Ergonomic evaluation of DSV cockpit console based on comprehensive decision making method

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Abstract
In order to guarantee the effectiveness of operation, ergonomic evaluation of deep-sea submersible vehicle (DSV) cockpit console has been widely researched and developed. However, due to the characteristics of information integration on the console, and the way of information interaction becomes more and more complicated currently. The existing evaluation method mostly based on partial attributes result in unilateral issue. Considering that ergonomic evaluation processes of DSV cockpit console involves multiple decisions for multifarious attributes under vague conditions, we established an evaluation system with an improved Delphi method based on experts’ opinions and introduce a comprehensive ergonomic evaluation model by using the two-tuple weighted averaging operator (T-WA) and extended Vlsekrterijumska Optimizacija I Kompromiso Resenje(VIKOR). Finally, an illustrated example on DSV cockpit console evaluation was performed, and the evaluation result was compared with other four typical evaluation method, it indicates the effectiveness and feasibility of the proposed method.

Keywords: DSV cockpit console, Index system, Comprehensive evaluation, Delphi, T-WA, VIKOR

1. Introduction

Deep-sea human occupied vehicle (DSV) is mainly used to perform underwater detection, underwater exploration, marine development and rescue missions, it plays an increasing significant role in the research and exploitation of ocean. The cockpit is an important part of DSV, it is the main work and active region for operators and researchers. All the display equipment, operating equipment, oxygen supply system and seats are arranged in the limited space which is sphere with a diameter of 2 meters around [Kohnen, 2005, Shepard, 2001]. The console has the function of nerve center in DSV cockpit, there are all kinds of control and display devices which are playing important role in the work process of DSV. The designers usually arrange a variety of information components in the control area according to the layout specification and mission requirements. Thus, to increase operate performance and work efficiency, the console ergonomic evaluation is a pivotal decision process and has become a very fundamental part of the cabin layout design.

At present, there is no research on the ergonomic layout evaluation of DSV cockpit console, and for the existing ergonomic evaluation methods, the application in the cockpit of military aircraft is relatively consistent mostly based on view distribution [Brody,1993], and many other cockpit consoles are also based on these methods as a basis for "transplantation". But in fact, an optimal layout of the cabin console needs not only to consider the scientifcity and rationality of the display device for the operator's information feedback, it is also necessary to ensure that operators can manipulate the manipulators comfortably and accurately, and these two parts are interrelated and interacting, it is impossible to get a correct and valuable result by evaluating only a single factor. Besides, the design concepts and design requirements of DSV cockpit console are different with aircrafts. Firstly, the space structure is different, unlike the heterogeneous cabin of the aircraft, the DSV cabin has spherical shape, and the observation window of DSV cabin is much smaller than the aircraft. In order to meet the requirements of viewing when driving and working, the display of extravehicular video content in the cabin should be taken into consideration, while the aircraft is not required. And because DSV takes more than one person, the layout design and evaluation of the console should meet the convenience...
of multi-user. Second, the task is different, DSV is mainly applied in the field of scientific research and rescue, its task is to shoot the underwater object by manipulating the external manipulator and the video recording device when diving up to the specified depth, so there are a number of display and control terminal on the DSV console. But the airplane is to fulfill other tasks under the premise of flight safety, such as launch, etc., so the main task of the aircraft's console is to achieve the safe flight of the aircraft. Therefore, the layout and evaluation method of the aircraft cabin console can’t be applied directly to the DSV console. Although there are some comprehensive evaluation methods[Chen, et al.,2014, zong, et.al,2014] which can better consider and evaluate the various qualitative and quantitative indicators, however, these comprehensive evaluation methods can’t get rid of the randomness and the fuzziness of the experts' understanding in the evaluation process, and constant weight is mostly used in evaluation method, so the "buckets effect" may occur in the evaluation system, that is in ergonomics evaluation index system, giving different weights to the same index will make the difference of evaluation results, also it has a great influence on the final evaluation results when a certain index has a high degree of deterioration. In view of the above problems, it is necessary to establish a set of comprehensive evaluation system and an evaluation model in accordance with characteristics of DSV cockpit console facilities, operators and human-machine, so that we can reasonably and effectively design and evaluate the DSV console. Hence, the study on the DSV cockpit console ergonomic evaluation method is of practical significance.

