Handling diversity during development when using design trade-offs

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ABSTRACT

The handling of diversity of user characteristics in maritime developments has become increasingly important. A novel technique is proposed for use when designing for diversity in cases where optimum solutions cannot be attained and when trades must be made between variables within design options. A brief review is provided on the technique of "trade-offs" in design. A novel "trade-off" technique is proposed. This approach enables an acceptable design to be identified which includes a statement to support risk assessment. The approach is being developed within BAES for maritime systems and helps ensure that individual, including gender differences, are addressed successfully.

KEYWORDS

Diversity, trade-off, development

Introduction

Spiwak, M, Woolridge, A. R. and Lusebrink, R (2021) provide a high level statement on the importance of diversity at the HFES 65th International Annual Meeting. They report a definition of diversity as "anything that makes someone unique, so it can be ethnicity, socioeconomic background, disability status". However, when taking account of user characteristics, in maritime developments, it has been common practice to use either professional judgements or measures of central tendency to inform a judgement of acceptability of design features. The intent of these practices is to meet the guidelines within DEFSTAN 00-251. However, for naval maritime systems, it now required to take a fuller account of diversity than in the past, and this policy covers all operational users, both male and female within specified anthropometric ranges.

Gender and ranges of anthropometric and related human measures which are indicators of diversity, are now employed when making design judgements. This includes cases where compromises need to be made through a process of "trade-offs". Hence, it is necessary to develop a technique to enable designing for diversity when making trade-offs between design variables, their priorities and their constraints.

The ergonomics literature contains examples where the use of trade-offs has been advocated or trade-offs have been conducted. For example, Catterall and Galer (1990) considered its importance within a review paper on the way that we "market" ergonomics, while ISO 18152 addresses its use. More recently Fischer (2020) reviewed design trade-offs but without describing the technique precisely.

Trade-offs are seen as an important part of the way that we handle information when making ergonomics decisions, but neither of these reviews or ISO 18152 describes the technique in detail.

Current Concepts

The research literature suggests that the phrase "trade-off" may refer to:

- 1. **Selecting between alternatives**. For example, Howard (1997) described the process of designing a menu hierarchy, selecting between shallow and broad, versus narrow and deep. The selection technique was referred to as a "trade-off".
- 2. **Obtaining a design set from a range of options**. Work has been conducted in aircraft design (Johansson, Derelov and Olvander, 2017) to consider sets of options. In this case they considered the trade between three variables i.e. safety, reliability and weight within a development programme. This was achieved by expressing each of the variables along a common dimension and weighting their importance. This technique enabled a preference to be selected to give an acceptable solution. A similar technique has been developed to address software design issues (Ardito, Desolda, Lanzilotti, Malizia and Matera, 2020) and hazard analysis Health and Safety Executive (2001).
- 3. Selecting functions for automation to enable optimisation (Jamieson and Skraaning, 2020). Trade meaning to allocate i.e. trade one option for another in task design, and allocate a function to a role (Maguire, 1998). This is used within the RESPECT tool. In both these cases functions are identified for subsequent action within the design process.
- 4. Selecting options as part of conflict resolution within organisational management. Operations management has been addressed (Longoni, Pagell, Shevchenko and Klassen, 2019). Similarly, management of intensive care has been discussed (Reader, Reddy and Brett, 2017) where the concept of risk is used and considered in the context of decision theory (Coombs, Dawes and Tversky, 1970). In a production application, trades have been studied between production effectiveness and safety. Wilson, Ryan, Schock, Ferreira, Smith, and Pitsopoulos (2009) considered the risks associated with handling safety within the production process in rail engineering. In all cases there are important organisational considerations expressed in terms of risk.

Summary of review outcome

From the approaches above, it is possible to summarise some characteristics of a "trade-off":

- 1. Its starting point is the relationship between two or more ergonomics variables/system characteristics which constrain one another more of one implies less from the other.
- 2. The relationship between the variables, is focussed on identifying/selecting the optimum point in the relationship of the ergonomics variables/system characteristics. This optimum may not be where both variables are specified at their preferred values there are conflicting demands.
- 3. The optimal values should be useful for resolving ergonomics conflicts, reducing risk to outcomes, and be open to management. This includes the opportunity to satisfy the requirements of the stakeholders including the diverse potential users.
- 4. The trade-off process should be able to support ergonomics work within the development process as expressed in current standards.
- 5. The trade-off process is seen as part of the risk management process (Wilson et al 2009, Reader et al 2017, Frosti 2014).

Initial considerations in the development of a novel technique

The starting point, when trading one variable against another is to express them both in terms of a common variable (Coombs et al. 1970). Hence it is necessary to employ a concept such as utility,

value, space, human resources or cost so that the variables being traded are expressed in common units.

