to fulfill current safety standards, which means it needs to be flame resistant in the first place for protection from flash fire, as well as provide protection from steam and hot water exposure, and should function well in different thermal conditions.

The functional requirement is mostly achieved through design, which is the focus of the research. It requires the garment system to fit a range of body sizes and provide a high level of mobility to minimize interference with work performance. Moreover, functional pockets should be provided to hold tools and accessories, and adjustable closure systems should be included to enhance ease of donning and doffing. The fit of the garment system also needs to be superior in order for workers to accomplish their job expectations including routine and exceptional tasks. The final garment system also needs to be easy to launder and maintain since a dirty garment reduces the level of function and protection (*e.g.*, if it is soiled it may increase flammability of garment).

It was also significant that the garment system be aesthetically appealing and acceptable to the workers in their work environment. The garment system also needed to be comfortable so that workers are more likely to wear them. In terms of manufacturing the garment, it should be feasible for mass production, for instance, seam types and seam finishes should be appropriate for the chosen fabrics and at reasonable cost.

Interaction Matrix of Established Design Criteria

In order to understand a comprehensive design criteria for the design of a steam and hot water protective garment system an interactive matrix is established. The interactive matrix listed the design specifications randomly that were interpreted and identified based on the interrelatedness between each of the characteristics (see Table 4-3). “0” indicated no conflict between the two design specifications in the corresponding row and column; “1” indicated accommodation was needed between the two specifications; “2” indicated conflicts existed and one of the less critical design specifications might be comprised.

The matrix illustrates an overall well-coordinated interaction between most of the design specifications. The major accommodation were desired between full body coverage and freedom of movement and functional fit, which can be achieved though functional design. One pair of “2” presented in “fit at crotch” and “fit Level 1 garment when layering”, as the underneath layer, usually a coverall would have an extended crotch design which means the Level 2 garment that goes on top has to provide extra room for it, thus not fitted at crotch. The other pairs of “2” both associated with seams in terms of protection and production. Certain seam types and finishes were expected to perform better than others, however were not as comfortable due to the folding fabric, seam sealing *etc.* that creates the bulk or stiffness. “Few seams as possible” was desired to reduce perforation as well as the cost, yet the attachment of pockets and other details would always add extra seams. Although protection was prioritized in the design criteria it was necessary to explore all the criteria for creation of a garment system that protects from steam and hot water. Consequently, the preliminary design and placement of pockets were incorporated and would be evaluated in the next step.

Table 4-3 Interaction matrix of design specifications for Level 2 garment

Design Specifications	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Cover torso completely		0	0	1	1	0	1	1	1	0	1	0	0	1	0	1	1	1	1	1	0
2. Cover limbs completely			0	1	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1	1	0
3. Flame, steam and hot water resistant				1	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0	1	1
4. Functional in different thermal conditions					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5. Adjustable and provide better fit						0	0	1	1	0	1	1	0	1	1	0	1	0	1	0	0
6. A range of sizes available							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Fit at crotch								1	2	0	1	0	0	0	0	0	1	1	1	0	0
8. Ease of donning and doffing									0	0	0	1	0	0	0	0	0	1	1	1	0
9. Fit level 1 garment when layering										0	1	1	0	1	1	0	1	1	1	0	0
10. Provide functional pockets											0	0	1	0	0	0	1	1	2	0	0
11. Allow for body movement by movement analysis												1	0	1	1	0	1	1	1	0	0
12. Avoid excess fabric for safety concerns													0	0	0	0	0	0	0	0	0
13. Garment holding any accessories should minimize interference of mobility														0	0	0	1	1	1	0	0
14. Thermal comfortable at place where heat dissipation is high (waist, back, underarm)															0	1	1	1	0	0	0
15. Collar should not chafe neck, chin and lower face																0	1	1	0	0	0
16. Seam and seam finishes should not diminish comfort																	0	0	0	0	0
17. Garment color and style should be accepted by oil-industry workers																		0	1	0	0
18. Garment system should be aesthetically appealing																			1	0	0
19. Few seams as possible																				0	0
20. Garment system should be durable and compatible with other PPE (protective gloves, boots, hardhats)																					0
21. Ease of storage and maintenance																					

0= No conflict; 1= Accommodation; 2= Conflict

Summary

Starting with the general request for an improved garment system that lead to the need for Level 2 workwear, this chapter presents the earlier phases in the functional apparel design process that explored the design situation and identified the problem, as well as to establish the design criteria and specifications. The data collected builds upon an in-depth understanding of the context of oil industry workers' use-scenarios and user activities, and leads to the next phase of developing and evaluating a mock-up and prototype.

CHAPTER 5 PROTOTYPE DEVELOPMENT AND EVALUATION

Based on the analysis of the design problem, this chapter focuses and delineates the last two phases in the functional apparel design process that include mock-up and prototype development and evaluation.

Mock-up and prototype development

The development of a mock-up and prototype for protection against steam and hot water involved a complicated process that began with preliminary ideation and sketch generation, half-scale mock-up development, full-scale muslin mock-up development and fully patterned and sized fabric prototype development. Focus group evaluation for the preliminary design at the mock-up phase was conducted before turning the idea into prototypes, and then seam types were selected and tested to assemble the fabric prototype. To ensure that the prototypes fit properly, participants were recruited at an early stage in order to measure body dimensions. Upon completion of all the above procedures the fabric prototypes were produced by a local manufacturer.

Preliminary sketch & mock-up

A combination of short jacket with a dropped back and high-waisted pants with patch pockets, closure system and ventilations in the preliminary sketch were proposed for the initial garment system (see Figure 5-1). The jacket and pant combination was proposed as a replacement for a longer coat and bibbed pant system currently made from a plasticized impermeable film material. The new design aims to improve fit around key areas such as shoulder, waist and crotch, as well as to provide sufficient level of mobility and adequate garment interfaces between jacket sleeves and gloves, jacket collar and face shield or head gear, jacket and pants, pant legs and boots. An athletic and sporty style is created for a more modern look and feel to give an aesthetically appealing garment.

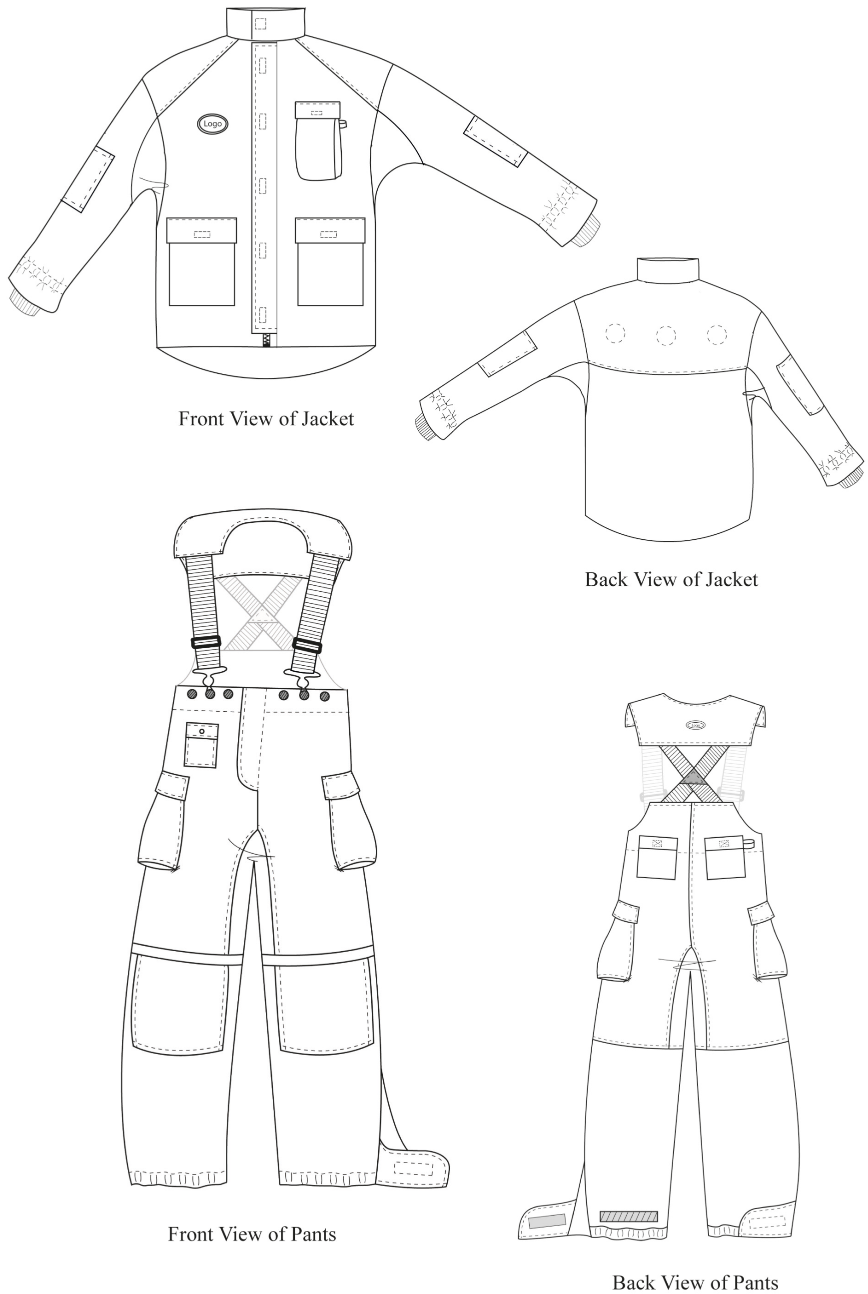


Figure 5-1 Preliminary sketch of new workwear (Level 2)

Design features and half-scale mock-up

At this point the preliminary sketch was presented with design details that responded to the design criterion and guidelines established at the earlier phases of the design process. The established design features were adapted and innovated based on the precedent garments and the design criteria established. Important features that were incorporated in the sketch and mock-up included:

- Standing collar with hook and loop closure for neck coverage
- Extended shoulders and widened armhole for ease and layering
- Stretch panel underarm for improved mobility and venting
- Interior sleeve cuff with adjustable tab
- Dropped hem at the back of the jacket
- Venting with storm flap at the back of the jacket
- High-waist style pants with vest
- Inseam panel for added ease for crotch
- Gusset with adjustable tab at pant hems

The standing collar in the new design replaced the traditional convertible collar on workwear in order to provide more protection at the neck and lower face, and the outer layer of the collar used the tri-laminate fabric, and the inner layer of the collar used knitted rib for comfort next to skin. The fabric utilized had limited stretch and was too thick to be pleated or gathered, in which case extended length, width and stretch panels became necessary to accommodate body movement and layering of garments (*e.g.*, extended shoulders, stretch panels at underarm and at the inseam). To enhance the protection of the vulnerable areas of the body such as the wrist and lower torso, interior cuffs, a dropped hem at the back, and high-waisted pants were designed to create multi-layered garment interfaces, ensuring adequate coverage of a workers' body while workers engage in dynamic motions. The high-waisted style of pants with attached vest also accommodated more body shapes (men and women) compared to the coveralls and bibbed pants. Another designed-in aspect to improve donning and doffing included gussets being inserted at the pant hems with adjustable tabs that could go over boots and be fastened. Venting at the back was also added to improve heat dissipation using three holes with Nomex® mesh and a single-layer Nomex® flap. The underarm stretch panel was achieved with the same fabric combination. Half-scale mock-ups of the preliminary design were made out of muslin for tangible presentation (see Appendix C for photos). Plain seams were applied with no seam finishes because these were not relevant at this phase of the design process.

Focus group evaluation

A focus group to evaluate the preliminary design was carried out in mid-November 2011 among nine industry-related participants, including safety advisors, textile and apparel manufacturers, and protective clothing sales representatives. A set of documents were prepared and handed out to the participants to collect data, including personal information sheet and evaluation form of the jacket and the pants (see Appendix D). During the focus group, researchers showed the mock-up and explained the intention for specific design features. Each participant looked at and handled the mock-up to see construction details and made comments and suggestions; open discussions were carried out and all of the participants wrote their comments on the evaluation sheet to indicate the strengths and weaknesses of the proposed design (see Table 5-1). This focus group lasted 40 minutes and was recorded with mp3 recorders. Written data were coded and audio data were partially transcribed.