In consideration of the fact that the ergonomic performance evaluation of DSV cockpit console includes many uncertainty attribute, and it is a multi-target and multi hierarchy comprehensive evaluation decision problem. So a multi-attribute group decision making method should be proposed to apply in the ergonomic evaluation process, such as combing the analytic hierarchy process (AHP) [Saaty, 1994, Izquierdo, 2015] and technique for order preference by similarity to ideal solution(TOPSIS) [Park, 2016] to evaluation performance [Zyoud, 2017], the case ranking preferred by the Analytic network process [Nilashi, et al., 2016], entropy weight method [Delgado and Romero, 2016], multi objective optimization and genetic algorithm [Gossard, et al., 2013] and the elimination et choice translating reality [Kumar, et al., 2017]. However, in face of multiple attribute evaluation information of multiple alternatives, how to determine index weights is the key to aggregating evaluation information, especially for the evaluation problems of optimal scheme with incomplete or completely unknown attribute weight information, such as subjective preference and lack of theoretical data support, experts fail to provide accurate decision bases frequently. In this study, we employed a hybrid multi-attribute group decision making method to the performance evaluation of DSV cockpit console mainly based on two-tuple linguistic information processing and Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR), in which first put forward by Herrera [Herrera, 2000] and Opricovic respectively [Opricovic, 1998], has been regarded as a compensatory aggregation method to deal with discrete uncertainty attribute decision issues. This method mainly to solve multi-attribute group decision making problems with multi-granularity linguistic phrases of index values and index weights. The specific evaluation process as shown in Fig.1:
In the first phrase, subject-matter experts and submariners as the members of expert groups, they are familiar with the work function in the DSV, and have a wealth of practical experience. Subsequently, an evaluation system is built primarily, then refactoring comprehensive evaluation system based on improved Delphi method. In the second phrase, subjective weights and objective weights of indexes are concentrated into comprehensive weights, in which the objective weights are obtained by the consistency principle of group evaluation opinions, subjective weights of every index are calculated by using the two-tuple weighted averaging operator. In the third phrase, selecting and ranking the comprehensive performance of DSV cockpit console based on the extended VIKOR method.

2. Construct the evaluation index system

2.1 The construction method of evaluation indexes system based on improved Delphi

The goal of constructing ergonomics evaluation index system is to guide the overall design of the console, on the one hand, makes "the operator applicable to the machine", on the other hand, "the machine is applicable to operator". The establishment of ergonomics evaluation index system should include: the construction of overall framework, the screening of specific indexes and the establishment of the final system. According to the analysis of the relevant indexes of ergonomics, the index to be screened will be constructed. In view of the difficulty of quantifying qualitative indexes, an improved Delphi method is employed to determine the ergonomic evaluation index of the DSV cockpit console.

The Delphi method, put forward firstly by Dalky and Helmer [Dalky and Helmer,1963]. It is a multistage survey that is often used to develop consensus or collective agreement among a panel of independent experts [Paquetwarren, et al., 2017]. It has three most noteworthy characteristics that are distinct from other subjective forecasting methods, namely anonymity, multiple feedbacks, and group statistical answers. Domestic and foreign research mainly focus on choosing appropriate experts, shortening the consultation process and solving convergence speed [Ishikawa, et al., 1993, Wang, et al., 2008], etc. However, there is no research on the subjective quantification, so an improved Delphi method is known as rigorous guidelines for effectively reduce the influence of subjective factors during the generating process of index system [Strosberg, 2013]. Besides, comparing with the traditional Delphi method, the improved Delphi method has the higher efficiency, because a preliminary index system has been prepared in advance according previous theory and experience. The specific steps of improved Delphi method are shown as:

Step1- Construct preliminary evaluation index system and quantify evaluation factors: By researching relevant national and industry ergonomics standards, the domestic and international standards are mainly including GB/T 13602-2010(marine centralized control board of cabin), GB/T 7269-2008(Layout, type and basic size of an electronic device console), ISO 9355-1:1999(Ergonomic requirements for the design of displays and control actuators -- Part 1: Human interactions with displays and control actuators, Ergonomic requirements for the design of displays and control actuators; Part 2: Displays, Ergonomic requirements for the design of displays and control actuators; Part 3: Control actuators), analyzing submariners' operation and information exchange process, then a preliminary evaluation index system will be predetermined. Meanwhile, the submariners, professional researchers and other relevant personnel will be invited as the members of expert groups. The expert group need to determine and quantify the evaluation factors of the index system before expert grading for each index. The evaluation factors include evaluation level, judgment basis \( C_a \) and familiarity \( C_s \). The quantitative method of evaluation level and familiarity is based on seven-point Likert Scale [Zanten, 2006]. The judgment basis \( C_a \) is divided into four classes: Operation experience, Theoretical analysis, Work dabble, Subjective judgment. And the quantitative value of the evaluation index is shown in Table 1:

<table>
<thead>
<tr>
<th>Degree classification</th>
<th>value assignment</th>
<th>Judgment basis ( C_a )</th>
<th>Degree classification</th>
<th>value assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deeply important</td>
<td>7</td>
<td>Operation experience</td>
<td>Deeply familiarity</td>
<td>1.0</td>
</tr>
<tr>
<td>Very important</td>
<td>6</td>
<td>Theoretical analysis</td>
<td>Very familiarity</td>
<td>0.8</td>
</tr>
<tr>
<td>Important</td>
<td>5</td>
<td>Work dabble</td>
<td>Familiarity</td>
<td>0.6</td>
</tr>
<tr>
<td>Moderate Important</td>
<td>4</td>
<td>Subjective judgment</td>
<td>Moderate familiarity</td>
<td>0.4</td>
</tr>
<tr>
<td>Mild important</td>
<td>3</td>
<td></td>
<td>Mild familiarity</td>
<td>0.2</td>
</tr>
<tr>
<td>Minimal important</td>
<td>2</td>
<td></td>
<td>Minimal familiarity</td>
<td>0.1</td>
</tr>
<tr>
<td>Not important</td>
<td>1</td>
<td></td>
<td>Unfamiliar</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Familiarity ( C_s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unimportant</td>
</tr>
<tr>
<td>Minimal</td>
</tr>
<tr>
<td>Mild familiarity</td>
</tr>
<tr>
<td>Familiarity</td>
</tr>
<tr>
<td>Moderate familiarity</td>
</tr>
<tr>
<td>Deeply familiarity</td>
</tr>
</tbody>
</table>

Table 1 The quantitative value of evaluation factor

Step 2 - Expert scoring for preliminary evaluation index system (2-3 rounds): The expert group scoring for each index of preliminary evaluation system first time, this is the first round evaluation, then the results of the first round will be gathered to get the statistical result. After that, the consistency, the average value and the results distribution of each index are given back to each expert in the second round, then experts reassess the importance of each index based on these feedbacks. In general, the experts’ opinions are dispersed in the first round, but the experts’ opinions are gradually become unified through information feedback, the process of obtain a unified experts’ opinions could be finished within two or three rounds.

