Mismatching products and safety

Design of personal protection equipment for cold environments

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ABSTRACT

New discoveries of oil in the far north present new challenges for the oil industry facing cold climate. The existing equipment is not designed for such purposes and exposes workers for noise and cold related injuries in worst case, as well as reduced capacity due to lack of working comfort. The article points out the hazards related to cold and noise, as well as suggesting design methods to solve complex problems taking both technical and user demands into consideration.

KEYWORDS (Arial 10): Safety, design methodology, cold, noise, personal protection, apparel design.

1. INTRODUCTION

The oil industry is moving further north in its search for oil. 30 % of the undiscovered gas and 12 % of the worlds undiscovered oil may be found north of the Arctic circle[1]. This implies new challenges regarding the extreme environments in this area. For workers on an installation this includes extreme cold, (January average of -10 to - 20˚C in [2]) wind, and ice. This has to be taken into consideration when designing new equipment to provide better working conditions. As well as freezing, sweating is important to avoid while dressing for cold environments [3]. Sweating will result in a wet layer of clothing that may freeze, resulting in reduced insulation. Workload, conditions and individual differences makes this a challenging task. Existing garments doesn't offer good enough regulation of the clothing insulation to match the varying physical strain. Workers are not likely to have sufficient knowledge on how this applies to them, not used to such conditions. Combining existing solutions to meet the needs of both industrial safety and cold weather protection has shown reduced performance in the equipment[4], meaning reduced total safety and comfort for the workers [5]. Earlier reports point out the need to design new equipment to better meet the challenges related to the field of ergonomics and human factors.[6]

1.1 Design for the oil industry

The oil industry has strict requirements for equipment used on a platform, amongst them NORSOK [7].Factors such as explosion hazard are limiting the freedom of design solutions, in addition to requirements found elsewhere in heavy industry. Designing new products has to take all of these requirements as well as the existing products used into the consideration. How can redesign of equipment such as a balaclava adds the necessary protection to the cold environments without compromising the safety in other fields? New equipment should feel like a natural extension of the usual equipment, to secure optimal comfort and focus on the task. The high cost related to working-hours on a platform, and personnel being unable to do their job, is another reason to further work on this field. Solutions that could increase the window of safe operations on a platform will be of high value to a company. This article will take a look at problems related to personal protection equipment and extreme climate. Through a design perspective search for ways to find solutions that could improve today's situation and present suggestions to improvements of personal equipment for protection of cold weather with a special focus on the combination of cold and hearing protection.

2. SPECIAL CONDITIONS

2.1 Environmental conditions

There are several factors that impact the heat exchange between the human body and the environment. Amongst these are temperature, humidity, air movement, radiative heating, exertion levels, clothing, and duration of exposure [8]. The four first are given by nature, while we can minimize their consequences by adjusting the three last ones. There are several measuring methods developed to predict the effects on human; The Wind Chill Index (WCI) was developed to calculate the risk of frostbite on given wind and temperature. Later research found some errors in the calculation methods and developed the Wind Chill Equivalent Temperature index (WCET). The new index uses modern methods to give a more precise temperature equivalent to calculate the risk of frostbite. The Required insulation (IREQ) [9] index was developed to guide workers in dressing to maintain the human heat balance. This takes the whole body cooling into consideration, by adding factors such as the metabolic rate and heat loss from the body. An interview conducted on Glestad and Flesland after their attempt to reach the north- pole showed a reality beyond the levels of this scales during the coldest days. Examination of the IREQ index shows that workers have problems with dressing sufficiently when the insulation required is higher than 2 Clo. Clo is a unit that describes the level of clothing insulation where 0 Clo corresponds to a naked person, and 1 Clo corresponds to the insulation needed to maintain comfort in room temperature (21°C) wearing a business suit. [10]

