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Research on Weight Factors of the Evaluation Indexes of Cockpit Display Ergonomics

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Abstract: The ergonomic evaluation of cockpit display plays key role in the new-type cockpit development. In the previous research, the ergonomic evaluation indexes of cockpit display were build. This study is to determine the weight factors of the evaluation indexes of cockpit display ergonomics. For this purpuse, the order relation analysis method is proposed. With the aid of this method, 15 experienced pilots on active service who flied several types of aircraft were recruited as experts to be surveyed. The weight factors of evaluation indexes are calculated according to the investigation results. Then, the weight factors based on different numbers of experts are analyzed in order to study their reliability. The analysis results indicate that the weight factors are stable when the expert number up to some threshold value. Therefore the weight factors of the evaluation indexes calculated according to the investigation results can be used as the guidance to the design and evaluation of cockpit display ergonomics.

Key words: Ergonomics, display, weight factor

INTRODUCTION

To complish the ergonomic evaluation of cockpit display, it needs to build the evaluation indexes and to determine the weight fators of the evaluation indexes. The ergonomic evaluation indexes of cockpit display were built in the study of Li and Yuan (2006). This study chiefly studies how to determine the weight factors of the evaluation indexes of cockpit display ergonomics and the research results can be used as the basis for the evaluation of display ergonomics and the guidance for the design of engineering department.

Weight factors are to express the relative important degree of evaluation indexes in numerical form and it is important to determine the precision of comprehensive evaluation model. Therefore, a reasonable distribution of weight factors of indexes is the key to quantified comprehensive evaluation. There are many methods to determine weight factors of evaluation indexes, published materials say that the Analytic Hierarchy Process (AHP) method is the most widely used. However, Guo (2002) and Chen (2000) said that the AHP has inevitable defects both in principle and process, such as, the sole criterion for this method would be useless sometimes. The judgment matrix isn't a united matrix; moreover, the AHP method can't be directly applied when the number of comparative indexes exceeds 9. For these reasons, Professor GUO of Northeastern University proposed the order relation analysis method to determine weight factors of evaluation indexes. Its basic thought is: array the evaluation indexes follow some evaluation criterion first and then compare and judge the adjacent indexes with a calibration on a particular scale and assign a quantitative value, then process the judgment mathematically and obtain the weight factors of evaluation indexes. As for AHP, the order relation analysis method has the following characteristics:

- Don't need structure the judgment matrix and the consistency check
- The amount of calculation diminishes exponentially compare to Analytic Hierarchy Process
- The number of indexes on the same level is unrestricted
- Order preserving characteristic. Order preserving characteristic is a nature for the same method to determine weight factors of indexes, no matter what the index changes, the relative important degree between indexes should be constant
- The method is simple, direct-viewing and convenient for application

MATERIALS AND METHODS

Based on the above-mentioned considerations, the order relation analysis method is proposed to resolve the problem of weight factors of cockpit display ergonomics in this study. Designate the index set as $\{u_1, u_2,..., u_n\}$. To

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determine the weight factors of indexes, the order relation analysis method includes three steps as follows.

Set ordering relation: If the important degree of evaluation index u_i is greater than or equal to u_j according to some evaluation criterion, write it as $u_i > u_j$.

The evaluation indexes u_1, u_2,..., u_n are said to have set ordering relation followed ">", if the evaluation indexes accord with the relation formulas following some evaluation criterion.

$$u_1 > u_2 > \ldots > u_n \quad (1)$$

Designate the Eq. 1 as $u_1 > u_2 > \ldots > u_n$ still for convenience. The ordering relation that determined by different experts is different for the influence of subjective factors.

Judge the ratios of relative important degree of two adjacent elements: Suppose the ratios of important degree of u_{k-1} and u_k that judged rationally by experts is:

$$w_{k-1}/w_k = r_k,\ k = n, n-1, n-2,\ldots,3,2 \quad (2)$$

The values of r_k can reference Table 1.

