Validation of a cooling vest's usability matrix for deep and ultra-deep mining environments

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Abstract. Exposure to high heat and humidity in underground mining calls for a cooling vest for miners. 16 criteria were proposed as part of a usability matrix that takes into account design, user requirements and constraints, based on a literature review and an exploratory field study. To validate this matrix, an expert elicitation was conducted with eight health and safety experts from university and industry. The objective was to determine a hierarchy to the criteria as well as their worth. To process the information, a mathematical aggregation method, linear opinion pooling, was used to merge the data. Results show that all experts agree on design aesthetic as being the least important at this point of the product development, while efficiency is of highest priority. More research will need to be done over a larger pool of participants to be able to completely converge on all criteria.

Keywords: cooling vest, usability matrix, ultra-deep mining

1. Introduction

Harvesting precious metals at lower depth expose miners to heat strain. A cooling vest can reduce heat strain in workers (Guo et al. 2017; Reinertsen et al. 2008) but the particularities of deep and ultra-deep mining, high temperature and high humidity, make it difficult for conventional cooling vests to be used (Al Sayed et al. 2016). Recently, an exploratory study was conducted to determine what constraints and requirements underground miners faced in Quebec's gold mines. By using the information from literature reviews, semi-directed interviews with miners and work observations, Ngô et al. (2017) were able to construct a usability matrix containing 16 criteria (Table 1). The criteria were separated in two categories, user and design.

Table 1. *Usability matrix criteria (Ngô et al., 2017)*

User	Design
Fit	Efficiency
Robustness	Back-end risks
Snagging	Working environment
Weight	Energy expenditure
Hindrance	Maintenance
Ease of movement / Mobility	Cost
Comfort	Conformity to existing laws, regulations and standards
Design aesthetics	
Usability / user friendliness	

To the best of our knowledge, there is no existing matrix made specifically for a cooling equipment destined to be worn in deep and ultra-deep mines. Expert elicitation is a systematic approach in which subjective judgements from experts are collected to gain information on variables about which there is substantial uncertainty (O'Hagan et al. 2006). In this research project, uncertainty remained about the relevance of most criteria except design aesthetic and efficiency.

The aim of this paper is to present a brief summary of results on the hierarchy of criteria established by the experts.

2. Methodology

The process was subjected to approval by the ethical committee of ÉTS which was obtained in January 2018. The search region for experts was limited to Canada and it was necessary for them to be actively involved in research or practice in occupational health and safety. Industrial experts in OHS from the mining sector were included in the study because of their in-depth knowledge of mining practices and regulations. After the initial contact and verbal or email agreement, a consent form and a questionnaire was sent to the expert to be completed. The expert had three weeks to complete both forms and send them back to the researchers.

The first section of the questionnaire focused on criteria definitions as seen in Ngô et al. (2017). The second section of the questionnaire presented a two by two comparison of criteria. In that section, experts determined, for each comparison, which criterion took precedence over the other. For example, the experts had to decide between robustness and cost, which criteria would be prioritized and check the box accordingly.

Once all the consent forms and questionnaires had been received, data was analyzed and compiled to obtain a single distribution representing the hierarchical importance of each criteria. There are two options to obtain a single distribution following expert elicitation (O'Hagan et al. 2006). The first way is to use mathematical aggregation and consists of obtaining each expert's opinion individually, then combining them mathematically. The second option is to use behavioral aggregation, which requires interaction between all experts to get a single distribution as a whole, this implies consensus in between all experts.

In this case, a mathematical aggregation method was used to merge the data, linear opinion pooling. This was done because of the geographical repartition of the experts and the time constraints; it was not realistic to think they could be assembled to generate the single distribution in the form of behavioral aggregation. In linear opinion pooling, experts' opinion are all of equal weight, the results encompass all values and no values are ruled out.

Results were analyzed in the following way:

- All checkmarks were summed to determine overall hierarchy (highest number of checkmarks indicate criterion that took precedence the most).
- The number of checkmarks for each criterion by expert was compared individually and associated with a rank (1 to 16, 1 = most important, 16 least important), when two criteria had the same number of checkmarks, they received the lowest rank possible, the next criteria after that had the rank + (number of equal checkmarks). Ex. Robustness and work environment

have the same number of checkmarks 10, comfort has 12, this ranks both robustness and work environment at rank 4 and comfort will be rank 6.