The quantity being traded is constrained and hence must be apportioned to one variable or another. The variables may be seen as if "in conflict" – the gain for one may result in a loss for the other. The relationship between the variables may not be unconstrained in quantity: in this case there is no need to trade.

Hence, it is useful to consider risk: the risk of a lack of availability of the object, commodity, resource or other where there are conflicting needs. In general, during risk assessments, we are considering the risk associated with only one variable – in this case, there is a risk to both.

In this case risk is considered in terms of likelihood and impact. Risk is indicated by a combination of likelihood and impact for two variables which can be represented within a risk matrix as defined by the Health and Safety Executive (HSE) on their website.

Assessment for a trade-off between two variables with different characteristics

It is possible to present the results from the two independent assessments within a single matrix (Table 1) to consider their combined outcome. For purposes of this presentation, a "three by three" matrix is used here, as it is straightforward to divide populations into three groups: one at each of the extremities and a single majority around the midpoint. The approach proposed here can be used with any size of matrix equal to or greater than "two by two."

The Groups are referred to as "1" and "2". It may be that the groups are independent (from the same population), or it may be that the groups referred to as "1" and "2" are the same individuals operating under conditions "A" and "B".

The impacts shown in Table 1 are the quantities associated with Variable A and Variable B while the measures of likelihood are the proportion of the group that will meet the criterion for Variable A, or Variable B at those levels.

The need for a trade-off arises because the preferred levels of A and B are not possible simultaneously. In the case of 100% acceptability then the top left cell applies.

If the preferred values are not both possible and practicable then a trade-off is required. The ergonomics issue is to discover values for Variable A and Variable B so that a preferred level of acceptability and practicability is achieved for both. One design aim might be to avoid the case represented by the cell at the bottom right.

Table 1: General	Trade-off Matrix	for	diversity
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	Group 2, Variable B				
Group 1, Variable A		Set of users at high end of scale	Set of users around/above midpoint	Set of users at low end of scale.	
	Set of users at high end of scale	A is acceptable to all of Group 1, and B is acceptable to all of Group 2.	A is acceptable to all of Group 1, and B is acceptable to a majority of Group 2.	A is acceptable to all of Group 1, and B is acceptable to a minority of Group 2.	
	Set of users around/above midpoint	A is acceptable to a majority of Group 1, and B is acceptable to all of Group 2.	A is acceptable to a majority of Group 1, and B is acceptable to a majority of Group 2.	A is acceptable to a majority of Group 1, and B is acceptable to a minority of Group 2	
	Set of users at low end of scale.	A is acceptable to a minority of Group 1, and B is acceptable to all of Group 2	A is acceptable to a minority Group 1, and B is acceptable to a majority Group 2.	A is acceptable to a minority of Group 1, and B is acceptable to a minority of Group 2	

Acceptability in Group 1 is shown as increasing in an upward direction. The vertical dimension is divided into three defined by the sets of users for whom it is acceptable. Acceptance by Group 1 is dependent on the degree to which the variable is available. Hence if only the category identified in the bottom row finds the value of the variable acceptable, then there is a minority acceptance. Similarly, if the bottom two rows are identified as finding the value acceptable then a majority of the group finds it acceptable. Finally, if all three categories find the value acceptable then there is 100% acceptability of "A".

Similarly, the horizontal dimension is divided into categories to which the variable is defined. Acceptance by Group 2 is dependent on the degree to which the variable is available. Acceptability in Group 2 is shown to increase moving right to left.

Hence the top left cell shows the case with the two variables can have values that are acceptable to all (i.e.no need to trade) with the bottom right as acceptable only to the set defined by minorities.

During development and mainly during the design stages, the preferred values for Variable A and Variable B are explored to ensure understanding and agreement on the constraints associated with the ergonomics variables.

Hence the outcome of "the trade-off" can be derived in terms derived from a matrix as shown in Table 1, where the acceptable characteristics of the design for "Group 1, Condition A and Group 2 Condition B" are the best possible for the largest number of users which would be expected in the central rectangle.

The values of the variables associated with the mid cell of this matrix may be regarded as operating restrictions defined by the design, and these will be carried through into its use.

Assessment for a trade-off between two groups with different variable characteristics and a number of cases

Three sets of consideration may need to be addressed:

- 1. It is unlikely that in any complex investigation the investigation would address a single combination of values as shown in Table one. It is possible that a set of combinations would be considered for the two Groups "1" and "2". However, that additional technique is not considered here.
- 2. It may be necessary to ensure that any conditions the precede or succeed the conditions that are shown in in Table 1 are assessed. This would most clearly be the case if a task were being assessed that was part of a critical sequence e.g. where safety or emergency states were involved.
- 3. It may be necessary to ensure that the preferred outcome as indicated by the analysis shown in the Trade-off Matrix is acceptable at the functional levels higher in the functional architecture (Tainsh, 2017) e.g. do not violate policy or legal requirements.