Step 3 - The statistical analysis on experts’ opinions to determine the final evaluation index system: The unified experts’ opinions on the evaluation index need to be analyzed statistically so that we can verify if the evaluation indexes are valid or not, the base of verification is to calculate the consistency of all experts’ opinions, the greater consistency result indicates the better evaluation index system. There are four statistical indicators to check the consistency of all experts’ opinions, which include the degree of authority $C_R$, concentration of expert opinions $E$, the dispersion of expert opinions $\sigma_i$ and the degree of coordination. They can be calculated by the following process.

1. The authority of an expert has a great impact on the outcome of the evaluation. Therefore, in dealing with the evaluation results, we should consider the authority degree of experts to an evaluation indexes. $C_R$ is generally determined by two factors: one is the basis for experts to judge $C_a$, the other is the expert's familiarity with the problem $C_s$.

$$C_R = \frac{C_s + C_a}{2}$$  \hspace{1cm} (1)

2. The concentration degree of expert opinions $E$ is reflected by the weighted average of the evaluation index, and the greater the weighted average, the higher the corresponding index importance.

$$E_i = \sum_{j=1}^{q} E_j m_{ij}/q, \ (i = 1,2, ... n)$$  \hspace{1cm} (2)

where $E_j$ is used to represent the quantized value of index importance to the evaluation of ergonomics, the range of the quantized value is between 1=Not important and 7=Deeply important, $m_{ij}$ is the sum of experts who gave the index $i$ the same score $j$, $n$ is index number and $q$ is expert number.

3. The dispersion of expert opinions $\sigma_i$ indicates the discrete degree of expert consultation results. The smaller the value, the smaller the dispersion of the expert evaluation results.

$$\sigma_i = \left[ \sum_{j=1}^{q} m_{ij} (E_j - E_i)^2/q - 1 \right]^{1/2}$$  \hspace{1cm} (3)

4. The coordination degree of the expert opinions can be reflected by the coefficient of variation $V_i$ and the coefficient of concordance $W$ [Wen, 2013], it reflects the consistency of different expert opinions.

$$V_i = \sigma_i/E_i$$  \hspace{1cm} (4)

$$W = \frac{12}{q^2(n^3-n)-q \sum_{k=1}^{n} R_k^2} \sum_{i=1}^{n} (R_i - \bar{R})^2$$  \hspace{1cm} (5)

where $V_i$ indicate the degree of coordination among experts on the evaluation of index $i$, the smaller the value $V_i$, the higher the degree of coordination among the experts. $W$ indicates the coordination degree of experts to the evaluation of ergonomics index system, the value of concordance coefficient is between 0 and 1, the greater the coefficient, the more consistent the experts' views are, then the higher the confidence level. Among them, $R_i$ is the sum of index level, and $\bar{R}$ is the arithmetic mean of the sum of all the indexes importance level.

The significance of the coefficient of concordance $W$ can be tested by $x^2$ test (chi-square test) [Satorra, 2001].

$$x^2 = \frac{\sum_{i=1}^{n} S_i^2}{qn (n + 1)} - \frac{1}{n-1} \sum_{k=1}^{q} T_k$$  \hspace{1cm} (6)

where $S_i = R_i - \bar{R}$, $S_i$ is the arithmetic mean difference between the sum of index $i$ level and the sum of all indexes level, $T_k$ is correction coefficient. In which the df (degree of freedom) =$n$-1, When the df >30, statistical results should be determined according to the standard normal distribution rule. Under 95% confidence level, when $p<0.05$, the coordination coefficient of expert opinions is statistically significant, not by accidental, so the ergonomic evaluation result is desirable, but when $P >0.05$, the ergonomic evaluation result is inadvisable, the expert group need to reassess.
the evaluation index one more round until \( p < 0.05 \), then the final evaluation index system could be constructed.

### 2.2 Evaluation index system of DSV cockpit console

According to the two rounds of consultation, the statistical results of some indexes are compared as shown in the table 2. By comparing the results of the two rounds of consultation, it can be seen that most of the indexes are stable. And in the second round, almost all indexes of standard deviation \( \sigma \) and coefficient of variation \( V \) are smaller than the previous round. In addition, all the values of \( C_R \) are greater than 0.5, indicating that experts have high authority, and the results are reliable.