3. Results

A total of eight experts responded to the questionnaire. University experts had expertise in varied fields such as human factors, protective clothing and thermal constraints. The industrial experts were working or had worked in the mining industry for at least 15 years.

After summing the results, two criteria stood out from the rest: design aesthetic and efficiency (Table 2). In the case of efficiency, it arrived in first place overall with all experts opinions combined while design aesthetic arrived in last place. There was no significant difference for these results when combining only the opinions of university experts and field experts by themselves.

Table 2. *Hierarchy of criteria*

Criteria	Overall rank by total number of votes	Mean and standard deviation between each expert
Efficiency	First (101/120)	12.60 ± 1.19
Design aesthetic	Last (4/120)	0.50 ± 0.53

The overall rank was also evaluated in both cases, with efficiency arriving in 1st position with an average rank of 2.8 ± 1.2 (5 experts put it in 2nd place, 1 in 3rd, 1 in 4th and 1 in 5th place). Design aesthetic in last position with an average rank of 15.7 ± 0.5 (5 experts put it in 16th place, 3 in 15th place). Results for the remaining criteria did not converge, with many of the criteria receiving equal number of checkmarks in individual expert ranking and overall ending up with very similar total number of checkmarks.

4. Discussion

The fact that the questionnaire was self-administered, might have played a role in the clear cut of results. It would have been preferable to have face-to-face interviews or at least phone interviews with all participants to prevent misunderstanding that can lower the quality of their response (O'Hagan et al. 2006). Initially, experts were contacted by phone or email and were supposed to answer the questionnaire with the interviewer on the phone. However, because of the geographical repartition (throughout Canada), the time difference and the fact experts are busy people, the decision was made to send the questionnaire to be filled as their schedule allowed. This was done to better retain the experts.

Further exploitation of the acquired data might be interesting. For example, to evaluate how many times a specific criterion was prioritized over another (robustness being consistently picked over cost by all experts).

In product design, usability is ensured by following human-centered design principles (Lewis 2014). As such, the participants that should be involved in the creation of the usability matrix should be the miners themselves. However, at this point in time, the usability matrix has been tested in a controlled environment, which is consistent with the technology readiness level 6 of this project. With the information acquired from this phase of the project, it will be possible to improve the usability matrix and future testing should allow the researchers to obtain convergence on the remaining criteria.

5. References

Al Sayed, C., L. Vinches and S. Hallé (2016). Towards Optimizing a Personal Cooling Garment for Hot and Humid Deep Mining Conditions. Open Journal of Optimization 5(1): 35-43.

Guo, Yueping, Albert PC Chan, Francis KW Wong, Yi Li, Shu Sun et Xiao Han. 2017. Developing a hybrid cooling vest for combating heat stress in the construction industry. Textile Research Journal, vol. 0, no 0, p. 1-16.

Lewis, James R. 2014. Usability: Lessons Learned … and Yet to Be Learned. International Journal of Human–Computer Interaction, vol. 30, no 9, p. 663-684.

Ngô, V. T. M., S. Nadeau and S. Hallé (2017). Ergonomic design of a cooling vest in deep and ultra-deep mining environments. Occupational Ergonomics 13(S1): 115-126.

O'Hagan, A., Caitlin Buck, Alireza Daneshkhah, J. Eiser, P. H. Garthwaite, D. J. Jenkinson, Jeremy Oakley et T. Rakow. 2006. Uncertain Judgements: Eliciting Expert Probabilities. John Wiley & Sons Ltd., 321 p.

Reinertsen, Randi Eidsmo, Hilde Færevik, Kristine Holbø, Ragnhild Nesbakken, Jarl Reitan, Arne Røyset et Maria Suong Le Thi. 2008. Optimizing the Performance of Phase-Change Materials in Personal Protective Clothing Systems. International Journal of Occupational Safety and Ergonomics, vol. 14, no 1, p. 43-53.

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