Table 5-1 Strengths and weaknesses of preliminary design for new workwear (Level 2)

Jacket	**Pants**
Strengths	Strengths
- Standing Collar (4)* - Interior cuff (3) - Venting at the back (2) - Adjustable waist (1) - Dropped hem at the back (1) - Big storage pockets (2)	- High-waist style (2) - Vest for comfort (3) - Inseam panel (3) - Leg opening with tab closure (1)
Weaknesses	Weaknesses
- Slit pocket (6) - Stretch panel underarm (5) - Elbow patch (1) - Hook & loop closure (3) - Three holes on the mesh (1)	- Vest for extra cost (3) - Side Pockets (5) - Hip pocket (2) - Knee patch opening (2)

* The number indicates the frequency of strengths and weaknesses on the evaluation sheet

It appeared that weaknesses were more frequently indicated on the evaluation sheets, as general agreement of strengths towards overall style, collar and cuff design were reached orally; thus, not all participant wrote these down. The concept of creating a two-piece workwear system was well received, as well as the athletic, sporty and hardwearing style. The standing collar and interior cuffs were also greatly favored in terms of better protection. Most of the focus group participants were positive about innovative features such as adjustable waist tab, inseam panel, bigger leg opening and the vest on the pants; however, the general concern about these features was that they were potentially very costly to manufacture.

Opinions of pocket design and placement varied, but the consensus was that they all needed to be covered by pocket flaps to avoid collecting hot water or debris. Therefore the slit pockets at the front were considered unsafe and unnecessary. Also, the opening of the knee patch pocket for inserting kneepads was suggested to be located at the bottom to release water or debris if any. The side pockets on the pants were considered redundant when overlapped by the jackets. However, one of the sales representatives remarked that all the pocket details could be customized upon specific request from different companies. Besides, focus group participants suggested removal of the underarm stretch panel to reduce seams and move all the venting to the back of the jacket for added safety and protection, which was comparatively less vulnerable than the front torso. What was also recommended was to cut a full piece of Nomex® mesh for the back venting instead of three separate round pieces to reduce extra labor during manufacture.

Following the feedback and evaluation of the mock-up the design was refined towards developing the full-scale prototype. Most of the weaknesses were removed in the prototype development; however, the innovative features were kept for trial purpose regardless of the potential cost at this phase.

Full-scale muslin prototype

Prior to using the expensive tri-laminate fabric provided by the manufacturer, full-scale muslin prototypes were produced to evaluate the design features and to test the overall fit of the garment system on a mannequin upon completion of alterations of the design (see Appendix E for photos).

Design alterations

Alterations of the design were made based on the focus group evaluation: 1) the slit pockets on the jacket and all the pockets on the pants except for one hip pocket at the back were removed, 2) the elbow patches were removed, and the knee patch pocket were widened to the same width as the pant legs with opening at the bottom, 3) the underarm stretch panels were deleted, 4) the mesh holes were replaced by a full piece, 5) the straps on the back of the pants were straightened rather than orienting them in a cross formation, and 6) the bottom pant leg panels used mesh and a single-layer Nomex® combination for venting.

To ensure the pattern could be assembled properly, it was scaled up manually and a full-scale muslin prototype was produced. A mannequin used for fitting had a medium/large build with height of 175 cm, chest circumference of 108 cm, waist of 92 cm and hip of 105 cm. The overall length of the jacket was deemed appropriate, and the overlap between the jacket and the high-waisted pants was also excellent. A red pencil was used to mark desired changes (*e.g.*, position of the flap at the back venting, shoulder length, side venting at the back). Also, it was decided to incorporate a front placket on the jacket with the collar to eliminate gaping at the neckline. Widths were calculated and added at the chest for the jacket, and thigh and hip circumferences to accommodate underlayer garments for the pants. All the minor alterations were documented and marked on the production pattern. The pattern was then digitized with Gerber® AccuMark Pattern Design System with and at a local manufacturer (see Appendix F).

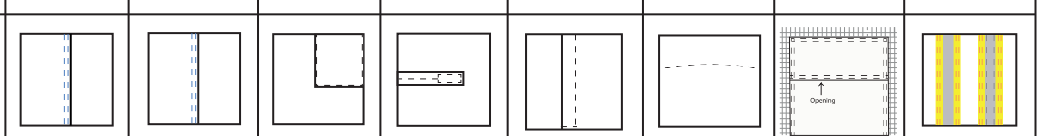
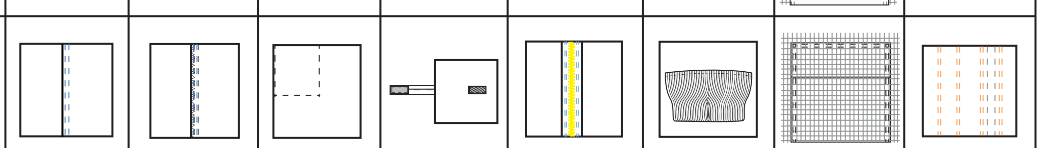
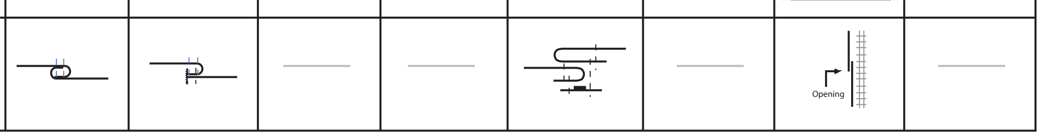
Seam Type Selection

The seam types needed to be purposefully selected before turning the muslin prototype into a full-scale prototype in order to meet required protection levels in terms of strength, fabric perforation and feasibility for each tri-laminate, single-layer and mesh Nomex® fabrics. Moreover, the design could incorporate different components on the prototype including seam types to assemble, for example, shoulder seams and hem finish, zipper placement and style line topstitch. The seam samples were selected, designed and produced (*e.g.*, straight seam, patch pocket stitching, zipper attachment) for testing at the Protective Clothing and Equipment

Research Facility in the department of Human Ecology. The seams were tested to indicate whether they could prevent second and third-degree burns.

A standard sample size of the seams were each 21cm by 21cm to fit the size of the testing apparatus with a sensor in the center, for which the seam was required to be placed against. Eight seam samples were illustrated in Table 5-2 below. All the samples were produced by industrial sewing machines, and the thread used was 60 tex Nomex® thread with stitch length of 2.76/cm set up by the manufacturer. Three sets for each sample were made and these were conditioned in the laboratory for 24 hours. The data acquisition time was 60 seconds for each sample, including 10 seconds of saturated steam exposure (95-150°C, 60-620 kPa) and 50 seconds of post exposure. All results from the testing had a mean value that were calculated and displayed on a computer screen (Ackerman *et al.*, 2012). Based on ASTM D6193-11 standard practice for stitches and seams (2011), two types of seams for major assembly were selected, the flat-felled seam (#1) and the plain seam with serged-edge and double needle top stitch (#2).

Table 5-2 Illustrations of selected and tested seam samples

#	1	2	3	4	5	6	7	8
Sample	Straight seam	Straight seam	Patch pocket	Hem straps	Zipper	Interior cuff	Venting mesh	Refelctive tape
Front View								
Back View								
Side View								

The results indicated that #1 seam performed best yet only met the Level 1 protection requirement. Further testing on combination of the tri-laminate fabric with underlayer fabrics were conducted and indicated better protection compared to without underlayers; however, it did not lead to a conclusive result of the "best seam" and some inconsistency were revealed in the test results due to technical problems of the apparatus and sample production (Sunder *et al.*, 2012). Further testing on seam types will continue over the coming months; however, the basic results reported here provided enough information to continue with prototype development and wear trials.

Full-scale fabric prototype

In order to identify the quantity and sizes of the fabric prototypes, participants from the oil industry were sought and recruited. The measurements of their body dimensions were taken, and grading was performed on the digitized pattern for final prototype production. The prototypes were not custom made; however, a standard fit was selected for each participant. That is, each participant was fit to the XS, S, M, L, Xl, XXL, XXXL sizing system.

Anthropometric study

To minimize the effect of ill fitting, a small-scale anthropometric study to collect critical measurement of the participants is useful prior to sizing the prototype. The selected measurements were based on basic body dimensions (*e.g.*, height, chest and waist circumference) and other important dimensions to properly size the garment (*e.g.*, waist height, sitting height, crotch height). An anthropometric protocol for the selected measurement and corresponding procedure was developed and modified for purpose of this study (Myers-McDevitt, 2004) and included in Appendix G.

Recruitment of participants

Upon development of the anthropometric protocol a recruitment notice, information sheet and consent forms were prepared and circulated to contacts of interest (see Appendix H). Four male participants aged between 21 to 49 years of age confirmed participation in the field trial all based at the same oil company at Jackfish Lake, Alberta, near Lac La Biche. Two of the participants work in the oilfield, one in the plant, and one in maintenance at the plant. The job variety covered an adequate range of tasks that involved steam and hot water, and their working experience in the oil industry was between one year and seven months minimum, and maximum of fifteen years.

Measurement of participants

The site visit was set up in a meeting room at the Jackfish Lake processing plant on November 1, 2012. A full package of evaluation materials was distributed to each participant, which included the package instruction and preparation form (see Appendix I). The package was explained at the introductory meeting before participant anthropometric measurements were taken. Two sets of measurement were taken, one set over a baseline clothing (snuggly-fitted cotton T-shirt and jeans), and the other set over typical coveralls worn over a baseline underneath (see Table 5-3). For confidentiality, each participant was assigned a letter (A to D) for identification.

Height and sitting height were not affected by the clothing worn, thus not repeated in the second set of measurements. In general, wearing the coverall indicated bigger dimensions, however for the crotch height, the inseam length on the lower torso of the coverall was smaller than baseline, resulting in smaller measurements compared to fitted jeans. The arm length measured over the coverall was the sleeve length, and on participant A and C the sleeve cuff did not reach the wrist bone, thus indicating a smaller measurement than that over baseline. The Level 2 workwear prototype is intended to be the outmost layer and accommodate underneath layers. The measurement of participants revealed a consistent variation in body dimensions over baseline and coverall; in case workers wear coveralls underneath, the fabric prototype needs to fit the bigger measurement except for the smaller crotch height.

Table 5-3 Measurement of participants over baseline and coverall

(CM) ID MEASUREMENT	PARTICIPANT A		PARTICIPANT B		PARTICIPANT C		PARTICIPANT D	
	BASELINE	COVERALL	BASELINE	COVERALL	BASELINE	COVERALL	BASELINE	COVERALL
1. Height	188	--	171	--	176	--	169	--
2. Neck	44	56	41	51	40	51	41	50
3. Chest circumference	114	124	96	105	112	114	105	111
4. Waist circumference	108	118	89	108	102	113	100	109
5. Hip circumference	112	123	111	113	103	111	106	108
6. Front shoulder	45	52	44	48	45	47	50	51
7. Back shoulder	48	60	45	51	49	48	53	53
8. Arm length	70	69	62	65	66	64	62	62
9. Waist height	115	118	107	109	110	110	108	108
10. Crotch height	83	78	76	71	82	76	75	72
11. Sitting height	75	--	69	--	71	--	69	--

Fabric prototype production

Compared with the local manufacturer's size chart, participant B, C and D were considered within the size range of XL, and participant A was XXL. Appropriate amount of ease was added to the digitized pattern to make it XL, and grading was performed to 2XL in Gerber® AccuMark Pattern Design System. Four sets of prototype were then produced by at the local manufacturer and delivered to the participants (see prototype photos in Appendix J). With permission the researcher was able to work closely with the manufacturer in their sewing room and be involved at all stages of prototype production. Although the #1 seam was determined to be the one that would protect most, it was not considered appropriate for manufacture due to excessive bulkiness when using the tri-laminate fabric. That is, the #1 seam was tested for one prototype and identified to be too stiff and bulky, therefore the #2 seam was applied to the rest assembly process.

Prototype Evaluation

Evaluation is a crucial step in the design process, and the last phase in the functional apparel design process for the study herein. In Chapter 3 several methods that can be used in evaluation stage such as focus group, interview, controlled exercise *etc.* were discussed, while in the study herein, where a small group of participants are involved and finished prototypes are available, the optimal way to evaluate the garment system would be wear trials in real-life working situations (*e.g.*, oilfields, processing and refinery plants). These wear trials are considered the best way to gain detailed information about subjective sensation of fit and comfort.

The main purpose of this phase of the design process is to achieve objective 3 in Chapter 1 "to evaluate the prototype with oil workers/operators for functional fit, mobility, subjective comfort and acceptability through wear trials". Trial procedure and evaluation results and feedback are presented here, and discussion relating to the objectives and purpose of the study will be addressed in Chapter 6.