Wind speed (km h⁻¹)	Air temperature (°C)											
Calm	5	0	–5	–10	–15	–20	–25	–30	–35	–40	–45	–50
5	4	–2	–7	–13	–19	–24	–30	–36	–41	–47	–53	–58
10	3	–3	–9	–15	–21	–27	–33	–39	–45	–51	–57	–63
15	2	–4	–11	–17	–23	–29	–35	–41	–48	–54	–60	–66
20	1	–5	–12	–18	–24	–30	–37	–43	–49	–56	–62	–68
25	1	–6	–12	–19	–25	–32	–38	–44	–51	–57	–64	–70
30	0	–6	–13	–20	–26	–33	–39	–46	–52	–59	–65	–72
35	0	–7	–14	–20	–27	–33	–40	–47	–53	–60	–66	–73
40	–1	–7	–14	–21	–27	–34	–41	–48	–54	–61	–68	–74
45	–1	–8	–15	–21	–28	–35	–42	–48	–55	–62	–69	–75
50	–1	–8	–15	–22	–29	–35	–42	–49	–56	–63	–69	–76
55	–2	–8	–15	–22	–29	–36	–43	–50	–57	–63	–70	–77
60	–2	–9	–16	–23	–30	–36	–43	–50	–57	–64	–71	–78
65	–2	–9	–16	–23	–30	–37	–44	–51	–58	–65	–72	–79
70	–2	–9	–16	–23	–30	–37	–44	–51	–58	–65	–72	–80
75	–3	–10	–17	–24	–31	–38	–45	–52	–59	–66	–73	–80
80	–3	–10	–17	–24	–31	–38	–45	–52	–60	–67	–74	–81
	Low risk of frostbite				Increasing risk of frostbite within 30min of exposure	High risk of frostbite in 5 to 10min of exposure	High risk of frostbite in 2 to 5min of exposure		High risk of frostbite in 2min of exposure or less			

Note: Wind chill does not lower the actual air temperature and it does not take into account the effect of sunshine.
Source: Nelson *et al.*, 2002.

Figure 1 New wind chill equivalent temperature (WCET) chart

The effect of sunshine is not included in these indexes, but the arctic environments do have a high exposure of sunlight in the summer season, and UV rays and reflections from bright surroundings should be taken into consideration when designing PPE for the facial areas.

2.2 Design in restricted environments

To come up with new solutions in a field traditionally dominated by classic products, with little to no innovation the last years, puts pressure on the designer. In the case of safety helmets for industrial use they look more or less the same as they did 50 years ago. There have been some changes to materials and adjustments, but they still consist of a hard shell with an inner adjustable frame to fit to the head. Martin Liedtke [11] states the problem where directives aims for a certain standard, while in complex or new situations employers nor employees can fulfill this requirements because of unsatisfactory equipment. The same requirements from the EEC [12] puts

Protection	Head protection	Eye and face protection	Hearing protection	Respiratory protective equipment	Hand protection	Foot protection	Protective clothing	Equipment designed to prevent drowning	PPE against falls from a height
Head protection		X	X	X					X
Eye and face protection		X	X	X					X
Hearing protection			X	X			X		
Respiratory protective equipment							X	X	X
Hand protection					X		X		
Foot protection							X		
Protective clothing								X	X
Equipment designed to prevent drowning									X
PPE against falls from a height									X

Figure 2: PPE combinations, for which a decrease of protection level(s) may occur due to interactions, are indicated by the check mark symbol X.

Figure 2 Table of Conflicting PPE, (Finnish institute of Occupational Health, 2012)

responsibility on the designer of safety equipment to ensure that all equipment meet this standards. This makes it an expensive, time consuming and difficult task to come up with radical new designs in this industry. Talks with SINTEF on this front state the point that new designs can be hard to get through all the certification needed. The EC PPE guidelines [13], annex II states that these are made as "new approach" directive, which means that the manufacturer can use all available technology to meet the relevant Basic Health and safety Requirements (BHSRs).