Quantifying the outcome

There are two main cases to consider:

- 1. If the diverse population is the same in both cases, then the design or conditions are suitable for that portion that satisfies both sets of design criteria defined by the variables. This can be expressed as a population condition in terms of percentiles of population characteristics. This is a measure of likelihood who acceptability will depend on the design priorities.
- 2. If the two populations differ then a prioritising criterion must be employed so the result would be expressed as a set of one population defined in terms of percentiles and the other in terms of another set of percentiles. This might be the case where safety is involved and the design must satisfy the needs of one population while a less stringent criterion may apply to the second. In this case, there are two measures of likelihoods whose acceptability will depend on design priorities.

Consequences of the use of the Trade-off Matrix on previous reported work

The following issues might have been addressed in the paper's reviewed earlier if a trade-off matrix had been available at the time:

- 1. Selecting one option from a set or between sets of design options this appears a welldeveloped technique, but the question arises, how does the optimisation algorithm consider the consequences. An optimum may have been selected but there remains a need to understand the risks involved if the system moves to a state away from the optimum i.e what proportion of the population(s) have been supported and what proportion has not and is this solution acceptable.
- 2. Selecting functions for reorganisation/automation the users/operators may be effective when the automated functions fulfil their objectives, but it is necessary to know the consequences of a system moving away its expected behaviour and the risks to system effectiveness and safety. Trade meaning to allocate this work stems from ergonomics work on job design but appears mainly to be characterised as select and allocate. There is no consideration of risk or impact of the outcome of the decision.

3. Selecting between options for conflict resolution and the consideration of safety against production – both papers clearly use "trade-offs" as part of the risk management process. Unfortunately, neither indicate how the risk is going to be handled to aid the decision-making process.

Current experience in the use of Trade-off Matrix in maritime applications.

In maritime applications, it is essential for designs to meet national and international standards, and UK legislation. The design decisions must be compatible with UK safety and employment legislation. If the design only takes account of the average physical characteristics and capability, or employs professional judgement based on past practice then the needs of users who characteristics lie away from the central values will be ignored.

Current maritime platforms have defined "Target Audiences" which specify the gender and range of individual characteristics that must be taken into account. The definition of each platform's "Target Audience" reflects standards, legislation and the customer's policy on diversity.

Hence, for example, when designing space and facilities to enable movement in and out of a confined area. It is essential for there to be an appropriate space for users to move to a location for their work, but it will be essential to ensure that safety issues are taken into account. In this case there are three categories of user: Those in the category below that specified, a large central category, and those who are above the upper limit. This is true for both males and females. In this example, it is assumed that both males and females are required to work in a confined space.

In this case the trade-off matrix is constructed with two conditions for the same group. The space available to carry out work may be diminished through the provision of aids to support safety. In the first condition, with no safety considerations, access to the confined space may be limited at the high and low end because of size: the tall/large build group may have difficulty and equally the shorter group may be injured. This yields a likelihood for the Target Audience of being able to use the space effectively. This likelihood will be discussed within the design team to yield options. The inclusion of facilities to aid those who might be injured may have an adverse consequence for the larger user's ability to move and work. Again the likelihoods associated with all the potential users are discussed.

Designs are assessed with the use of a set of representative persons playing the role of users under simulated conditions. The complete range of users is represented.

The practical benefits of such an approach are manifest by the design teams who can quantify the outcomes of their designs in terms of likelihood and risk and the customers who can be assured that future users will be both effective and safe.

Conclusions

The requirement for diversity is an essential during development to ensure that the potential users are satisfied with the equipment supplied. Further, quantified evidence is needed to support claims for compliance, or non-compliance, and this technique will show how diversity requirements have been achieved.

The concepts of risk and risk reduction are central to the ergonomics contribution to system development, including design as exemplified in ISO 18152. However, in applications as exemplified by maritime systems engineering, risks can rarely be mitigated in isolation, they are subject to trade-offs. Hence there is a need for improved ergonomics techniques.

The Trade-off Matrix is in use in maritime applications and has been found beneficial in helping to take account of operational, maintenance and safety requirements and the full range of male and

female characteristics addressed during design studies. It has been found that this approach aids understanding of compliance with national and international standards and UK legislation.

Hence, it is suggested that the technique could be helpful in many other non-maritime applications to help demonstrate that full account has been taken of diversity. Current additional applications that are under consideration include:

- 1. Design of devices to match the forces that can be exerted by individuals over a period of time;
- 2. The use of display areas to meet the range of abilities of the future users.

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