Trial Procedure

The wear trial involve experienced workers/operators in the oil industry, for which they were required to wear the prototype to perform work tasks that involve steam and hot water exposure. The four participants all worked one-week work and one week off. To ensure sufficient time for the wear trial (approximately 10-14 days of trial) while adapting to project timeline (end of December 2012), a two-cycle wear trial was designed: Cycle One consisted of 7 days, starting from November 23, 2012 to November 29, 2012; Cycle Two consisted of another 7 days, starting from December 6 to December 12; with one week off in between.

The participant package distributed at the anthropometric study consisted of a set of evaluation documents that included pre-trial fit assessment forms, garment daily use record sheet, and wear acceptability scales (see Appendix K). Upon receiving the prototype, each participant was required to try them on and fill out the form "Pre-trial fit assessment for jacket/pants". Starting from Cycle One, they were asked to use the "Garment daily use record" to document their use of the prototype during work, Cycle Two was a repetition of Cycle One, and the "Wear acceptability scale" with open-ended questions was filled out upon completion of each cycle. Wear acceptability was rated on a 9-point scale on jacket, pants and combination of the two. Rated items included closure system, freedom of movement on critical areas (*e.g.*, shoulder, arms, knees) and different positions (*e.g.*, sitting, crawling, bending), and overall fit and acceptability. "Post-trial fit assessment for jacket/pants" is done after Cycle Two to complete the trial.

Evaluation and feedback

Evaluation sheets were completed and returned to researchers at the end of Cycle One and Cycle Two respectively. The results are presented below.

Pre-trial fit assessment

The pre-trial fit assessment was conducted the first time participant tried on the prototype and rated how every component fit based on a 5-point scale, "1" being very good fit, and "5" being very poor fit. Participants were free to determine what they wore underneath the prototype and required to indicate their under layers on the form: Participant A was wearing a T-shirt and coveralls; Participant B chose a combination of T-shirt, shirt, long underwear and pants; Participant C was wearing a hoodie and coveralls; and information is missing for Participant D due to incomplete package returned to research. The results are illustrated in Table 5-4 and Table 5-5.

Table 5-4 Pre-trial fit assessment for jacket

	Rating (X out of 5)								
ID	Collar height	Neckline	Chest girth	Waist girth	Center front	Center back	Sleeve length	Armhole width	Overall fit
A	2	1	1	1	2	2	1	2	2
B	2	2	2	2	2	2	2	2	2
C	2	1	1	1	1	1	1	1	1
D*	-	-	-	-	-	-	-	-	-

Table 5-5 Pre-trial fit assessment for pants

	Rating (X out of 5)								
ID	Waist girth	Thigh width	Knee width	Leg opening	Outseam	Front rise	Back rise	Knee height	Overall fit
A	1	2	1	4	2	1	1	1	1
B	2	4	4	4	3	2	2	2	2
C	1	1	1	4	1	1	1	1	1
D*	-	-	-	-	-	-	-	-	-

* *Incomplete information*

The "overall fit" rating indicates positive attitude of participants towards the prototype, and was quite consistent for the jacket among the four participants. As for the pants, the obviously higher rating was given to "leg opening", indicating all participants considered it as "poor fit". Participant B had a comparatively smaller measurement of waist girth, waist height and crotch height measurement to Participant C and D who were also sized XL, and he considered the pants were not fitted in widths and neutral about the "outseam", while Participant C gave a good rating on most items except for the "leg opening".

Garment daily use record

Each participant recorded fourteen days of prototype-use for the two-cycle wear trial periods. Across the entire trial period, the lowest temperature documented by participants was -35°C, and highest of -10°C, and the week in Cycle Two was

Table 5-6 A summary of garment daily use record

Participant ID		A	B	C	D*
Cycle One	**Shift**	6 day/1 night	7 day shifts	7 day shifts	
	Other PPE worn	• Coverall • Long johns • Gloves • Goggle • Boots • Headwear	• Shirt/Coverall • Sweats • Gloves • Boots • Headwear	• Shirt/Coverall • Hoodie • Gloves • Goggle • Boots • Headwear	
	Tools	• Radio • Pipe wrench • Flash light • Pens	• Valve wrench • Crescent wrench • Utility knife • Pens	• Keys • Wallet • Radio • Pipe wrench • Knife	
	Work/tasks	• Oil sampling • Water sampling • Tank checks	• Readings • Lock vaults • Steaming	• Sampling wells • Well lockout • Cleaning buildings • Driving	
	Work condition	• Office • Process building • Tank farm	• Outdoors (cold, windy) • Indoors (warm)	• Office • Well site • Truck	
		A	**B***	**C**	**D**
Cycle Two	**Shift**	7 night shifts		7 night shifts	2 day shifts
	PPE worn	• Coverall • Long johns • Gloves • Goggle • Ear plugs • Boots • Headwear		• Shirt • Jeans • Hoodie • Gloves • Goggle • Boots • Headwear	• Shirt • Long johns
	Tools	• Radio • Pipe wrench • Pens • Notepad • Marker		• Keys • Wallet • Radio • Pipe wrench • Pens	
	Work/tasks	• Oil sampling • Water tap checks • Taking apart pumps		• Sampling wells • Cleaning buildings	• General maintenance duties
	Work condition	• Office • Control room		• Office • Well site • Separate buildings • Truck	• Dusty, hot, greasy • General duty stuff

* *Incomplete information*

significantly colder. A summary of the garment daily use record is presented in Table 5-6, which illustrates participants' shifts (*e.g.*, day or night shift), other PPE that were worn with prototype, the tools they carried, the tasks they performed and the work condition.

Participant A and C are field workers who perform tasks in the processing plant and at wellhead sites. All their shifts were 12-hour shift. For Participant A, the average time duration that he wore the prototype was 7.7hrs/day in Cycle One, and 4.8hrs/day in Cycle Two; for Participant C, the average was 4.4hrs/day in Cycle One, and 6hrs/day. They both put on and took off the jackets a couple of times while the pants were worn throughout the entire trial and used consistently.

Participant B mainly works in day shifts inside the plant. He indicated all-shift use of prototype throughout Cycle One. Participant D is on maintenance duty but he only submitted a package for Cycle Two and indicated only two days of prototype use.

Wear acceptability scale

Each individual participant presented their own preference and rating, and comments were provided in responding to the open-ended questions of their wear trial.

In Cycle One, all participants indicated they had an "ordinary" week during work among all other adjectives (*e.g.*, stressful, challenging, happy). While in Cycle Two, Participant A indicated his week as "challenging", and Participant C and D were "happy" in their work. A summary of their evaluation scale of the prototype and comments and feedbacks to the open-ended questions are illustrated in Table 5-7. The overall acceptability was mostly neutral (between 4 and 5) for both Cycles, but the overall satisfactory fit demonstrated a much better rating in Cycle Two than

Table 5-7 Results of wear acceptability scale

Participant ID		A	B	C	D*
Cycle One	**Rating**	• Acceptability (5) • Freedom of movement (2/3) • Pockets (8) • Overall fit (5)	• Acceptability (3) • Freedom of movement (7) • Pockets (2) • Overall fit (6)	• Acceptability (5) • Freedom of movement (2) • Pocket (8) • Overall fit (4)	
	Dis-comfort	• Broken stiches • Pants bottom too wide and baggy	• Loose buckles • Pant legs too wide	• Pant straps inconvenient • Pants too big	
	Pocket use	• More pockets needed (side, back/front of pants) • Bigger pockets to fit radios	• Tool pocket faces forward • Wider/deeper • Pen slot on chest/arm pockets	• More pockets needed • Internal and left hand pockets needed on jacket	
	Wear/ Abrasion	• Very good • Solid design	• No issues	• General well	
	Three things like most	• Light weight • Comfortable • Waterproof	• Comfortable • Warm • Non-constricting	• Not feel steam when working • Ability to wear just the pants/shirt • Shoulder support	
	Three things dislike most	• Too big/baggy • Not enough pockets • Stiffness	• Pant legs • Buckles loose off • Venting	• Not enough pockets • Strap want to slides • Jacket buckle	
		A	**B***	**C**	**D**
Cycle Two	**Rating**	• Acceptability (4) • Freedom of movement (2/3) • Pocket (6) • Overall fit (3)		• Acceptability (-) • Freedom of movement (1/4) • Pocket (8) • Overall fit (2)	• Acceptability (-) • Freedom of movement (1/2) • Pocket (5) • Overall fit (3)
	Dis-comfort	• Broken strap • Too hot for inside wear • Don't like to strip off pants		• Not enough pockets • Vest on pants should use mesh (otherwise too hot)	• Possibly hot in summer • Jacket/pant combo does not allow to wear radio as normal
	Pocket use	• Not nearly enough pockets to carry things		• Need more pockets	• OK
	Wear/ Abrasion	• Good design		• Good	• OK
	Three things like most	• Light weight • Its purposes • It does work		• Light • Wind protection • Comfortable when using steam	• Comfortable • Flexible
	Three things dislike most	• Flared/wide bottom • Bulky • Not enough pockets		• Lack of pockets • Vest on pants could be mesh • Pants bottom too big	• Color • Tight fit around neck • Strap coming loose • "Bell bottom" pant legs

* *Incomplete information*

Cycle One for all participants. Participants were also happy about the freedom of movement of the prototype except for Participant B who gave "7" to all movement ratings, yet he commented that one of the three things he likes about the prototype was "non-constricting". "Adequate pockets" received the least favorable rating, which was also reflected in their comments of lack of pockets.

In their feedback based on the open-ended questions, all participants indicated the prototype was generally good in terms of wear and abrasion during the trial, and the garment system was favored for its light weight, flexibility and comfort. Participant C who works in the field also remarked that he "could not feel steam when working in steam situations", and he liked the ability to wear the pants and jacket separately. Most frequently discomfort and challenges solicited by participants was pocket issue, such as "need more pockets", "more pockets on both front and back of pants", "tool pocket should face forward"; moreover, the wide pant leg was considered "way too big", and Participant B commented "Pant legs too wide. Feels like wearing 70's Retro pants…" and Participant D coined it as "Bell Bottom". The straps on the pants were also considered unfavorable for several reasons: they were too loose and tending to slide even with the snap hook. Aesthetic detail mentioned was that the participants did not like the orange color. Other weaknesses included that the open venting at the back took in wind and could be chilly, and the buckle at the jacket waist was uncomfortable when sitting.

Post-trial fit assessment

The participants each conducted a post-trial fit assessment when they finished Cycle Two. At this stage they would have worn and interacted with the prototype for a quite long period, and became quite familiar with the garment. Participant A was wearing coverall, T-shirt and sweats combination; Participant B did not submit his complete package thus this information was missing; Participant C wore a shirt, a pair of jeans and a hoodie; Participant D wore a shirt and long johns. The ratings are illustrated in Table 5-8 and Table 5-9.

Table 5-8 Post-trial fit assessment for jacket

ID	Rating (X out of 5)								
	Collar height	Neckline	Chest girth	Waist girth	Center front	Center back	Sleeve length	Armhole width	Overall fit
A	2	2	3	2	2	2	2	2	2
B*	-	-	-	-	-	-	-	-	-
C	1	1	1	1	1	1	1	1	1
D	2	4	2	2	2	2	2	2	2

Table 5-9 Post-trial fit assessment for pants

ID	Rating (X out of 5)								
	Waist girth	Thigh width	Knee width	Leg opening	Outseam	Front rise	Back rise	Knee height	Overall fit
A	2	2	2	4	3	2	2	2	2
B*	-	-	-	-	-	-	-	-	-
C	2	1	1	5	1	1	1	1	2
D	2	3	3	4	2	2	2	2	3

* *Incomplete information*

Results across the trial were relatively consistent but had a slightly higher rating in most of the components and overall fit compared to pre-trial assessment, indicating a slightly decreasing satisfaction of fit. Participant D felt the neckline was a "poor fit" by, and all participants felt the "leg opening" was ill-fitting.

Summary

To complete the functional apparel design process, a series of activities of mock-up design and evaluation, full muslin and fabric prototype production was conducted. The refined fabric prototypes were evaluated in wear trials in real-life working situations with participants who work in the oil industry. Results from the evaluation in conjunction with feedback from oil industry workers link to the discussion and design recommendations, which are presented in the next Chapter.