3 LITTERATURE REVIEW

3.1 Complexity in the design process

Working with complex problems often leads to a feeling of not knowing where to start. In the book “Complexity and other beasts – a guide to mapping workshops”, [14] the author suggests mapping of the situation on a larger scale to get a good overview of what’s existing and to gain a common understanding of the problem. The starting point can be anywhere; the important thing is just to start somewhere. D. Norman states in the book “Living with complexity”[15] that complexity is a necessity in the world, simplicity has to be obtained in the brain. Humans use mind mapping as a tool to gain understanding of complex situation, making them more understandable. Tesler, former vice president of Apple argued that the level of complexity is constant; the problem is who has to deal with it. The designer’s role is to manage the complexity so that it isn’t complicated or confusing for the user. [16]Norman divides the goals of a task into higher- and lower-level goals and tasks. A single mechanical tool doesn’t cause problems, but as soon as the tools are used in a way not thought trough by the designer, problems start to show. Interruptions such as emergencies or communication problems between users could also be a problem source.

Emergency behavior takes the focus away from the importance of own safety and the risk of the user left unprotected. Using easy recognizable factors such as color coding and symbols to guide the user in stressful situations would support the “knowledge in the world” theory [15], and help users making the right decisions, without having to remember the specific details. Many products are designed as if they were the only object around. This may not be the main cause for PPE, but it does happen.

3.2 IDEO design philosophy

Understand; Observe; Visualize; Evaluate; Implement. [17] The phase of observing is a topic where IDEO turned normal research on its head. Instead of testing on a group of normal users, they find the extremities, completely strangers to the product on the one side, and extreme users, users that are directly in touch with this product every day. The value of traditional market research has little value, as users tend to describe what they think they do, not what they really do. In the next step, visualize, they use 3d models and mockups for what it’s worth. Testing on even a low-fi, real prototype usually gains better insights then presenting a 2d sketch. This method is commonly known as rapid prototyping. They then go out of the user centered process to evaluate the feedback and results they have gained. The final stage of Implementing brings the user back in, to figure out if this solution is realistic, and if it solves the client’s needs in the best way.

“The fuzzy front end” is a terminology used to describe the process going from a wide problem to more specific solutions. The description has its roots from the digital world; the problems are the same in any design process. Designers are trained with techniques to solve this in a less “fuzzy” way, and to pick processes with a better chance to come up with a suitable solution.

3.3 Apparel design

When designing apparel there are several areas that require attention to assure a good final product. These can be divided into the areas of

- Fabrics and materials
- Seams and construction

These are highly depending on each other. The process of selecting proper fabrics for the garment includes considering requirements given such as fire hazard, comfort, as well as insulation. Seams and construction techniques are sometimes given by the material, but the placing of seams, the distribution of different materials and the amount of ease and fitting is important for the end product to work properly in its intended use. Materials with stretch is commonly used for next to skin garments to provide individual fitting and good movement. The stretch of materials is quite varying, and will have a huge impact in how patterns will be developed. Choosing to use stretchy materials can exclude some features such as water resistance, and to a certain degree, implementation of electronic technology can be difficult to achieve and in the same time keep the ability to stretch. Special design methods are developed to meet the special needs in the apparel design process. Orlando’s "functional apparel design process", [18] is a seven step design process including a general request for the design, exploration of the design situation, problem structure, development of design criteria, interaction matrix, prototype and evaluation, with suggested techniques to each step. The process takes the priorities into consideration by listing, ranking and weighing design criteria. Lamb and Kallal's [19] FEA model for apparel design combines Functional, expressive and aesthetic considerations for different end users, based on their needs. The design process includes problem, ideas, design refinement, prototyping, evaluation and implementation. Considerations are made on the FEA model to establish priorities between the different needs, by looking into user needs. A problem with user based research is that users often don't know what is possible and what they can expect. When judging prototypes or ideas, they often judge out of practical means, such as good pockets, (better pockets than what I'm used too). Finally Yu-Sihong [20] presents a multi method approach where each step in the functional apparel design process are solved with non-empirical or empirical methods, chosen to solve the steps in the best way possible given the frames of the project.