Calculate the weight factor w_k: According to the value of r_k, calculate the weighted value w_i (i = 1,2, ..., n) of index u_i using the Eq. 3, 4:

$$w_n = (1 + \sum_{k=2}^{n} \prod_{i=k}^{n} [r_i)^{-1} \quad (3)$$

$$w_{k-1} = r_k w_k,\ k = n, n-1, n-2, \ldots, 3, 2 \quad (4)$$

When apply the order relation analysis method to determine weight factors of evaluation indexes of cockpit display ergonomics, in order to reduce the disturbances of expert's subjective factors and determine the weight factors of indexes more accurately, objectively, combining the fact, 20 experienced pilots were hired as experts and they were investigated accord with principles that the affection degree of pilot's operating ergonomics influenced by all indexes. Fifteen virtual copies of the completed questionnaire were collected and the basic information of the 15 experienced pilots is: Age years old is 29~44 (34.9±4.8), total flight time hours are 800~3000 (1626.4±739.7).

Table 1: Ratios of important degree of the two adjacent indexes

r_k	Explanation
1.0	Index u_{k-1} is as important as index u_k
1.2	Index u_{k-1} is a little more important than index u_k
1.4	Index u_{k-1} is obviously more import than index u_k
1.6	Index u_{k-1} is mightily more import than index u_k
1.8	Index u_{k-1} is extremely more import than index u_k

r_k: w_{k-1}/w_k, the u_{k-1} and u_k is the two adjacent indexes

RESULTS

Investigation results of the experts: The evaluation indexes system which contains 38 indexes for cockpit display ergonomics was built in the study of (Li and Yuan, 2006). Herein the evaluation indexes system frame is given, refer to Table 2. In Table 2, O represents the general evaluation objective, O_i (i = 1, 2,…,6) represent evaluation sub-objects, U_k(k = 1,2, …,6) represent the sets of evaluation indexes. Each index set contains many indexes, the specific index in details see the study of (Li and Yuan, 2006).

Because of the limitation of space, each subset in the total objective set O and the survey results of indexes in index set U_1, U_6 were given here, see Table 3, 4 and 5, respectively.

O = {O_1, O_2, O_3, O_4, O_5, O_6} = {consistency, readability, screen layout, explicitness, appropriate functionality, error prevention}.

U_1 = {u_{11}, u_{12}, u_{13}, u_{14}, u_{15} u_{16}} = {the consistency between displays or within a display, the consistency of colors throughout the displays, the consistency of symbols and other pictorial information throughout the display, the intuitiveness of the user

Table 2: Evaluation index system frame of cockpit display ergonomics

General objective layer	Sub-object layer	Index layer
Objective (O): The ergonomic evaluation index of cockpit display	O_1: Consistency	U_1
	O_2: Readability	U_2
	O_3: Screen layout	U_3
	O_4: Explicitness	U_4
	O_5: Appropriate functionality	U_5
	O_6: Error prevention	U_6

Table 3: Sequence relations of subset in set O and ratios of relative important degree of two adjacent elements