CHAPTER 6 DISCUSSION, FUTURE RESEARCH & CONCLUSIONS

Discussion

Wear trials feedback was received from participants who work in the oil industry, which include the experience and interactions they had with the prototype in the their real-life working environment. These wear trials assist to further identify the needs and expectations of workers who wear protective clothing. The evaluation feedback, in conjunction with the phases to characterize the design problem, was linked to the objectives and purpose of the study herein.

Functional fit and mobility

One of the objectives of this study was to evaluate functional fit and mobility of new workwear, as the level of fit and mobility that functional clothing provides are critical for users to perform required movement and specific tasks (Huck *et al.*, 1997; Watkins, 1995).

From the feedback of the wear trial evaluation, it can be seen when assessing fit and mobility participants were positive about freedom of movement at shoulders, arms, waist, crotch, knees *etc.*, as well as in specific working positions (*e.g.*, sitting, crawling, bending). In fact, the "overall satisfactory fit" and "freedom of movement (in indicated body parts)" received the best ratings for all participants. This might be due to the design having the proper cut and amount of ease, but also because of the frequently mentioned fact by participants that they could wear the garments separately and combined with other workwear (*e.g.*, shirt, jeans) as they desired under different working situations. Evidence of this is also reflected in the participants garment daily use record that shows various wearing styles. Although one participant did mention that he would like to see a one-piece coverall out of the same material, he still gave a good rating for the overall fit and freedom of movement of the two-piece workwear. Their preference of the light-weight and flexible garment system was often remarked in their comments as well; however, this was unexpected as the fabric and final prototype were considerably heavy compared to the traditional coverall materials and garments.

In spite of participant workers positive attitudes towards the fit and mobility of the prototype, negative comments about collar closure were indicated several times. Two participants considered the collar was too tight to close when shirt, hoodie or coverall was worn underneath, which is likely due to added bulk to the neckline resulting in a need for a wider collar to accommodate layers. Participants also felt the pants were too baggy and wide especially at the bottom, and suggested to create a more fitted pant leg. Although the original intention for the wide bottom was to fit their boots when they put the pants on and take off multiple times a day, it seemed that participants preferred to wear the pants more often and longer rather than for short time durations. Consequently, a more fitted pant leg for daily work comfort is required.

Subjective comfort

Comfort was rated in the subjective evaluation scale in terms of visual design and aesthetics (*e.g.*, “the design/look”), function (*e.g.*, “adequate pockets”, “cuff closure”) and thermal regulation (*e.g.*, “venting system”, “thermally comfortable”) were reflected in the comments of participants.

The ratings for the “design/look” were neutral between “5” and “6”. Although the design of jacket and pants combination was well received, and they were wearing the prototype for much longer time during their work shift than expected. Most participants disliked the unconventional orange color and “flared bottom” of the pants, which might lead to the lower level of satisfaction on the aesthetics of the garment system. Also, the buckles on the straps of pants and inside of jacket for waist adjustment were mentioned “uncomfortable”, “tended to slide” and “come loose”, which could have affected their impression on the design.

When rating and commenting about function, the overall closure system was considered well designed and adequate for body coverage, except for the tight-fitted collar that needs to be widened. Also, the vest on the pants was considered functional and comfortable. One of the biggest issues was inadequate pocket placement on the jacket and pants; yet this, on one hand, was to reduce seam perforation (all pockets were topstitched onto the tri-laminate fabric) and, on the other hand, was intentionally designed for participants to explore where they would like the pockets placed. Suggested placement for pockets were left chest, arms, front and back of pants, and bigger pockets on the lower front of jacket.

As the wear trial took place in winter, the prototype was considered thermally comfortable; however participants did indicate it might be hot in summer. The venting system received good rating and participants liked the fabric option of mesh materials. One of them working in the field solicited for a closure on the venting at the back of jacket so that he could control the size of opening to prevent air from flowing up the back of the jacket. Compared with the current “slicker” used in the oil industry for tasks involving steam and hot water, the new prototype was commented by participants to be more flexible and comfortable as it did not get stiff or crack in winter. Generally speaking, the perception of comfort of the prototype was positive.

Wear acceptability

Not only does the overall wear acceptability relate to how the prototype looks, fits and functions, it also relates to how the user perceives the garment and how they interact with it in various use-scenario, reflecting in their rating, comments and garment daily use record use of wear frequency.

In general, under an “ordinary” week of working in oilfields and plants, the overall wear acceptability of the new prototype tended to be neutral. Despite the rating, most participants seemed to like wearing the prototype for a long period of time during each shift, as illustrated through their garment daily use record. Additionally, operators whose tasks were mainly general maintenance duty might not wear Level 2 garment system as often as field workers, based on the record provided by Participant D of only two day of use in Cycle Two. Yet those who wore the prototype more often and longer seemed to be more conservative and adaptive towards the idea of their traditional one-piece workwear, while Participant D was satisfied with the overall fit and design, but negative about the unconventional bright orange color. The preliminary idea for the two-piece design was to increase ease of donning and doffing, as well as level of mobility; and the color was not a design factor but was a result of what fabric was available. If the Level 2 workwear could be refined towards a garment for daily use and provide adequate protection at the same time, the idea of developing a semi-fitted one-piece garment of the tri-laminate material may be an option, using a more traditional color such as navy blue.

Despite their perception and attitudes toward design, participants frequently mentioned the feeling of being protected and comfortable when wearing the prototype. Participants indicated that the prototype provided adequate body coverage and that they felt safer while wearing it, which increased their comfort for feeling secure. To summarize, the prototype achieved well when it came to functional fit and mobility, particularly aspects of improved comfort and protection. Even so, some design details were not favorably accepted, and participants provided suggestions and comments that help to identify existing issues towards refinement and improvement.

Recommendations

Based on the previous discussion, recommendations towards design guidelines, design improvement and refinement of the Level 2 workwear are provided as below:

1. The neckline on the jacket needs to be widened to fit better with under garments and layering (*e.g.*, shirt, hoodie). The collar should incorporate a bigger extension to create an overlap at the center front so that it is easier to close. Moreover, the collar height should be shortened slightly to avoid chafing wearer's chin. If the jacket is to be worn for daily use, a more flexible and softer fabric may be considered to be applied on the collar next to human skin.
2. The venting on the back of the jacket created with Nomex® mesh and single-layer Nomex® needs to employ a form of closure (*i.e.*, zipper) so that the wearer can adjust the amount of venting desired. This is especially important to accommodate different weather conditions and seasons. Although this will add extra cost, price can be reduced by mass production and outsourcing overseas.
3. More pockets are desired for both jackets and pants for tools and personal belongings, such as internal pocket, bigger storage pockets on the front of jacket, and front and back hip pockets. Full length hook and loop closure on the pockets are also expected rather than snaps. Pen slot can be added to the chest pocket as well. Adding pockets definitely increases the overall cost of the garment;

however, particularly in the Alberta context customization of garments by manufacturers can be done upon request.

4. The pants need to be tailored more and have the incorporated flared bottom removed. This was intended to fit the steel-toed boots without taking them off, yet if the garment system is to be worn for longer periods and not donned and doffed frequently, the pant leg can be much narrower and less baggy.
5. The straps and buckles used in the pants and jackets were not favored. A different buckle and tri-glide ladder hook can be used to adjust the strap and stabilize it better. The buckle inside the jacket at the waist was perceived uncomfortable and bulky when sitting, therefore the position of the buckle can be moved higher and replacement of a smaller sized buckle may help to alleviate the discomfort.

Future research

Although many features of the prototype have been found to be favorable, there are still opportunities to explore the current prototype before final detailing for production can take place. It is recommended that future research in the form of additional studies can be carried out to further identify the design problem and approach it from different angles:

1. A bigger group of participants can be recruited for wear trials in future research to increase the validity of data. Moreover, female participants can be recruited as their body shape and dimensions, working styles and perception of fit and comfort *etc.* can vary significantly from males.
2. A longer period of wear trial can take place in future research when participants can experience the prototype not only in winter but also in other seasons. This enables them to better explore the jacket and pants combo, the venting system, thermal comfort of the fabric *etc.* in different environments.

3. Future research can incorporate controlled exercise in an environment chamber where conditions are controlled and maintained; participants can perform simulated tasks while researchers observe the process and conduct on-site interviews. The data are more comparable within a group of participants since the environmental factors are controlled in the same situation.
4. Mannequin testing of the prototype can be performed with steam/hot water jets producing steam/hot water exposure in future studies, which generates objective data of the amount of energy absorption, the time to attain second- and third-degree burns (on areas with sensors), and can help identify whether the prototype meets the protection requirements in complement to human wear trials.

Summary and Conclusions

Summary

People working in the western Canadian oil industry are often exposed to hazardous working environments, equipment and tasks. Increasing number of steam and hot water related burn injuries have been reported in the past five years, and the PPE, especially the protective clothing currently available for oil workers is considered inadequate for protection against steam and hot water. The study herein aims at investigating and developing an improved garment system serving as Level 2 workwear in the oil industry that addresses the issue.

Consistent with a human ecological perspective, the functional apparel design process adapted from Orlando (1979) was applied as the conceptual framework and a user-centred design approach has been used. A multi-method approach was taken throughout different phases of the process to characterize the design problem including a comprehensive literature review, focus group interviews, analysis of field photographs, analysis of materials, and observation of precedent garments.

Literature around steam and hot water burns, functional fit, mobility and comfort of clothing was reviewed to identify key issues in the context of the study. Analysis of movement from photographic documentation and focus group interviews in conjunction with previous data collected in the project were useful to explore the use-scenarios and user activities. Moreover, from observation of precedent garment transferable and adaptable design features were closely looked at and documented, and fabrics were also selected and tested. Design criteria and an interaction matrix of design specifications were then established to guide the phase of prototype development.

Preliminary sketches and a half-scale mock-up were developed, and evaluated through a focus group with industry stakeholders. Full-scale prototype utilizing muslin and selected fabric were produced with a local manufacturer. In order to evaluate the prototype a two-cycle wear trials in real-life working environment was conducted with oil industry workers/operators. Upon completion of the trial, feedback and wear acceptability were received from participants, based on which recommendations towards design refinement and improvement were presented. Please see Appendix L for a flow of methods incorporated in the study.

Conclusions

The functional apparel design process with a strategy-control system is successfully employed in the study herein. The design criteria and specification established through characterizing the design problem served as the strategy control that controls and evaluates each step in the design process, and organizes them into a functioning system. The multi-method approach taken to identify the user-scenario and user activities in context of the oil industry provides a view on the design problem from various perspectives through multiple lenses and forms a more holistic perspective. Although limitations exist due to design methods, levels of human involvement, time allotted, budget and resources available, the conclusion can be drawn that this process and methods within are effective towards developing user-centred products and conducting related design activities.

The objectives for the study to develop an improved garment system and evaluate its fit and comfort in wear trials are well achieved. The new two-piece Level 2 workwear was more flexible and functional than the “slicker”, and workers felt safe and comfortable wearing the prototype that protected them when using steam. In fact, they wore it so often that they did not have to wear a coverall but used the prototype as a daily garment system instead, indicating the new design is a possible replacement for the two level garment systems if refined. Design details such as numbers and placement of pockets, hardware used to secure strapping, placement of straps, and the pant legs need further refinement. Although the overall acceptability rating was neutral, it can be seen from the participants’ comments that they were quite positive about the fit and level of comfort, and advocated for the numerous innovative design features that were incorporated into the prototype.

On the whole, this study significantly benefited from the unique human ecology approach combined with user-centred perspective, where a great deal of time was spent on identifying the complexities of design situation and characterizing the design problem. This more humanistic approach supports the design of products that are more focused on individual needs and specialty situations that related to health, wellness and safety. Additionally, only through a multi-method approach can the layers and overlaps of environment-human-clothing interactions be analyzed in a more holistic and systematic way; and only by reflecting on users’ needs, desires and expectations in circumstances of real-life use-scenario, can the study herein develop this new Level 2 workwear prototype towards this stage.