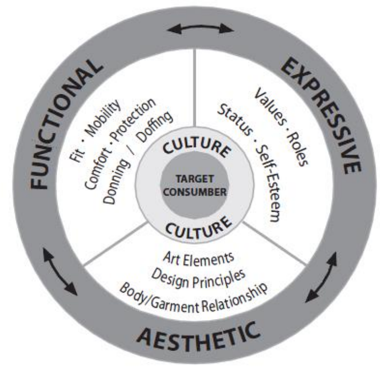

Figure 3 FEA consumer needs model (Lamb & Kallal, 1992)

The Quality Function Deployment planning tool (QFD) product planning matrix (figure 4) was discussed to plan the design of a fireman's safety harness [21]. The tool is useful to map out requirements from different holds, and give

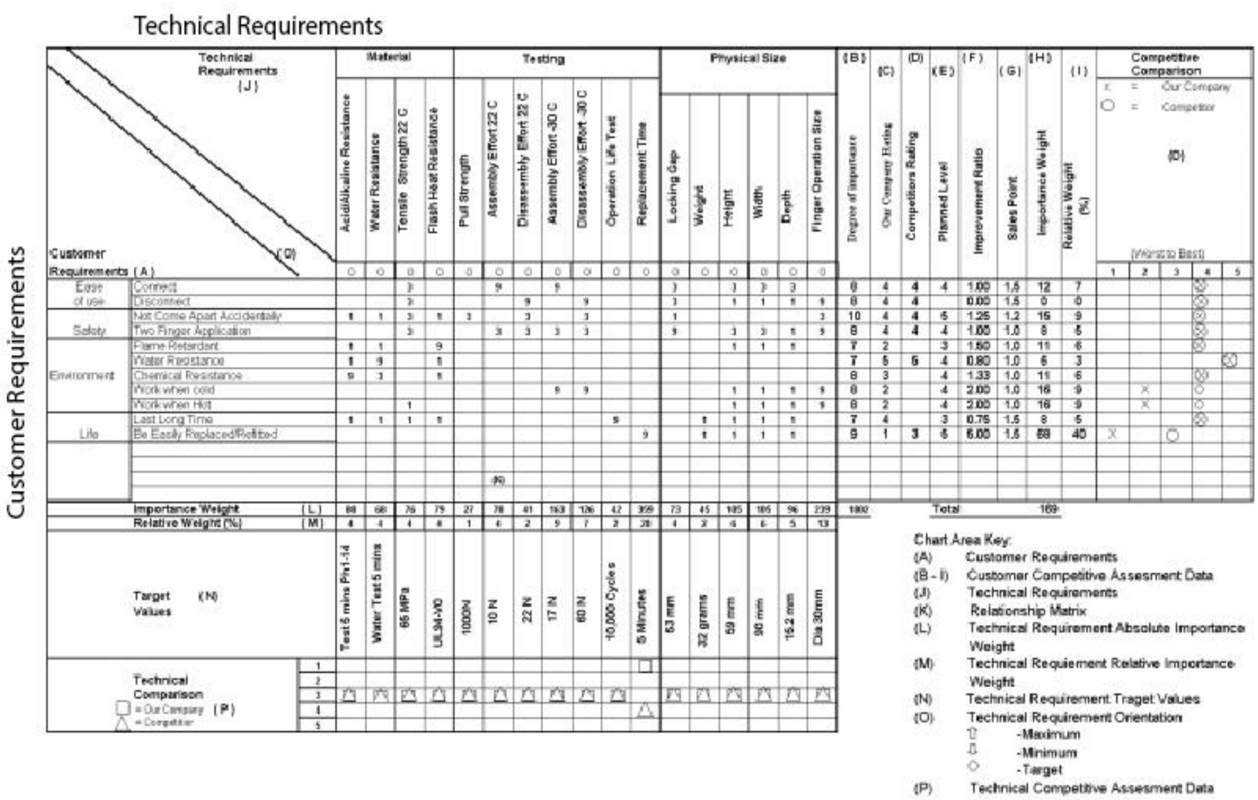

Figure 4 QFD Product Planning Matrix (Parkin, et al, 2008)

quantitative measures to guide design decisions.