<table>
<thead>
<tr>
<th>Statistical coefficient</th>
<th>The first round</th>
<th>The second round</th>
<th>( C_R )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( U_1 )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( U_{11} )</td>
<td>3.08</td>
<td>1.03</td>
<td>0.42</td>
</tr>
<tr>
<td>( U_{12} )</td>
<td>3.12</td>
<td>0.96</td>
<td>0.32</td>
</tr>
<tr>
<td>( U_{13} )</td>
<td>2.84</td>
<td>1.04</td>
<td>0.35</td>
</tr>
<tr>
<td>( U_n )</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( U_{n1} )</td>
<td>3.05</td>
<td>0.86</td>
<td>0.34</td>
</tr>
<tr>
<td>( U_{n2} )</td>
<td>3.50</td>
<td>0.63</td>
<td>0.22</td>
</tr>
</tbody>
</table>

* \( U_i \) represents the main index. \( U_{ij} \) represents the primary index

To calculate coordination coefficient according to the results of the consultation, as shown in the table 3. By comparison, the experts’ opinions tend to be unified, and the \( p \) tends to zero, which shows that the consultation results are effective and desirable.

<table>
<thead>
<tr>
<th>Coordination coefficient</th>
<th>The first round</th>
<th>The second round</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \chi^2 )</td>
<td>272.8</td>
<td>537.3</td>
</tr>
</tbody>
</table>

Combining with the results of statistical analysis, the final index system of ergonomics evaluation is screened out from the initial index system. So we establish a DSV console evaluation system as shown in Table 4.

### 3. Evaluation method for DSV cockpit console ergonomic evaluation

DSV cockpit console ergonomic evaluation is a typical multiple attribute decision making problem. The complexity and uncertainty of evaluation index make the evaluation information have the characteristics of uncertainty and linguistic
In the process of the multiple-case evaluation, supposing that a set of linguistic phrase evaluation sets with different granularity \( P = \{ S^{(1)}, S^{(2)}, ..., S^{(p)} \} \), where \( p \) is a natural number, whose cardinality value is an odd one, and it meets the following properties: (1) \( s_i > s_j \) if \( i > j \), (2) there is a negation operator \( \neg s_i = s_{i\prime} = t - i + 1 \), (3) \( \max(s_i, s_j) = s_i \) if \( i \geq j \), (4) \( \min(s_i, s_j) = s_j \) if \( j < s_i \) [Xu, 2004]. But in general, different types of linguistic information were provided by expert groups, and they may not match linguistic label in \( S \). So on the basis of linguistic evaluation set, the two-tuples \( (s, \alpha) \) is used to represent the language evaluation information based on symbolic transfer. Different from the discrete language phrases in the language evaluation set, the two-tuple semantics is continuous in its domain. The distance between any two-tuple semantics \( (s_i, \alpha_i) \) and \( (s_j, \alpha_j) \) is defined as following [Hofmann, et al., 2013, Herrera, F., & Martinez, L., 2000]:

\[
(d, \alpha) = \Delta((\Delta^{-1}(s_i, \alpha_i) - \Delta^{-1}(s_j, \alpha_j)))
\]

(7)

where \( d \in S, \alpha \in [-0.5, 0.5] \), \( \Delta \) is a function that translating the result of linguistic symbol aggregation into two-tuple linguistic forms, \( \Delta^{-1} \) is a function that transforming two-tuple semantics into its representative.

When aggregating a set of two-tuple semantics, if we do not know the weight information corresponding to the two-tuple semantics, we can consider using the weighted averaging operator to aggregate. Since the ordered weighted averaging operator does not consider the two-tuple semantic index weight information, it is necessary to obtain the group aggregation weight indirectly by the fuzzy quantization operator in the process of group aggregation, so the computation process is more complex. Because the two-tuple weighted averaging operator takes into account the two-tuple index weight information, it can directly aggregate the preference information of expert groups in the process of group aggregation, and simplify the calculation process and improve the evaluation efficiency.

Based on the above, the necessary description on the ideas of evaluation method is illustrated below:

The evaluation objects are the design cases \( x_i \in X(i = 1, 2, ..., n) \), the evaluation index \( u_j \in U(j = 1, 2, ..., m) \), and the set of expert groups is \( E = \{ e_1, e_2, ..., e_t \} \). The weighted vector of expert groups is \( W^e = (\omega^e_1, \omega^e_2, ..., \omega^e_t) \), where \( \omega^e_k \) is the weight of expert \( e_k \). The linguistic phrase evaluation set is \( S^{(k)} \in S^{(q)} \in S^{(q)} \). The set of subjective weight vector is \( \omega_u \in [0, 1] \), and the importance value of attribute \( u_j \) is \( \omega_u \). The subjective weight vector is \( \omega_u \) attached to the preference of subjective weight vector. The subjective weight vector is \( \omega_u \) attached to the preference of subjective weight vector. The subjective weight vector is \( \omega_u \) attached to the preference of subjective weight vector.

The objective weight vector is \( \omega_w \) attached to the preference of subjective weight vector.

The objective weight vector is \( \omega_w \) attached to the preference of subjective weight vector.

This section describes the determination of combined index weights based on T-WA operator.