GLOSSARY

- *Anthropometric study* – The study of measurement of the human body to understand the physical configuration of individuals in a user group (Watkins, 1995). For the purpose of this work, a focus on the anthropometrics of people-garment relationships is taken.
- *Comfort* – The harmonious state between human and environment in physiological, psychological, and physical aspects, and can be measured objectively and subjectively for research purposes (Slater, 1986). A state of comfort varies from person to person but is measurement through various techniques.
- *Design process* – A step-by-step problem-solving approach that designers use to create design concepts and solutions.
- *Ease* – The difference between the garment dimensions and the wearer dimensions; usually referred to extra fabric added on various locations of the garment for mobility or style.
- *Functional apparel* – Clothing that is designed to meet specific functional purpose as well as psychological and aesthetic needs of potential users (Orlando, 1979; Tan *et al.*, 1998).
- *Functional apparel design process* – A more holistic approach to creating functional apparel for potential users. The process is based on a strategy control system to explore the design problem, identify critical factors and design criteria, and subsequently develop the design solution and evaluate the design to complete the design process (Orlando, 1979).
- *Functional fit* – A combination of body measurements of a person in the anatomical position and the ease allowance necessary for movement to

perform the required activities (van Schoor, 1989). This depends on the style of the garment and is assessed through movement analysis of potential users.

- *Interaction matrix* – A matrix organizes and lists design criteria/specifications that are established to prioritize the combination of design features or ideas.
- *Mock-up* – Usually a scaled model for tests or evaluation purposes; in this research it is a half-scale muslin jacket and pants combination for visual and tangible presentation used in the focus group.
- *Multi-method approach* – An approach that incorporates a combination of various techniques and methods to conduct research in order to obtain a more holistic understanding about a research or design problem. A multi-method approach is detailed oriented and provides various perspectives towards the same problem.
- *Precedent research*– The research method using prior knowledge, experience or existing artifacts and materials to aid design process.
- *Tri-laminate fabric* – The fabric that contains three layers held together by particular substance.
- *User-centred design* – The design process that involves end-uses to take shape where user needs are emphasized and user activities and use-scenario are explored.
- *Use-scenario* – The situation in which end-users would use the product, such as their surroundings, tasks and interactions within.
- *Workwear* – Garment or garment system that is worn for daily work or specific task performance. In this research, the workwear refers to the garments worn by the oil-industry workers, which are categorized into two levels in terms of protection. A Level 1 workwear is worn on a daily routine

for prerequisite protection, while Level 2 workwear is the outmost layer worn in addition to Level 1 garment for short time durations for specific tasks that are more hazardous. Within the scope of this research, only a Level 2 workwear ensemble is designed and presented.

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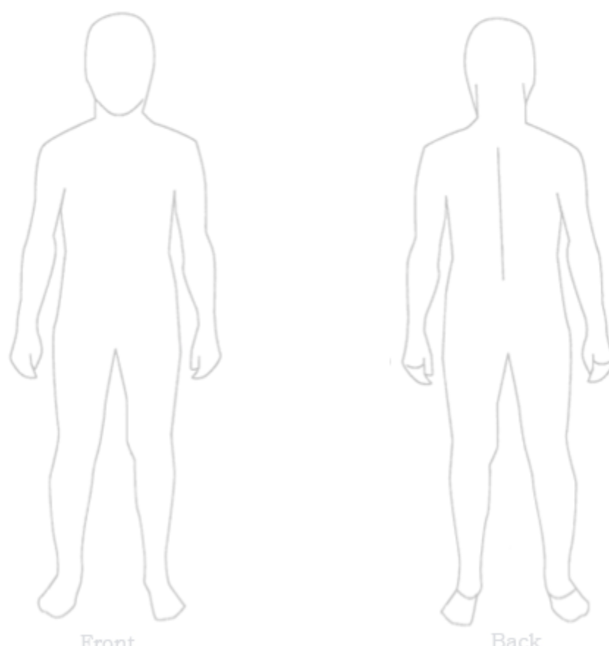
APPENDIX A OBSERVATION SHEET OF PRECEDENT GARMENT

Observation Sheet of Precedent Garment

Date_______________ Time___________________ Site________________

<table>
<tr><th rowspan="2">#</th><th rowspan="2">Brand</th><th rowspan="2">Price</th><th rowspan="2">Size</th><th colspan="3">Fabric/Fibre Content</th><th colspan="4">Garment Type</th></tr>
<tr><td>Shell</td><td>Lining</td><td>Other</td><td>Coverall</td><td>Coat</td><td>Pants</td><td>Other</td></tr>
<tr><td rowspan="4"></td><td rowspan="4"></td><td rowspan="4"></td><td>S</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td><td colspan="4" rowspan="4">User Context
• Firefighter • Disabled
• Military • Outdoor
• General Industry •
Other_____</td></tr>
<tr><td>M</td></tr>
<tr><td>L</td><td colspan="3">Thickness</td></tr>
<tr><td>Other</td><td>Light</td><td>Medium</td><td>Heavy</td></tr>
</table>



Garment Length __________ Layers___________ Accessory _____________

<table>
<tr><td rowspan="2">Detail</td><td>Collar/Neckline</td><td>Sleeve</td><td>Pocket</td><td>Closure system</td><td>Interface</td></tr>
<tr><td></td><td></td><td></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td rowspan="2">Fit & Mobility</td><td>Added Ease</td><td>Stretch Panel</td><td>Elastic Band</td></tr>
<tr><td></td><td></td><td></td></tr>
</table>

APPENDIX B   TECHNICAL DATA SHEET OF FABRIC difco

Tissus de Performance Inc.
Performance Fabrics Inc.
Une compagnie de
A company of
pgi

Technical Data Sheet

FN16066

Weight oz/yd ^{2} (g/m ^{2})			14.5 oz/yd ^{2} (490 g/m ^{2})	
Fibre Content			93% Nomex® / 7% PU membrane	
Weave Type			Face: Plain Back: Knit Fleece	
Width			57" (145 cm)	
End Use			Light Insulated Jacket	
Tests	**Methods & Specifications**		**Performances**	
Flame resistance - as is	**ASTM D 6413**		**Warp**	**Fill**
After flame (sec)		max. 2 sec	0	0
Char length (mm)		max. 100 mm or 4"	20.0 (0.8")	18.0 (0.7")
Melt / Drip		no melt, no drip	complies	
Heat resistance - as is	500℉/5 min.	no melt, separation, dripping or ignition	complies	
Thermal shrinkage (%) - as is		max. 10%	<3%	<3%
Electric Arc Resistance	ASTM F1959 **ATPV** **(cal/cm2)**		**ATPV: 41** After flame: avg. 6 sec. **E_{bt}:45** **Level 4**	
Cleaning shrinkage (%) 5 cycles	AATCC 135 1 - IV - Ai	max. 5%	≤ 3.0	≤ 3.0
TPP with spacer	NFPA 2112	Section 8.2	30 Cal/cm ^{2}	
Tensile Strength-Grab(N) - as is	Can/CGSB 4.2 No. 9.2 (ASTM D5034)		1400 (315 lbf)	780 (175 lbf)
Tear resistance-Elmendorf (N) - as is	ASTM D1424		90 (20 lbf)	45 (10 lbf)

Date: September 2008
Temporary development

APPENDIX C PHOTOS OF HALF-SCALE MOCK-UP

Front View of Jacket

Back View of Jacket

Front View of Pants

Back View of Pants

APPENDIX D FOCUS GROUP OUTLINE, PERSONAL INFORMATION SHEET AND EVALUATION SHEETS

Focus group: outline of discussion topics 2011

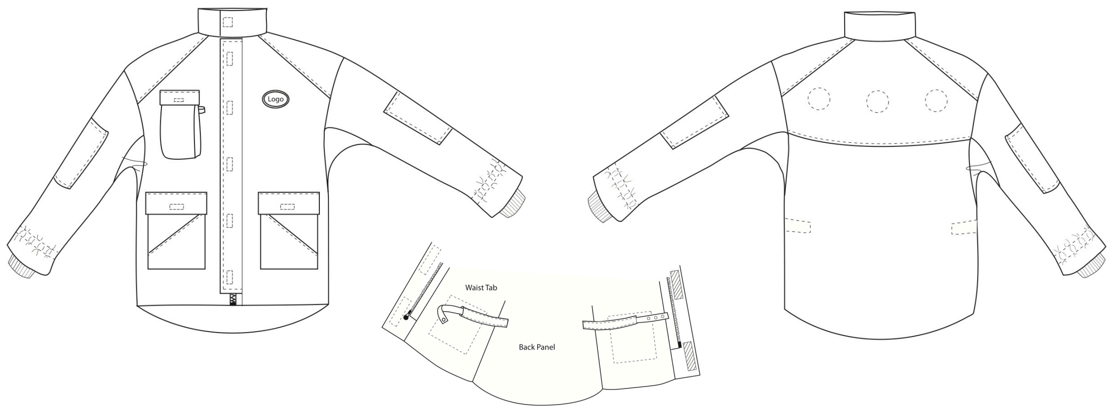
Introduction	• Researchers • Purpose of the focus group • Introduce the mock-up • How your participation helps
Environmental issues (sheet)	• Please fill out the supplied worksheet.
Ways to improve **protection**	• What are the features that you think provide adequate protection for the new garment system (*e.g.*, collar, placket, cuffs)? • What features do you think won't work or not suitable/why? • Any observed innovative solutions that have not been involved? • Any suggestions for improvements? • Any suggestion for placements of reflective tapes?
Ways to improve **comfort**	• What are the features that you think are comfortable to wear (*e.g.*, thermally, psychologically)? • What features do you think won't be comfortable/Why? • Any preferred color or style? • Any suggestions for improvements (*e.g.*, sleeve, waist, back)?
Ways to improve **fit**	• Any preferred style, loose-fitting or close-fitting? • What are the features that you think would improve the functional fit? • What features that you think won't work for fit? • Any suggestions for improvements (*e.g.*, waist, armhole, garment length)?
Manufacturing concerns	• Anything that you think might be problematic for manufacturing? • Alternative construction methods to reduce cost (e.g., seams, trims)? • Any suggestions for specific seam finishes or logo placements, etc.?
Design details to add	• Participant-driven
Summary & thanks	• Future goals & participation • Thanks

Personal Information Sheet

Name	
Age & Gender	Age __________ M ___ F ___
Position held (Title & Role)	
Working Experience in the oil industry (*e.g.*, days, months, years)	
Types of work shifts & average hours per week	Safety training ___ On-site inspection ___ Keeping records of incidents ___ Other please specify ____________________ PT ________ Hrs./Week FT ________ Hrs./Week
Use of protective clothing (Level 2 garment system)	Yes ___ No ___
Observe workers wearing protective clothing	Yes ___ No ___
Typical size worn (Multiple sizes may apply)	If "Yes" for yourself, please specify your size ___ If "Yes" for observe workers, please circle their typical sizes. XS S M L XL XXL Other ___
Typical tasks (Multiple tasks may apply)	• Steam sampling ___ • Cleaning filters & sludge traps ___ • Working close to/ Opening valves ___ • Loading & unloading hot water ___ • Spraying steam onto wellheads ___ • Other Please specify _______________________

Visual Evaluation Sheet (Jacket)

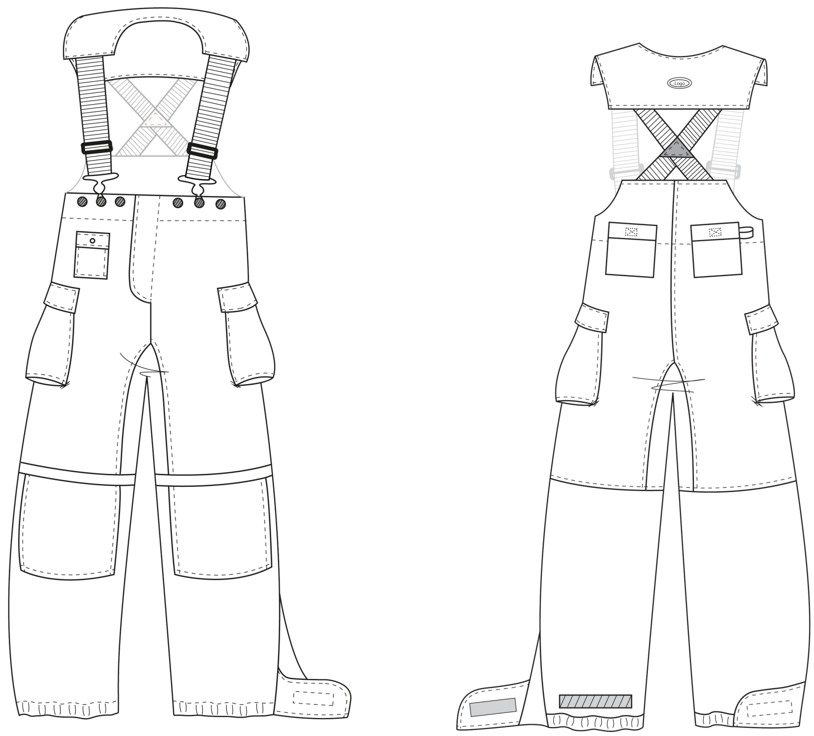
Garment system (Level 2)	Worn in addition to coveralls for short time durations
Requirements	Better protection, comfort & functional fit
*Please mark any likes in red and dislikes in blue. (Note comments below)	