3.4 Health effects on noise

In studies on hearing loss, workers in the oil and gas industry is in the highest risk group with an estimation of 27% at risk of hearing loss, which is 60% higher than the reference group [22]. The SINTEF report on wearing a balaclava in combination with hearing protection in the best case reduces hearing protection with about 5 dB, in an test environment with sound levels from 90 to 112 dB, relevant to noise levels on a working environment on an oil platform. The protection worn alone reduced sound levels by 30 dB, in combination with the best balaclava sound reduction was limited to 24 db. Adding protection eyewear to the test further reduced the potential reduction by 2-5 decibel. 85 dB is the safe limit for a working environment without hearing protection. The report points out various challenges with mismatching products, and the risks with wrong use of PPE. Every year the Petroleum Safety Authority Norway receives about 600 reports on cases of hearing impairment, and still there are believed to be under-reporting. Reports from field studies performed by SINTEF[23] shows that field measures are far away from laboratory measures of actual noise exposure and reduction of the protection from equipment used. Part of the reason is how workers use their equipment. Wearing comfort, communication problems while using PPE and users being uncertain of sound exposure, amongst them.

3.5 Health effects on cold

The impact of the low temperatures, wind, snow and ice are the main challenges to workers in the far north. The exposure of these elements can cause local frost injuries such as frostbite in the face. [24] Normal blood flow to the face is early reduced to save energy, which limits the sense of cold, and early signs of these injuries can easily be ignored when concentrating on other tasks. Immediate reaction is important to avoid serious injury. Cold air is also directly harmful for the lungs and can cause cold asthma, a chronic illness. This can be avoided by use of cold masks which heats air before it is breathed. Use of such equipment often causes humid air from breathing to freeze on the balaclava, causing a layer of ice directly in contact with the skin. Research has shown that the existing PPE in the petroleum industry in northern environments is insufficient. Already at -5 °C the performance of workers is reduced during low work intensity[25]. (Figure 5) from the same article shows usual clothing combinations at different temperatures. The table shows that the solution today is to put on an additional layer when it gets colder. This further reduces the effect of hearing protection, beyond the testing done in SINTEF’s lab. [4]. Normal work would be restricted in the worst conditions, only allowing emergency work necessary to keep the platform running. The face is vulnerable to exposure. It is prone to both non-freezing injuries, such as chilblains and immersion foot, and freezing cold injuries, where the fluids in the body tissue freeze. [26] The effect of cardiovascular response to cold, where the skin in the face loses its main source of heat, increases this risk [27].

	Ambient temperature 22°C	5°C	–5°C	–15°C	–25°C
Underwear	- JanusPro antiflame rib sweater - JanusPro antiflame rib pants	- JanusPro antiflame rib sweater - JanusPro antiflame rib pants	- JanusPro antiflame rib sweater - JanusPro antiflame rib pants	- JanusPro antiflame rib sweater - JanusPro antiflame rib pants	- JanusPro antiflame rib sweater - JanusPro antiflame rib pants
Middle layer garments		-JanusPro terry fleece jacket	-JanusPro terry fleece jacket -JanusPro antiflame rib polo neck sweater -JanusPro interlock thermal pants	-JanusPro terry fleece jacket -JanusPro interlock thermal pants	-JanusPro terry fleece jacket -JanusPro antiflame rib polo neck sweater -JanusPro interlock thermal pants
Outer garments		- Wenaas antiflame jacket - Wenaas antiflame pants	- Wenaas antiflame jacket - Wenaas antiflame pants	- Wenaas pyrokon parkacoat - Wenaas pyrokon overall	- Wenaas pyrokon parkacoat - Wenaas pyrokon overall
Protective head garments		- JanusPro balaclava - Peltor safety helmet	- JanusPro balaclava - Peltor safety helmet	- JanusPro balaclava - Devold balaclava - Peltor safety helmet	- JanusPro balaclava - Devold balaclava - Peltor safety helmet
Gloves		Odin work gloves	Odin work gloves	Odin work gloves	Odin work gloves
Socks	- wool/lycra	- wool/lycra - wool/ polyamid/ elastan -	- wool/lycra - wool/polyamid/ elastan	- wool/lycra - wool/polyamid/ elastan	- wool/lycra - wool/polyamid/ elastan
Shoes		Skolett Forma Work shoes	Skolett Forma Work shoes	Skolett Forma Work shoes	Skolett Forma Work shoes
Clo	1.18	2.49	2.72	4.20	4.27