For different cases, how to determine the weights of evaluation index is the key procedure in the course of the optimal selection of the case designs, especially, the group decision making problem with incomplete or complete unknown attribute weight information is considered. The combination weight in this paper is calculated by subjective weight and objective weight. The method about how to calculate the combination weight will be given in this section. The specific steps are as follows:

**Step1.** The index importance vector that each expert assigned is transformed into the two-tuple semantic form of the same granularity. \((\omega^{(k)}_{i}, \alpha^{(k)}_{i})\) can be represented by the following formula. [Han, 2015]:

\[
(\omega^{(k)}_{i}, \alpha^{(k)}_{i}) = \Delta \left( \frac{\Delta^{-1}(\omega^{(k)}_{i}, \alpha^{(k)}_{i})(Q-1)}{Q-k-1} \right)
\]

(8)
Step 2. Assuming the weight vector of expert groups is \( W^E = (\omega_1^E, \omega_2^E, ..., \omega_n^E)^T \), and meet \( \sum_{k=1}^n \omega_k^E = 1, \omega_k^E \in [0,1] \). Use the two-tuple linguistic distance formula (7) to calculate the distance between expert \( e_k \) and all other expert groups regarding to evaluation value of attribute \( u_j \). Then the deviation \( \rho_{kj} \) can be obtained by the following formula:

\[
\rho_{kj} = \frac{1}{n} \sum_{i=1}^{n} \sum_{h=1}^{n} |\Delta^{-1}(r_{ij}^k, a_{ij}) - \Delta^{-1}(r_{ij}^h, a_{ij})| \tag{9}
\]

where \( k=1, 2, ..., q; j=1,2,...,m \). so the total deviation \( \rho_j \) of the evaluation index \( u_j \) can be obtained by the following formula:

\[
\rho_j = \sum_{k=1}^q \omega_k^E \rho_{kj}, j = 1,2, ..., n \tag{10}
\]

Step 3. If the total deviation is larger, it is difficult to reach a consensus on this attribute, so a smaller weight should be assigned, on the other hand, it gives more weight to attributes. We can get the general objective weight \( \omega_{aj} \) with the statistical variance method:

\[
\omega_{aj} = \frac{\rho_j}{\sum_{j=1}^{n} \rho_j}, j = 1,2, ..., n \tag{11}
\]

Subjective weights \( \omega_{bj} \) of every attributes are calculated by using the two-tuple weighted averaging operator and meet \( \sum_{i=1}^{p} \omega_{bj} = 1, \omega_{bj} \in [0,1] \):

\[
\omega_{bj} = \frac{\sum_{k=1}^q \omega_k^E \Delta^{-1}(\alpha_{ij}, \beta_{ij})}{\sum_{k=1}^q \sum_{i=1}^{p} \omega_k^E \Delta^{-1}(\alpha_{ij}, \beta_{ij})}, j = 1,2, ..., n \tag{12}
\]

Step 4. The subjective weight and objective weight of the attribute are combined to make full use of objective importance information and take into account the subjective wills of the expert groups, so the combined weight is defined as follows:

\[
\omega_{ij} = \beta \omega_{aj} + (1 - \beta) \omega_{bj} \tag{13}
\]

where \( \beta \) is the proportion of objective weight in the combination weight, \( \beta \in [0,1] \), what is clear from the above Eq (13) is that the closer the \( \beta \) is close to 1, the more comprehensive the weight is closer to the objective weight, and the closer the \( \beta \) is close to 0, the more comprehensive the weight is closer to the subjective weight.[ Chi, 2010]

3.3 Comprehensive evaluation method research based on extended VIKOR method

The method about how to rank and select the optimal case will be given in this section. The ergonomic evaluation of DSV cockpit console layout case involves in many complicated factors. There are many factors in the evaluation system with randomness and fuzziness. Moreover, human judgment is subjective, therefore, the traditional evaluation method does not always obtain objective and feasible design case.

There are many methods to solve multi-attribute conflict problem, in which TOPSIS and VIKOR are the compromise solution that closest to ideal case. But the VIKOR method is usually proposed for multi-objective optimization of complex systems, its remarkable characteristic is that a special measure based on the closeness of ideal point, and the proposed compromise solution provides a balance between the total utility maximization and the minimization of individual regret. Certainly VIKOR method has an advantage of incorporating subjective preferences of experts group [Opricovic, 1998], it is helpful to ensure the rationality of ranking results. At present, this method has been extended to different forms of evaluation information environment, such as interval numbers [You, 2017], triangular fuzzy numbers [Molimari, 2017], two-tuple semantics [Han, 2015], generalized interval trapezoidal fuzzy numbers [Liu and Jin, 2012], etc. but the application of uncertain linguistic decision environment is less involved. The indexes and expert weights of the DSV cockpit console are uncertain linguistic multi-attribute group decision making problems with linguistic phrases. So the extended VIKOR method is validly introduced to solve the problem of evaluation and optimal selection cases. The specific steps are as follows:

Step 1. Attribute weights \( \omega_k \), experts weight \( \omega^E \) and uncertain linguistic evaluation matrices \( R_{ij}^k = (r_{ij}^k)_{m \times n} \) are transformed into two-tuple linguistic forms \( \tilde{\omega}_k^E, \widetilde{\alpha}_k^E \) and \( \widetilde{R}_{ij}^k = (r_{ij}^k)_{m \times n} \) respectively. Where the \( \tilde{\omega}_k^E = (\widetilde{\omega}_k^E, 0), r_{ij}^k = [(r_{ij}^{kl}, 0), (r_{ij}^{ul}, 0)], k = 1,2, ... p, \ i = 1,2, ... m, j = 1,2, ... n. \) Then the evaluation matrix of two-tuple linguistic form \( \tilde{R}_{ij}^k \)
and experts weight of two-tuple linguistic form \( \tilde{\alpha}_k \) are aggregated into group evaluation matrix \( R = [r_{ij}]_{m \times n} \) according to two-tuple weighted operator given by 3.1, and the formula is as follows:

\[
\hat{r}_{ij} = \left( r_{ij}^l, a_{ij}^l \right), \left( r_{ij}^u, a_{ij}^u \right) = \Delta \left( \frac{\sum_{k=1}^{n} \Delta^{-1}(a_{ik}, 0) \times \Delta^{-1}(r_{ij}^l, 0)}{\sum_{k=1}^{n} \Delta^{-1}(a_{ik}, 0)} \right) \left( \frac{\sum_{k=1}^{n} \Delta^{-1}(a_{ik}, 0) \times \Delta^{-1}(r_{ij}^u, 0)}{\sum_{k=1}^{n} \Delta^{-1}(a_{ik}, 0)} \right)
\]

(14)

where \( r_{ij}^l, r_{ij}^u \in S, \alpha_{ij}^l, \alpha_{ij}^u \in [-0.5, 0.5) \ i = 1,2, ... m, j = 1,2, ... n \).

**Step 2.** Define the positive ideal solutions and negative ideal solutions for all indexes [Han,2015]. In order to obtain the comparative sequences of all cases, the positive ideal solution and negative ideal solution with respect to each index can be defined as:

\[
\hat{r}_{ij}^+ = \left( \max_{1 \leq m \leq n} \alpha_{ij}^m, \max_{1 \leq m \leq n} \alpha_{ij}^m \right)
\]

(15)

\[
\hat{r}_{ij}^- = \left( \min_{1 \leq m \leq n} \alpha_{ij}^m, \min_{1 \leq m \leq n} \alpha_{ij}^m \right)
\]

(16)

**Step 3.** The group utility value \( u_i \) and individual regret value \( \Upsilon_i \) of each case are calculated.

\[
u_i = \frac{\sum_{j=1}^{n} \alpha_{ij}^l \times b_{ij}}{\sum_{j=1}^{n} \alpha_{ij}^l}
\]

(17)

\[
\Upsilon_i = \frac{\sum_{j=1}^{n} \alpha_{ij}^l \times b_{ij}}{\sum_{j=1}^{n} \alpha_{ij}^l}
\]

(18)

where \( b_{ij} = \frac{||r_{ij}^u - r_{ij}||}{||r_{ij}^l - r_{ij}||} \).

**Step 4.** Rank the evaluation cases by comparing compromise sort value.

\[
\delta_i = \varepsilon \frac{\Delta^{-1} u_i \Delta^{-1} u^+ + (1 - \varepsilon) \Delta^{-1} (\Upsilon_i - \Delta^{-1} \Upsilon^+)}{\Delta^{-1} (\Upsilon_i - \Delta^{-1} \Upsilon^+)}
\]

(19)

where \( u^+ = \min_{1 \leq m \leq n} u_i \), \( u^- = \max_{1 \leq m \leq n} u_i \), \( \Upsilon^+ = \min_{1 \leq m \leq n} \Upsilon_i \), \( \Upsilon^- = \max_{1 \leq m \leq n} \Upsilon_i \), \( \varepsilon \) is a compromise coefficient, and \( \varepsilon \in [0,1] \). This compromise solution is steady in top priority process, which could be “by maximizing group utility values to get the ranking result” \( \varepsilon > 0.5 \), “Consensus as an approach” \( \varepsilon = 0.5 \) or “Making decisions based on the situation of refusal” \( \varepsilon < 0.5 \). The difference of decision coefficient value leads to the change of compromise ranking value, the smaller the value \( \delta_i \), the better the case, and the ranking results of all the decision alternatives are obtained.

In the overall evaluation value \( \delta_i \), if the minimum value is \( \delta_b \), so the corresponding case is \( X_b \).

1) Acceptable advantage:

\[
\delta_a - \delta_b \geq \frac{1}{m-1}
\]

(20)

where \( \delta_a \) and \( \delta_b \) is the first and the second alternatives in the overall evaluation value \( \delta_i \), \( m \) is the number of evaluation alternatives.

2) The case \( X_b \) is optimal either in the rank of \( u_i \) or \( \Upsilon_i \):

- If the above two conditions are met simultaneously, \( X_b \) is the optimal case. If one of the conditions are not met simultaneously, a set of compromise solutions are developed, including:
  a. \( \delta_b \approx \delta_a \), when the first condition is not met, and the second condition is satisfied, \( \delta_a \) is defined by the relation

\[
\delta_a - \delta_b < \frac{1}{m-1}
\]

for the maximum value. Compromise case is the all case that the overall evaluation value is between \( \delta_b \) and \( \delta_a \).

b. \( X_b, X_a \), when the first condition is satisfied, and the second condition is not met.

From the above procedure, we know that the proposed method first calculates the deviation of each index between each expert and all other experts and calculates the total deviation of the experts group in the evaluation of each index. Then use T-WA operator to determine the final combined weight and according to the group utility value, the individual regret value and the overall evaluation value of each case, to rank and select the cockpit console layout cases, which can carry out the optimal case without loss of any information and make the final decision result effective and reasonable.
4. Verified experiment

In this section, we make the comprehensive evaluation of DSV cockpit console, it is an instance to indicate the effectiveness of the proposed model, the final evaluation index system is applied to rank the DSV cockpit console layout performances shown in part 2.2. And the method mentioned above as example to select the optimal case.