Likes	Improvements needed
Collar	
Sleeve/armhole	
Pockets	
Closure systems	
Reinforcement	
Other	

Visual Evaluation Sheet (Pants)

Garment system (Level 2)	Worn in addition to coveralls for short time durations
Requirements	Better protection, comfort & functional fit
*Please mark any likes in red and dislikes in blue. (Note comments below)	



Likes	Improvements needed
Straps	
Waist	
Closure systems	
Pockets	
Reinforcement	
Other	

APPENDIX E PHOTOS OF FULL-SCALE MUSLIN PROTOTYPE

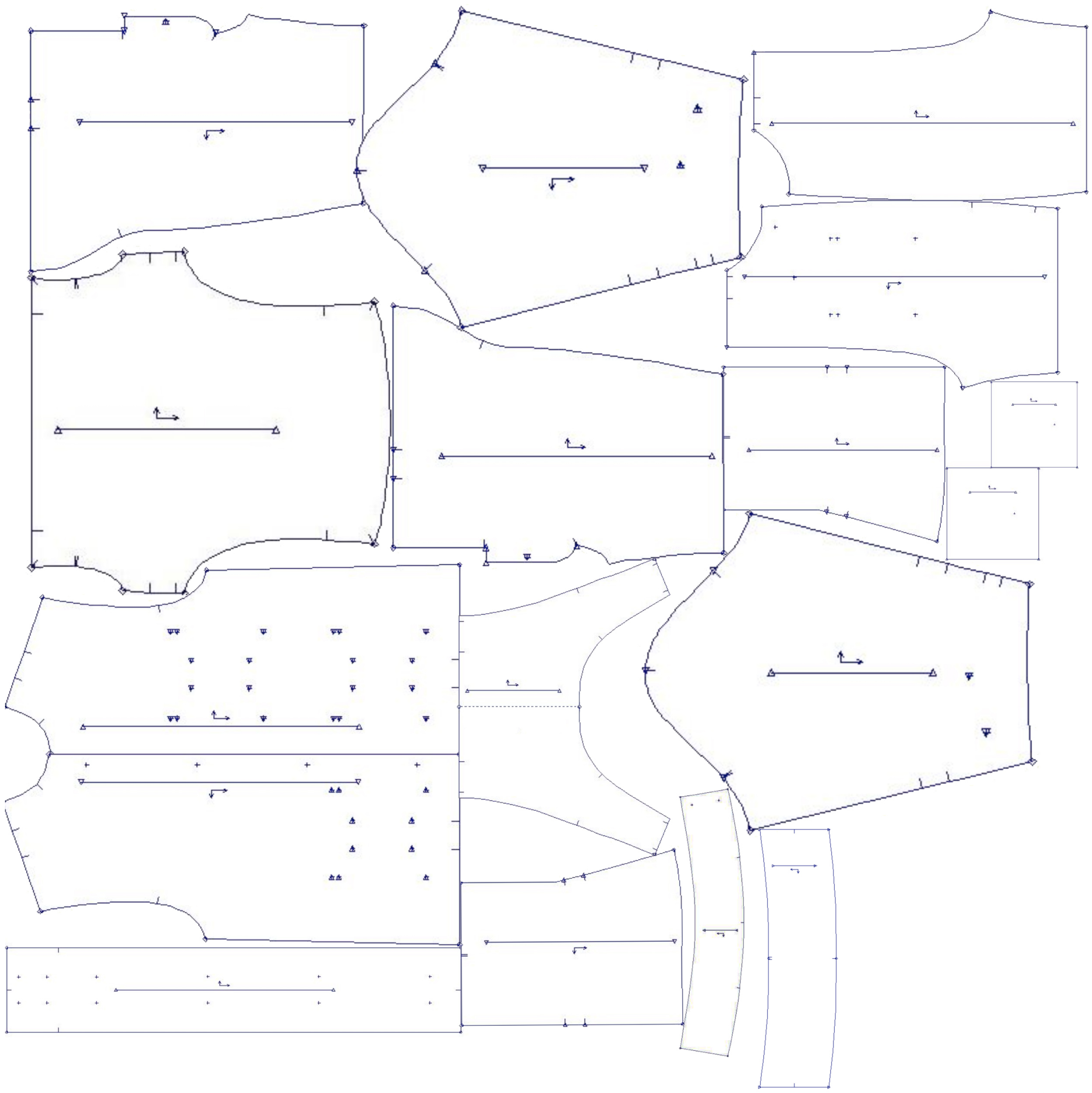
Front View of Jacket

Back View of Jacket

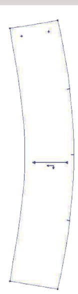
Front View of Pants

Back View of Pants

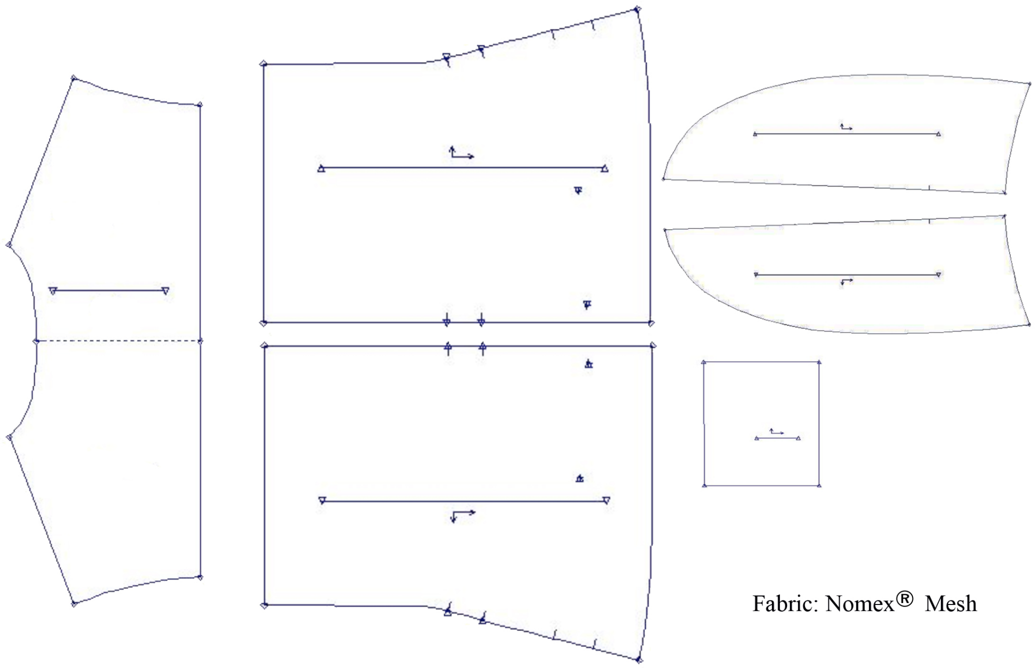
APPENDIX F   PATTERN FOR WORKWEAR DESIGN



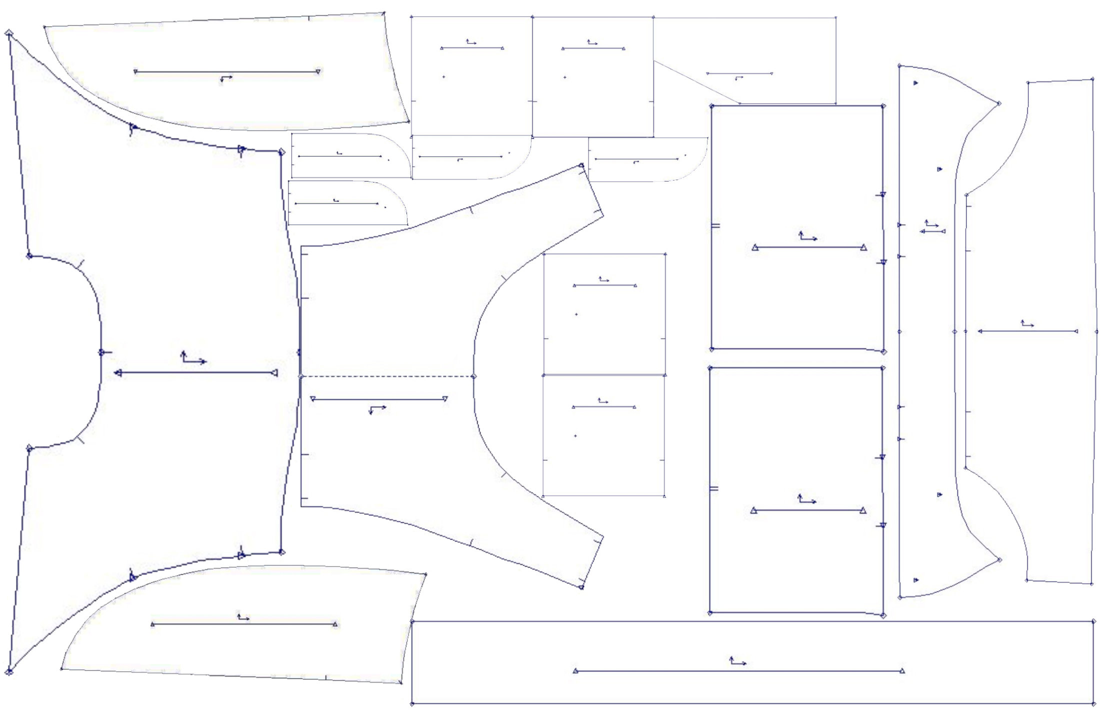
Fabric: Tri-laminate Nomex®



Fabric: Knitted rib



Fabric: Nomex® Mesh



Fabric: Single-layer Nomex®

APPENDIX G ANTHROPOMETRIC PROTOCOL

Anthropometric Protocol

1. *Height* – For baseline, measure vertically from the floor to the top of the head. The person stands erect, looking ahead, the arms relaxing at the sides.

2. *Neck circumference* – For baseline, measure from the center of the clavicle (collar bone) across the neck base and back to the center of the clavicle. For coverall, button up the collar and repeat the procedure on the outside of collar. The person stands erect, looking ahead, the arms relaxing at the sides.

3. *Chest circumference* – For both baseline and coverall, measure from the fullest part of the chest, the tape measure remaining horizontal at all positions (parallel with ground). The person stands erect, looking ahead, both hands putting on the waist.

4. *Waist circumference* – For both baseline and coverall, measure from the biggest part of the torso (at waist or stomach), the tape measure remaining horizontal at all positions (parallel with ground). The person stands erect, looking ahead, both hands putting on the waist.

5. *Hip circumference* – For both baseline and coverall, measure from the fullest part of the hip, the tape measure remaining horizontal at all positions (parallel with ground). The person stands erect, looking ahead, both hands putting on the waist.

6. *Front shoulder* – For baseline, measure from the right shoulder to left shoulder on the front (feeling for shoulder bones). For coverall, measure the widest part from the right shoulder to left shoulder on the front. The person stands erect, looking ahead, the arms relaxing at the sides.

7. *Back shoulder* – For baseline, measure from the right shoulder to left shoulder at the back (feeling for shoulder bones). For coverall, measure the widest part from the right shoulder to left shoulder at the back. The person stands erect, looking ahead, the arms relaxing at the sides.

8. *Arm length* – For baseline, measure from the shoulder bone (adjoining point) to elbow point and to the wrist bone on the right arm. For coverall, measure from the top of sleeve to the sleeve or cuff hem. The person stands erect, looking ahead, and bends right arm slightly.

9. *Waist height* – For baseline, measure from the center front waist straight down to floor. For coverall, measure from the waistband straight down to floor. The person stands erect, looking ahead, the arms relaxing at the sides.

10. *Crotch height* – For baseline, measure from the crotch (base of torso) to floor. For coverall, measure from the adjoining inseam at crotch to the floor. The person stands erect, legs very slightly apart, and holds end of the tape measure against the crotch.

11. *Sitting height* – For baseline, measure from the prominent bone at the back to the seat surface. The person sits erect, looking straight ahead, hands in lap and thighs horizontal.