Code of expert	Ordering relation	Ratios of important degree r_2	r_3	r_4	r_5	r_6
L_1	$O_3 > O_1 > O_6 > O_5 > O_2 > O_4$	1.0	1.2	1.2	1.2	1.2
L_2	$O_4 > O_1 > O_3 > O_6 > O_5 > O_2$	1.2	1.0	1.2	1.0	1.2
L_3	$O_1 > O_5 > O_4 > O_2 > O_6 > O_3$	1.8	1.2	1.4	1.2	1.0
L_4	$O_3 > O_2 > O_4 > O_5 > O_1 > O_6$	1.4	1.2	1.2	1.2	1.2
L_5	$O_4 > O_6 > O_5 > O_3 > O_2 > O_1$	1.2	1.2	1.0	1.0	1.0
L_6	$O_4 > O_3 > O_6 > O_2 > O_5 > O_1$	1.0	1.0	1.4	1.2	1.0
L_7	$O_5 > O_1 > O_4 > O_2 > O_3 > O_6$	1.0	1.2	1.2	1.2	1.2
L_8	$O_4 > O_1 > O_6 > O_2 > O_3 > O_5$	1.4	1.4	1.2	1.2	1.2
L_9	$O_6 > O_4 > O_3 > O_5 > O_1 > O_2$	1.6	1.2	1.2	1.0	1.0
L_{10}	$O_6 > O_4 > O_2 > O_3 > O_1 > O_5$	1.0	1.0	1.2	1.4	1.0
L_{11}	$O_2 > O_3 > O_5 > O_4 > O_6 > O_1$	1.0	1.0	1.0	1.2	1.2
L_{12}	$O_4 > O_6 > O_2 > O_3 > O_1 > O_5$	1.0	1.2	1.0	1.0	1.2
L_{13}	$O_5 > O_6 > O_4 > O_2 > O_3 > O_1$	1.0	1.0	1.2	1.0	1.0
L_{14}	$O_2 > O_3 > O_4 > O_5 > O_6 > O_1$	1.4	1.2	1.2	1.0	1.2
L_{15}	$O_1 > O_4 > O_6 > O_5 > O_2 > O_3$	1.0	1.0	1.2	1.0	1.0

Table 4: Sequence relations of indexes in set U_1 and ratios of relative important degree of two adjacent elements

Code of expert	Ordering relation	Ratios of important degree r_2	r_3	r_4	r_5	r_6
L_1	$u_{14}>u_{15}>u_{13}>u_{12}>u_{11}>u_{16}$	1.2	1.0	1.0	1.0	1.2
L_2	$u_{13}>u_{14}>u_{12}>u_{11}>u_{15}>u_{16}$	1.2	1.4	1.0	1.4	1.2
L_3	$u_{11}>u_{12}>u_{14}>u_{13}>u_{15}>u_{16}$	1.0	1.0	1.2	1.0	1.0
L_4	$u_{14}>u_{13}>u_{11}>u_{12}>u_{15}>u_{16}$	1.4	1.2	1.0	1.2	1.2
L_5	$u_{14}>u_{15}>u_{16}>u_{13}>u_{12}>u_{11}$	1.4	1.2	1.0	1.2	1.0
L_6	$u_{15}>u_{14}>u_{16}>u_{12}>u_{13}>u_{11}$	1.0	1.2	1.0	1.0	1.0
L_7	$u_{13}>u_{14}>u_{16}>u_{15}>u_{12}>u_{11}$	1.0	1.2	1.2	1.2	1.2
L_8	$u_{11}>u_{13}>u_{16}>u_{12}>u_{14}>u_{15}$	1.4	1.2	1.2	1.2	1.0
L_9	$u_{14}>u_{15}>u_{13}>u_{11}>u_{12}>u_{16}$	1.2	1.2	1.0	1.0	1.0
L_{10}	$u_{14}>u_{12}>u_{15}>u_{13}>u_{11}>u_{16}$	1.0	1.2	1.0	1.2	1.0
L_{11}	$u_{14}>u_{15}>u_{16}>u_{12}>u_{11}>u_{13}$	1.2	1.0	1.0	1.2	1.0
L_{12}	$u_{14}>u_{11}>u_{13}>u_{15}>u_{16}>u_{12}$	1.0	1.0	1.2	1.4	1.2
L_{13}	$u_{14}>u_{15}>u_{16}>u_{13}>u_{11}>u_{12}$	1.4	1.2	1.2	1.0	1.0
L_{14}	$u_{14}>u_{15}>u_{16}>u_{13}>u_{11}>u_{12}$	1.0	1.0	1.0	1.2	1.0
L_{15}	$u_{11}>u_{14}>u_{12}>u_{13}>u_{15}>u_{16}$	1.0	1.2	1.0	1.0	1.0