Figure 5, Clothing concepts (Wiggen et al., 2011)

3.6 Testing and verification

The balaclavas and equipment tested by SINTEF are so far only tested by the means of hearing, not for cold protection. A test of both this important features would be of high relevance for the project. Testing with UV cameras is one way to detect hot areas on the layers, e.g. where insulation is the weakest. For Standards Testing, a moving thermal manikin such as “TORE” could be used to test the thermal insulation. . (EN ISO 15831:2004)[28] The evolving of this, “SAM” a sweating manikin could be used to further test for measuring the resistance of evaporative heat transfer from a heated thermal manikin. So far the standards only describe this for a calm environment. (ASTM-F1291-05(2005)) [28]. Another solution that might be sufficient could be to test only on a thermal head model [29]similar to what was used for evaluation of safety helmets in a hot environment. This is highly depending on the final design. For all tests it would be interesting to compare with movements and wind since it can reduce the clothing insulation by 70% compared to a reference in calm conditions.[30] The currents standards do so far only define requirements only for the outermost layers. The testing methods have different strengths and weaknesses. A lab test would be conducted with complete control over the temperature, humidity and censors, a platform test would give the most realistic conditions, but it would be hard to measure the exact exposure levels, individual metabolism and comfort in cold is another variable. It could also be difficult and expensive, and potentially unsafe, and for those reasons hard to get allowance test prototypes in a real setting. Another way of testing could be to stage a usability test in similar conditions and similar tasks, but in a controlled environment onshore.

3.7 Relevant technologies

Electrically heated clothing has been used with success for a while in, amongst others, surfing wetsuits, where freedom of movement is important. In this case such technology could be relevant due to its high thermal effect compared to its thickness. Depending on lifetime of batteries in these temperatures, it is reasonable to think that today's technology will provide acceptable weight/power ratio for the heating to last until next break. Battery capacity which is normally a challenge in cold environments must be investigated further for the given situation to assure it does not introduce further unnecessary breaks in the workflow due to changing of batteries. The UI of the system should also be designed with the already complex situation in mind. [31] Phase changing materials [32] have been used in the design of new helicopter suits for the North Sea [33], with good results. Such materials could be used to guide heat from spots with excessive heat production, to more exposed areas. Garments sewn for optimal air flow to the conditions is used in sports. Different weaves and textures in combination with different materials is a way to achieve this. Helly Hansen's H2FLOW™ technology [34] is a good example of this in existing garments. Smart use of technologies in textiles is developing quickly. As a designer it is important to keep up to date with new technologies. It is however important to keep in mind that technologies isn't always the smartest solution. Introduction of technology to a garment may affect garments washability, stretch and weight, amongst others.

DISCUSSION

Designing for complex products and situations is a complicated task. Talks with designers on the field strengthen this thought. By looking at previous working methods to improve equipment for similar situations, the importance of a solid working process shows important value to the designers. To select a suitable method for the exact project is important. To do this requires planning and a preface that includes a solid understanding of the current situation, as a starting point. This process will further aid in the decision to find the best available solutions to the problem. The design methods briefly looked at in this article are all user centered, which should be the main focus in development of new equipment. Every project will need a different approach. When the brief of a project seems clear, taking time to think through each step of the process and plan out a detailed process should be done at this stage.

CONLUSION

This article points out several ways to solve a complex design brief. There are good opportunities to improve the working conditions for workers in the north. A study of existing solutions and equipment shows a wide range of possible outcomes that could improve today's situation. The outcome could be from simple re-designs to more original thinking on the field of protection. Further insights in the use of existing products, as well as testing on the equipment and its performance with both cold and hearing protection on the same time would be necessary to make products that is good enough for the situations workers will face. The problems pointed out are likely to be relevant for more than just offshore workers, including forest workers, mining industry, and other groups that are combining hearing protection with cold protection.

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