APPENDIX H RECRUITMENT NOTICE, INFORMATION SHEET & CONSENT FORM

UNIVERSITY OF ALBERTA
DEPARTMENT OF HUMAN ECOLOGY

302 Human Ecology Building
University of Alberta
Edmonton, AB T6G 2N1
Phone: (780) 492-3824 | Fax: (780) 492-4821

Recruitment Notice

Date: ____

To: Employees of ______(specific firm being visited)_______

☐ Safety advisors
☐ Workers

Re: **Participants Needed** for research on Design and Evaluation of Garment System for Protection from Steam and Hot Water

I am seeking participants for field trial and evaluation of the new garment system for protection from steam and hot water in your work environment. Two groups of participants are anticipated: the safety advisors and the workers, who have at least half a year working experience in the oil industry regardless of gender, age, stature etc. The safety advisors will take part in a one-session indoor controlled exercise with on-the-spot interview and observation, and the workers will take part in a two-week field trial. Your participation is entirely voluntary.

If you are interested in discussing the steam and hot water hazards in the oil industry, or you are the potential wearer of the garment system and wish to contribute to the evaluation of it, you are especially invited to participate.

If you have concerns or questions about this research before volunteering, you may contact me directly or may speak to (name of plant safety advisors/supervisor). If you wish to volunteer, please complete the form below and return it to me or give it to (name of the safety advisor/supervisor).

Yes, I am interested in participating in the field trial on the new garment system for protection from steam and hot water to take place at ___(specific firm being visited)_____

Name: ___________________________ Job title: ___________________________

Phone at work: ___________________ E-mail (if applicable): ___________________

UNIVERSITY OF ALBERTA
DEPARTMENT OF HUMAN ECOLOGY

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Design and Evaluation of Garment Systems for Protection from Steam and Hot Water

[Information Sheet]

Principle investigator: Sihong Yu University of Alberta (780) 667-4403
Supervisor: Dr. Megan Strickfaden University of Alberta (780) 729-0143

Purpose: The purpose of this research is to investigate and develop improved garment system for the oil industry workers for protection from steam and hot water. This garment system is designed for handling specific tasks with steam and/or hot water involved. Specific objectives for this evaluation are to evaluate the new garment system in the real working environments.

Method: You will take part in a one-month long field trial. We will provide the garment and you will wear it to perform tasks involving steam and hot water or whenever you want. You will keep a daily record of garment use (sheet provided) which will take about ten minutes each day, and complete an evaluation scale at the end of the week which will take about fifteen minutes. Four weeks of participation is anticipated.

Confidentiality: With your consent, the interview will be recorded and will be later transcribed by the investigator or an assistant. The investigator will not record your name. Photographs will not include any identifiable information (*e.g.*, avoid your face, head or name badge). Consent forms with your signature will be lock up separately from the interview transcripts. If other than one participant is present, all of them will be asked to respect confidentiality and feelings of others.

The data will be stored in a secure location (e.g., a locked file cabinet and secure computer) that is accessible only to the researchers. The coded results will be used for the purposes of a graduate thesis only, and if used in any future presentation/publication, all the identities will be protected (e.g., using assigned ID number instead of real name, faces blurred in photos). All the data will be kept for five years, and after this period they will be destroyed and deleted.

Benefits: The expected long-term benefits of this research will be that the garment system is more effective and comfortable in protecting from steam and hot water.

Risks: We do not anticipate any risks associated with your participation in this research.

Withdrawal from the Study: It is completely voluntary to take part in this research, and you may withdraw from the study at any time for any reason without any disadvantage to yourself. If you complete the study you may ask to remove your data any time before it is

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analyzed (before January, 2013) by contacting the researcher in person, by telephone or email.

Should you have any questions or concerns regarding your rights as a participant, or how this study is being conducted, you may contact the University of Alberta's Research Ethics Office at 780-492-2615. This office has no affiliation with the study investigators.

Study investigators:
Sihong Yu, MSc Candidate
Graduate student | Department of Human Ecology| University of Alberta
sihong@ualberta.ca | 780-667-4408
Megan Strickfaden, PhD
Assistant professor | Department of Human Ecology| University of Alberta
megan.strickfaden@ualberta.ca | (780) 729-0143

UNIVERSITY OF ALBERTA
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Design and Evaluation of Garment Systems for Protection from Steam and Hot Water

[Consent Form]

Principle investigator: Sihong Yu University of Alberta (780) 667-4403
Supervisor: Dr. Megan Strickfaden University of Alberta (780) 492-3012

Do you understand that you have been asked to be in a research study?	Yes	No
Has this research been explained to you by the researcher?	Yes	No
Have you read and received a copy of the attached Information Sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this research study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate, or to withdraw from the study at any time without any disadvantage to yourself?	Yes	No
Do you understand that you will be recorded during the interviews?	Yes	No
Has the issue of confidentiality been explained to you?	Yes	No
Do you understand who will have access to your information?	Yes	No

_________________________________ _____________________

Signature of Research Participant Date

____

Printed Name

APPENDIX I   PACKAGE INSTRUCTION & PREPARATION FORM

PACKAGE INSTRUCTION

- **In this package you will receive a set of 9 documents, including:**

    #1. Information sheet (2 pages)
    #2. Consent form (1 page)
    #3. Preparation form (1 page)
    #4. Pre-trial fit assessment for jackets/pants (2 pages)
    #5. Garment daily use record [1] (2 pages)
    #6. Garment daily use record [2] (2 pages)
    #7. Wear acceptability scale for the prototype [1] (2 pages)
    #8. Wear acceptability scale for the prototype [2] (2 pages)
    #9. Post-trial fit assessment for jackets/pants (2 pages)

To keep your information confidential, you would be assigned an ID when recording these documents. The researcher would need to collect the consent form and the preparation form after the first meeting, and you would keep and record the rest of the documents.

- **Procedure of recording the documents:**

Cycle One: Upon distribution of your sized prototype, you are required to try it on and fill out the form **Pre-trial fit assessment for jackets/pants** (#4). Please start recording in the **Garment daily use record [1]** (#5) on the first day that you wear the prototype for work purpose. Please fill out the form for **Wear acceptability scale for the prototype [1]** (#7) upon completion of the **Garment daily use record [1]**. In Cycle One 7 days of prototype use record is expected.

Please send completed document #4, #5 and #7 in the envelope in your package to the researcher at the end of Cycle One.

Cycle Two: After returning to work from your week off, please start recording in the **Garment daily use record [2]** (#6). Please fill out the form for **Wear acceptability scale for the prototype [2]** (#8) upon completion of the **Garment daily use record [2]**. In Cycle Two another 7 days of prototype use record is expected. At the end of Cycle Two, please try on the prototype again and fill out the **Post-trial fit assessment for jackets/pants** (#9).

Please send completed document #6, #8 and #9 in the envelope in your package to the researcher at the end of Cycle Two.

Thanks very much for your corporation.

During any stage of the trial, please feel free to contact the researcher, **Sihong Yu** via the contact* below.

*Email: sihong@ualberta.ca | Tel: (780) 667-4403 | Skype ID: shelley.dhu

PREPARATION FORM

[This sheet is to record background information and to ensure proper fit, upon which a best-fitting prototype will be distributed to the participant.]

1. Participant Information

ID	AGE	POSITION	RESPONSIBILITY	EXPERIENCE
		☐ Safety advisor ☐ Regular operator	☐ Plant ☐ Field ☐ N/A ☐ Maintenance	____Year_____Months

WORKING SCHEDULE	WEEK 1		WEEK 2		WEEK 3	
	☐ Mon	☐ Tue	☐ Mon	☐ Tue	☐ Mon	☐ Tue
	☐ Thur	☐ Fri	☐ Thur	☐ Fri	☐ Thur	☐ Fri
	☐ Sat	☐ Sun	☐ Sat	☐ Sun	☐ Sat	☐ Sun
	☐ Off		☐ Off		☐ Off	

2. Background Information

DATE	SITE	TEMPREATURE	RH
_____/_____/2012		Low / High ℃	_______%

3. Measurements for baseline

	cm		cm		cm
1. Height		5. Hip		9. Waist height	
2. Neck		6. Front shoulder		10. Inseam	
3. Chest		7. Back shoulder		11. Sitting height	
4. Waist		8. Arm length			
* All participants need to wear fitted clothing as baseline (*e.g.*, T-shirt, jeans)					

4. Measurements with coverall over baseline

	cm		cm		cm
1. Neck		4. Hip		7. Arm length	
2. Chest		5. Front shoulder		8. Waist height	
3. Waist		6. Back shoulder		9. Crotch height	
* All participants need to wear coverall over their baseline					

5. Size of Best-fitting Prototype

☐S ☐M ☐L ☐XL ☐XXL ☐3XL ☐4XL ☐5XL ☐Other__________

6. Comments

APPENDIX J PHOTOS OF FABRIC PROTOTYPE




APPENDIX K GARMENT DAILY USE RECORD, FIT ASSESSMENT & EVALUATION SHEET

Contact: Sihong Yu
sihong@ualberta.ca| (780) 667-4403

GARMENT DAILY USE RECORD

ID:_____ PROTOTYPE SIZE: ________

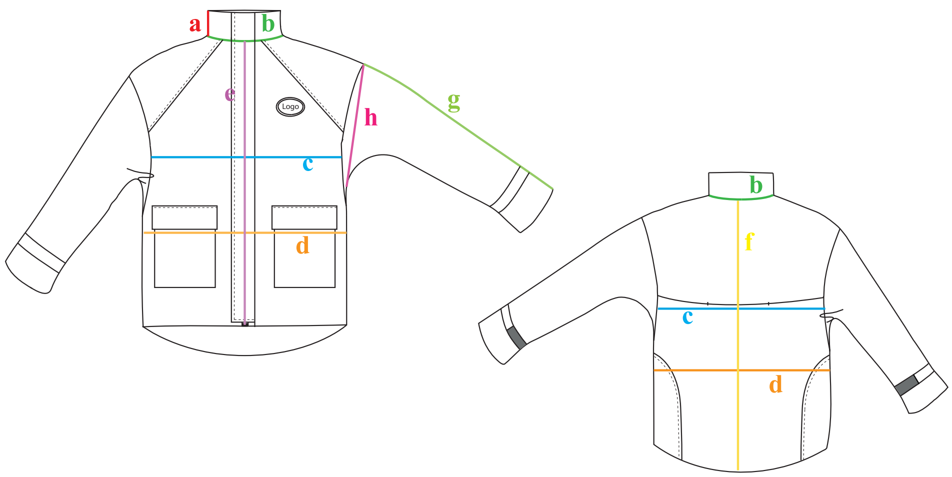
[The purpose of this sheet is for you to record the frequency of wearing the prototype and the working conditions on a daily basis.]

1. Date (mm/dd/yy)					
2. Weather of the day (temperature)		Low / High ℃	Low / High ℃	Low / High ℃	Low / High ℃
3. Shift – if applicable		☐ Day ☐ Night	☐ Day ☐ Night	☐ Day ☐ Night	☐ Day ☐ Night
4. Shift starts/ends (e.g., 9:00 am/3:00 pm)		/	/	/	/
5*. How long did you wear the jacket/pants/combination of the two for (e.g., 30 min/1.5 hrs/all shift)?	Jacket				
	Pants				
	Combination				
6**. How many times did you put on/take off the jacket/pants?	Jacket	Put on ______× Take off ______×	Put on ______× Take off ______×	Put on ______× Take off ______×	Put on ______× Take off ______×
	Pants	Put on ______× Take off ______×	Put on ______× Take off ______×	Put on ______× Take off ______×	Put on ______× Take off ______×
7. Clothing worn underneath and other PPE worn - Select all that apply. * Multiple ways of wearing may apply and please fill out however long you wear each of the indicated ones. Combination means you wear the jacket and the pants at the same time. ** Please include the first time putting it on for work and taking if off after work (e.g., put on __1__ ×, take off __1__ ×)		☐ Coverall ☐ Shirt ☐ Jeans ☐ Gloves ☐ Goggle ☐ Boots ☐ Headwear ☐ Other ________	☐ Coverall ☐ Shirt ☐ Jeans ☐ Gloves ☐ Goggle ☐ Boots ☐ Headwear ☐ Other ________	☐ Coverall ☐ Shirt ☐ Jeans ☐ Gloves ☐ Goggle ☐ Boots ☐ Headwear ☐ Other ________	☐ Coverall ☐ Shirt ☐ Jeans ☐ Gloves ☐ Goggle ☐ Boots ☐ Headwear ☐ Other ________
8. Did you carry any personal tools (e.g., cellphone/keys/wallet) today? Please specify.					
9. How do you feel wearing the jacket/pants/ combination (e.g., cold/hot/warm/cool) today?	Jacket				
	Pants				
	Combination				
10. Work/tasks worn (e.g., welding/steam sampling/ vehicle operation/loading hot water) – Please specify.					
11. Work condition (e.g., muddy location/greasy /office work/clean)					

PRE-TRIAL FIT ASSESSMENT FOR JACKET

[Please fill out this form at the **beginning of the trial**, e.g., at the first time you try it on.]