While three groups of experts familiar with DSV were established to complete the linguistic ratings for indexes. Table 5 shows the fundamental state of the three expert groups, each group contains five experts.

Table 5. The fundamental state of the three expert groups.

<table>
<thead>
<tr>
<th>Expert group 1</th>
<th>Expert group 2</th>
<th>Expert group 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work Experience (year)</td>
<td>Professional Background</td>
<td>Occupation</td>
</tr>
<tr>
<td>Expert group 1</td>
<td>&gt; 7</td>
<td>Ergonomics</td>
</tr>
<tr>
<td>Expert group 2</td>
<td>&gt; 5</td>
<td>Mechanical engineering</td>
</tr>
<tr>
<td>Expert group 3</td>
<td>&gt; 8</td>
<td>Ergonomics</td>
</tr>
</tbody>
</table>

There are four alternative cases modeled by computer aided industrial design software (Figure 3). According to the aim of ergonomic evaluation, expert groups select evaluation indexes from Table 2, which are the operator handling comfort ($X_3$), order identification of manipulation ($X_2$), console convenience ($X_4$), and antiglare degree ($X_5$), they are respectively from the main index, primary index, secondary index, in the evaluation index system. In this case study, experts will determine the optimal case based on these five indexes. Linguistic phrase evaluation sets of three different granularities were used respectively in three groups of experts. They are given as follows: $S^1 = \{S_{s1}^1, S_{s2}^1, S_{s3}^1, S_{s4}^1, S_{s5}^1\}$ = {worst, not good, fair, good, best}; $S^2 = \{S_{s1}^2, S_{s2}^2, S_{s3}^2, S_{s4}^2, S_{s5}^2, S_{s6}^2\}$ = {worst, not good, fair, good, better, best}; $S^3 = \{S_{s1}^3, S_{s2}^3, S_{s3}^3, S_{s4}^3, S_{s5}^3, S_{s6}^3, S_{s7}^3, S_{s8}^3\}$ = {worst, worse, bad, not good, fair, a bit good, good, better, best}. If one group of experts uses seven granularity linguistic phrase evaluation sets to evaluate the console convenience between bad and not good in case four, in which $S_{s1}^2$, represents bad and $S_{s2}^2$, represents not good, it can be filled in like $S_{s1}^2, S_{s2}^2$.

The process of expert groups evaluation is arranged with the DSV cockpit console ergonomics evaluation list shown in figure 2, which including expert weight distribution, evaluation sets of linguistic phrases with different granularities and index reference.

Figure 2. DSV cockpit console ergonomics evaluation list.
And then give a decision making matrix as listed in following formula:

\[
R^1 = \begin{bmatrix}
X_1 & X_2 & X_3 & X_4 \\
s_4 & s_5 & s_3 & s_5^5 \\
[s_5^5, s_5^2] & [s_5, s_5^2] & [s_5, s_5^2] & [s_5^5, s_5^2] \\
[s_5^2, s_5^5] & [s_5^2, s_5^2] & [s_5^5, s_5^2] & [s_5^5, s_5^2] \\
[s_5^3, s_5^2] & [s_5^2, s_5^2] & [s_5^5, s_5^2] & [s_5^5, s_5^2] \\
[s_5^2, s_5^3] & [s_5^2, s_5^2] & [s_5^5, s_5^2] & [s_5^5, s_5^2] \\
[s_5^2, s_5^2] & [s_5^2, s_5^2] & [s_5^5, s_5^2] & [s_5^5, s_5^2] \\
\end{bmatrix}
\]

\[
R^2 = \begin{bmatrix}
X_1 & X_2 & X_3 & X_4 \\
s_6 & s_7 & s_3 & s_5 \\
[s_5^7, s_5^2] & [s_5^7, s_5^2] & [s_5^7, s_5^2] & [s_5^7, s_5^2] \\
[s_5^2, s_5^7] & [s_5^2, s_5^7] & [s_5^7, s_5^2] & [s_5^7, s_5^2] \\
[s_5^3, s_5^7] & [s_5^3, s_5^7] & [s_5^7, s_5^2] & [s_5^7, s_5^2] \\
[s_5^7, s_5^2] & [s_5^7, s_5^2] & [s_5^7, s_5^2] & [s_5^7, s_5^2] \\
[s_5^2, s_5^7] & [s_5^2, s_5^7] & [s_5^7, s_5^2] & [s_5^7, s_5^2] \\
\end{bmatrix}
\]

\[
R^3 = \begin{bmatrix}
X_1 & X_2 & X_3 & X_4 \\
s_6 & s_7 & s_3 & s_5 \\
[s_5^6, s_5^7, s_5^9] & [s_5^4, s_5^9] & [s_5^7, s_5^9] & [s_5^7, s_5^9] \\
[s_5^7, s_5^6, s_5^9] & [s_5^7, s_5^9] & [s_5^7, s_5^9] & [s_5^7, s_5^9] \\
[s_5^3, s_5^9] & [s_5^3, s_5^9] & [s_5^9, s_5^9] & [s_5^9, s_5^9] \\
[s_5^9, s_5^9] & [s_5^9, s_5^9] & [s_5^9, s_5^9] & [s_5^9, s_5^9] \\
\end{bmatrix}
\]