Instruction: Evaluated the following component of the prototype by placing a check on the rating scale provided, “1” indicating very good fit and “5” indicating very poor fit.



JACKET	1 Very good fit	2 Good fit	3 Neutral	4 Poor fit	5 Very poor fit
a Collar height	________	________	________	________	________
b Neckline	________	________	________	________	________
c Chest girth	________	________	________	________	________
d Waist girth	________	________	________	________	________
e Center front length	________	________	________	________	________
f Center back length	________	________	________	________	________
g Sleeve length	________	________	________	________	________
h Armhole width	________	________	________	________	________
Overall fit	________	________	________	________	________

What are you wearing underneath?

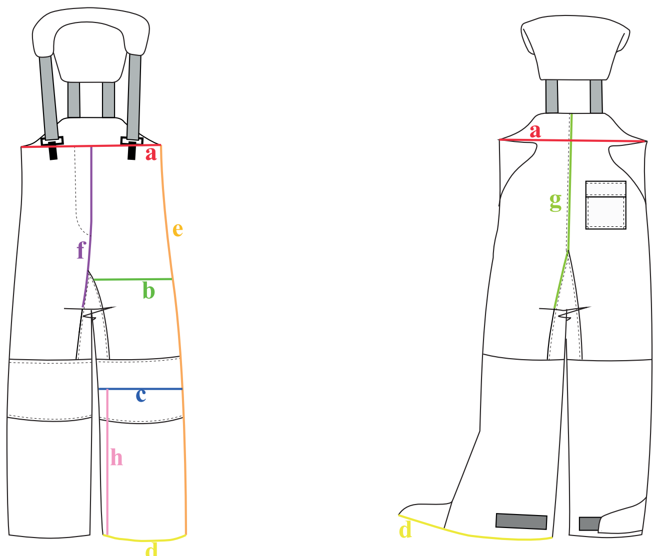
☐ Coverall ☐ Shirt ☐ T-shirt ☐ Jeans ☐ Overall ☐ Other ________

ID: _______

PRE-TRIAL FIT ASSESSMENT FOR PANTS

[Please fill out this form at the **beginning of the trial**, e.g., at the first time you try it on.]

Instruction: Evaluated the following component of the prototype by placing a check on the rating scale provided, “1” indicating very good fit and “5” indicating very poor fit.



	PANTS	1 Very good fit	2 Good fit	3 Neutral	4 Poor fit	5 Very poor fit
a	Waist girth	______	______	______	______	______
b	Thigh width	______	______	______	______	______
c	Knee width	______	______	______	______	______
d	Leg opening	______	______	______	______	______
e	Outseam	______	______	______	______	______
f	Front rise	______	______	______	______	______
g	Back rise	______	______	______	______	______
h	Knee height	______	______	______	______	______
	Overall fit	______	______	______	______	______

What are you wearing underneath?

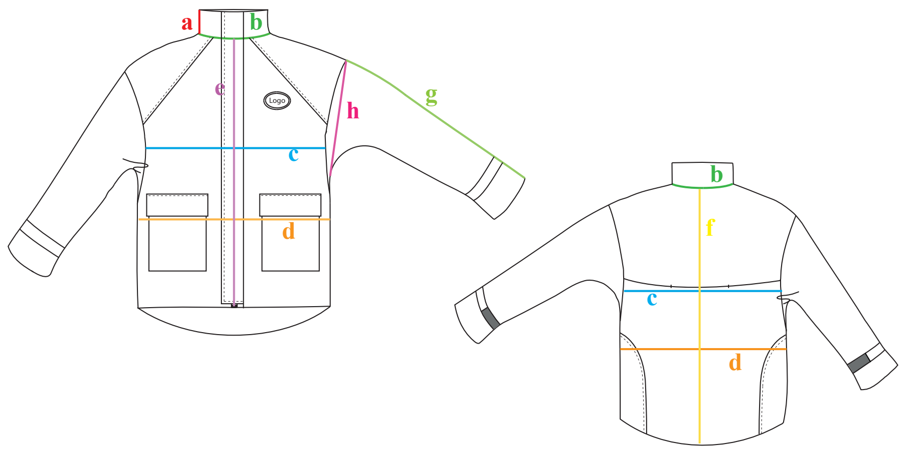
☐ Coverall ☐ Shirt ☐ T-shirt ☐ Jeans ☐ Overall ☐ Other ______

ID: ________

POST-TRIAL FIT ASSESSMENT FOR JACKET

[Please fill out this form at the **beginning of the trial**, e.g., at the first time you try it on.]

Instruction: Evaluated the following component of the prototype by placing a check on the rating scale provided, “1” indicating very good fit and “5” indicating very poor fit.



	JACKET	1 Very good fit	2 Good fit	3 Neutral	4 Poor fit	5 Very poor fit
a	Collar height	________	________	________	________	________
b	Neckline	________	________	________	________	________
c	Chest girth	________	________	________	________	________
d	Waist girth	________	________	________	________	________
e	Center front length	________	________	________	________	________
f	Center back length	________	________	________	________	________
g	Sleeve length	________	________	________	________	________
h	Armhole width	________	________	________	________	________
	Overall fit	________	________	________	________	________

What are you wearing underneath?

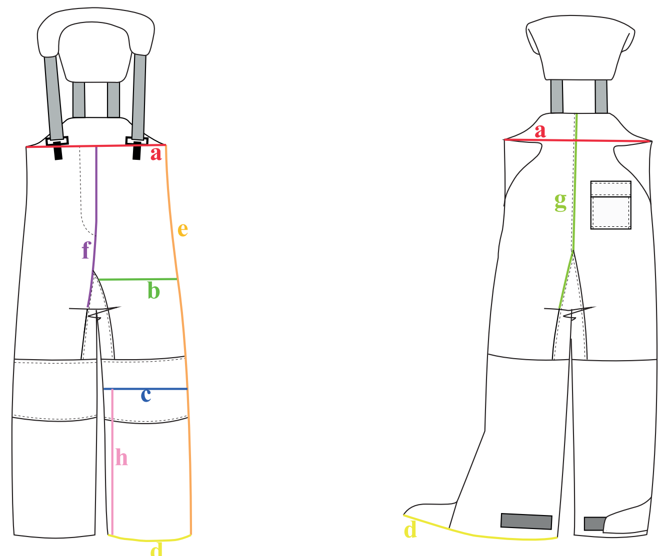
☐ Coverall ☐ Shirt ☐ T-shirt ☐ Jeans ☐ Overall ☐ Other ________

ID:________

POST-TRIAL FIT ASSESSMENT FOR PANTS

[Please fill out this form at the **beginning of the trial**, e.g., at the first time you try it on.]

Instruction: Evaluated the following component of the prototype by placing a check on the rating scale provided, “1” indicating very good fit and “5” indicating very poor fit.



	PANTS	1 Very good fit	2 Good fit	3 Neutral	4 Poor fit	5 Very poor fit
a	Waist girth	______	______	______	______	______
b	Thigh width	______	______	______	______	______
c	Knee width	______	______	______	______	______
d	Leg opening	______	______	______	______	______
e	Outseam	______	______	______	______	______
f	Front rise	______	______	______	______	______
g	Back rise	______	______	______	______	______
h	Knee height	______	______	______	______	______
	Overall fit	______	______	______	______	______

What are you wearing underneath?

☐ Coverall ☐ Shirt ☐ T-shirt ☐ Jeans ☐ Overall ☐ Other ______

WEAR ACCEPTABILITY SCALE FOR THE PROTOTYPE

[To be completed after finishing 'Garment Daily Use Record [1]', rating on a 9-point scale, "1" being most favorable and "9" being least favorable]

Instructions: Please circle only one rating per item. If not applicable, you can draw a line across the item without rating.

Overall good acceptability	1	2	3	4	5	6	7	8	9	Overall poor acceptability
JACKET										
1. Good collar closure	1	2	3	4	5	6	7	8	9	Poor collar closure
2. Good cuff closure	1	2	3	4	5	6	7	8	9	Poor cuff closure
3. Freedom movement/shoulders	1	2	3	4	5	6	7	8	9	Restricted movement/shoulders
4. Freedom movement/arms	1	2	3	4	5	6	7	8	9	Restricted movement/arms
5. Freedom movement/waist	1	2	3	4	5	6	7	8	9	Restricted movement/waist
6. Good venting system	1	2	3	4	5	6	7	8	9	Poor venting system
7. Satisfactory fit	1	2	3	4	5	6	7	8	9	Unsatisfactory fit
PANTS										
1. Ease of putting the pants on	1	2	3	4	5	6	7	8	9	Difficulty putting pants on
2. Ease of taking pants off	1	2	3	4	5	6	7	8	9	Difficulty taking pants off
3. Freedom movement/crotch	1	2	3	4	5	6	7	8	9	Restricted movement/crotch
4. Freedom movement/knees	1	2	3	4	5	6	7	8	9	Restricted movement/knees
5. Good hem closure on pants	1	2	3	4	5	6	7	8	9	Poor hem closure on pants
6. Freedom movement/sitting	1	2	3	4	5	6	7	8	9	Restricted movement/sitting
7. Freedom movement/crawling	1	2	3	4	5	6	7	8	9	Restricted movement/crawling
8. Freedom movement/climbing	1	2	3	4	5	6	7	8	9	Restricted movement/climbing
9. Freedom movement/bending	1	2	3	4	5	6	7	8	9	Restricted movement/bending
11. Comfortable vest/strap	1	2	3	4	5	6	7	8	9	Uncomfortable vest/strap
12. Satisfactory fit	1	2	3	4	5	6	7	8	9	Unsatisfactory fit
COMBINATION										
1. Light garment system	1	2	3	4	5	6	7	8	9	Heavy garment system
2. Flexible	1	2	3	4	5	6	7	8	9	Stiff
3. Thermally comfortable	1	2	3	4	5	6	7	8	9	Thermally uncomfortable
4. Body adequately covered	1	2	3	4	5	6	7	8	9	Body inadequately covered
5. Adequate pockets	1	2	3	4	5	6	7	8	9	Inadequate pockets
6. Likes the design/look	1	2	3	4	5	6	7	8	9	Dislikes the design/look
7. Overall satisfactory fit	1	2	3	4	5	6	7	8	9	Overall unsatisfactory fit

Open-ended questions

A. Overall rate your work during this time period. Multiple choices and your own words may apply.

Angry **Stressful** **Challenging** **Neutral** **Ordinary** **Happy**

B. Describe any challenges/discomfort you have with the jacket/pants/combination (e.g., zipping up the jacket, putting the pants on, stretching arms, interfered with gloves or other PPE, too hot to wear in summer).

C. Describe pocket use (e.g., whether pockets are enough, where to place the pockets, how the pocket flap works).

D. Wear/Abrasion – Describe your impressions.

E. What are the three things you like most about the garment system?

F. What are the three things you dislike most about the garment system?

* If you need any assistance or explanation regarding this form or research, we can be reached by the contact below:

E-mail: sihong@ualberta.ca | Tel: (780) 667-4403 | Skype: shelley.dhu

APPENDIX L FLOW OF METHODS INCORPORATED IN THE STUDY

- ▲ Call to action
- ▲ Focus group interviews
- ▲ Field observations & on-site interview
- ● Analysis of photographic documentation
- ● Site visits
- ● Precedent garment observation
- ● Ideation of sketches & mock-up development
- ▲ Textile tesing
- ● Focus group evaluation on preliminary design
- ● Desgin criteira, guidelines & recommendations
- ▲ Seam testing
- ● Pattern design & prototype development
- ● Site visits for anthropometric study
- ● Prototype production with manufacturer
- ● Wear trial

▲ = Teamwork conducted in the bigger project

● = Methods and research activities performed in this study