In the following parts, we utilize the proposed method to rank and select the optimal case, the specific steps are as follows:

**Step 1.** We get the vectors of five index values corresponding to the four evaluation cases from Table 1. The linguistic evaluation matrix and the index importance vector are unified into two-tuple linguistic form under the nine granular linguistic evaluation set according to Eq. (8). Use Eq. (8) to calculate the evaluation deviation of each index, and get the overall evaluation deviation of expert groups on each index according to Eq. (10):

\[
\rho_1 = 12.27, \quad \rho_2 = 16.12, \quad \rho_3 = 16.86, \quad \rho_4 = 12.33.
\]

**Step 2.** Use Eq. (11) and Eq. (12) respectively to get the objective and subjective weight vector of the five indexes:

\[
W_o = (0.2056, 0.2189, 0.1974, 0.2003)
\]

\[
W_s = (0.1621, 0.1773, 0.2053, 0.2512)
\]

Differentiate the objective function, and assign the result is 0, we can get \( \beta = 0.5 \), so the combined weight vector of the index obtained by Eq. (13):

\[
W = (0.1839, 0.1981, 0.2014, 0.2258)
\]

**Step 3.** Index weights, expert weights and uncertain linguistic evaluation matrices are transformed into two-tuple linguistic forms, and use Eq. (14) to obtain the group evaluation matrix.

**Step 4.** According to Eq. (15) and Eq. (16), we determine the positive and negative ideal point vectors of the ergonomic evaluation indexes of layout cases.

\[
r^+ = \begin{bmatrix} 0.531, 0.362 \\ 0.719, 0.109 \\ 0.877, 0.081 \\ 0.582, 0.404 \end{bmatrix}
\]

\[
r^- = \begin{bmatrix} 0.400, 0.518 \\ 0.552, 0.339 \\ 0.432, 0.489 \\ 0.826, 0.075 \end{bmatrix}
\]

**Step 5.** Group utility value and individual value of regret for each case can be calculated by Eq. (17) and Eq. (18).

\[
u_i = (0.45, 0.41, 0.52, 0.63), \quad Y_i = (0.19, 0.25, 0.31, 0.38)
\]

**Step 6.** Finally we can determine \( \Delta_i \) according Eq. (19) to rank the cases.

\[
\begin{align*}
\epsilon < 0.5 & \quad X_1 > X_2 > X_3 > X_4 \\
\epsilon = 0.5 & \quad X_1 > X_2 > X_4 > X_2 \\
\epsilon > 0.5 & \quad X_1 > X_3 > X_4 > X_2
\end{align*}
\]

According to the sorting results of the three categories, \( X_1 \) is in the first place, so the optimal DSV cockpit console ergonomic layout case is \( X_1 \).

**Figure 3.** DSV cockpit console ergonomics evaluation cases

By analyzing the above cases, we try to choose the optimal case that could solve the ergonomics issue. In order to verify the availability of the proposed method, we compared the proposed method with other typical evaluation methods including fuzzy AHP method (FAM) [Izquierdo, 2015], fuzzy center of gravity method (FCG) [Guo, 2017], fuzzy TOPSIS method [Sun, 2010] and the ordering method (OM) [Shi, 2002]. The combined weights obtained in chapter 3.2 are applied to these four methods. The evaluation results are shown in Table 6, it indicates that Case 1 and Case 3 are the optimal and second preferred case respectively. The evaluation result is identical with the proposed method.
Table 6. The evaluation results of four cases with different method

<table>
<thead>
<tr>
<th>Evaluation object</th>
<th>FAM</th>
<th>FCG</th>
<th>F-TOPSIS</th>
<th>OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.734</td>
<td>1</td>
<td>0.517</td>
<td>0.386</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.489</td>
<td>4</td>
<td>0.231</td>
<td>0.264</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.655</td>
<td>2</td>
<td>0.508</td>
<td>0.288</td>
</tr>
<tr>
<td>Case 4</td>
<td>0.513</td>
<td>3</td>
<td>0.281</td>
<td>0.240</td>
</tr>
</tbody>
</table>

## 5. Conclusion

The ergonomics evaluation of DSV cockpit console is an important procedure in the process of DSV research and development. The ergonomics evaluation of DSV cockpit console is a multi-target and multi-hierarchical decision-making process. Because there are many fuzzy and qualitative indexes in the evaluation system, the hybrid framework for evaluating the ergonomics was proposed in this paper, which can efficiently promote the operation of DSV cockpit console. We established the ergonomics evaluation index system of DSV cockpit console after analyzing the characteristics of evaluation object. The evaluation index system has three levels, it includes all evaluation indexes which are assigned to different levels. The improved Delphi method was recommended to select ergonomic evaluation index scientifically based on experts’ opinions, the evaluation system of DSV cockpit console can be a reference for the future research on cabin console. In order to deal with the fuzziness of expert groups and discrepancy of evaluation index, the two-tuple weighted averaging operator and extended VIKOR were applied to evaluate the comprehensive performance. Compared with other four typical evaluation method on the DSV console, the proposed method has been proved to be feasible and effective.

The proposed evaluation method in this study can quantificationally evaluate the DSV cockpit console case and compare the pros and cons of different cases clearly, avoiding expert evaluation bias and shortening development cycle. Moreover, the research method can also provide a reference for ergonomic evaluation of related cabin.

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