Table 5: Sequence relations of indexes in set U_6 and ratios of relative important degree of two adjacent elements

Code of expert	Ordering relation	Ratios of important degree r_2	r_3	r_4	r_5
L_1	$u_{63}>u_{65}>u_{62}>u_{61}>u_{64}$	1.0	1.0	1.0	1.0
L_2	$u_{63}>u_{62}>u_{65}>u_{64}>u_{61}$	1.2	1.0	1.2	1.2
L_3	$u_{64}>u_{62}>u_{61}>u_{63}>u_{65}$	1.8	1.0	1.0	1.0
L_4	$u_{63}>u_{65}>u_{64}>u_{62}>u_{61}$	1.6	1.4	1.2	1.4
L_5	$u_{65}>u_{61}>u_{63}>u_{64}>u_{62}$	1.2	1.0	1.0	1.2
L_6	$u_{63}>u_{64}>u_{65}>u_{62}>u_{61}$	1.8	1.0	1.0	1.0
L_7	$u_{64}>u_{63}>u_{65}>u_{62}>u_{61}$	1.0	1.0	1.4	1.2
L_8	$u_{61}>u_{64}>u_{65}>u_{62}>u_{63}$	1.4	1.2	1.2	1.2
L_9	$u_{65}>u_{61}>u_{63}>u_{64}>u_{62}$	1.6	1.0	1.0	1.4
L_{10}	$u_{64}>u_{65}>u_{61}>u_{63}>u_{62}$	1.2	1.2	1.0	1.0
L_{11}	$u_{61}>u_{64}>u_{65}>u_{63}>u_{62}$	1.0	1.2	1.0	1.0
L_{12}	$u_{64}>u_{65}>u_{63}>u_{62}>u_{61}$	1.0	1.0	1.2	1.0
L_{13}	$u_{63}>u_{64}>u_{65}>u_{61}>u_{62}$	1.0	1.0	1.2	1.0
L_{14}	$u_{65}>u_{63}>u_{64}>u_{62}>u_{61}$	1.2	1.0	1.0	1.2
L_{15}	$u_{64}>u_{65}>u_{62}>u_{61}>u_{63}$	1.2	1.0	1.0	1.0

interface, the consistency of digital information, the consistency of the format and method in which the operator enter particular types of information throughout the display}.

U_6 = {u_{61}, u_{62}, u_{63}, u_{64}, u_{65} } = {the extent to which the system informs the operator when information entered is out of range, the extent to which the operator are able to check what he have entered before it is processed, the extent to which it is easy for the operator to correct errors, the extent to which the information displayed is sufficiently accurate, the extent to which the system prevents the operator from taking actions that are invalid}.

The calculated results and analysis of weight factors: According to the survey results of experts and the Eq. 3, 4 the weight factors of indexes which is in set O or in set U_1~U_6 were figured out they are:

{w_{o1}, w_{o2}, w_{o3}, w_{o4}, w_{o5}, w_{o6}} = {0.1694, 0.1588, 0.1678, 0.1886, 0.1489, 0.1665}

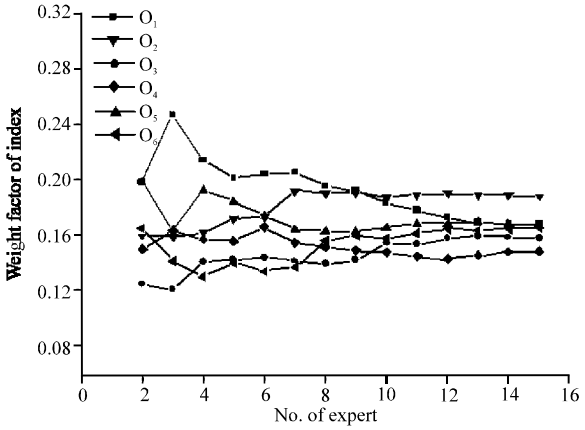

Fig. 1: Comparison of weight factors of subset in set O

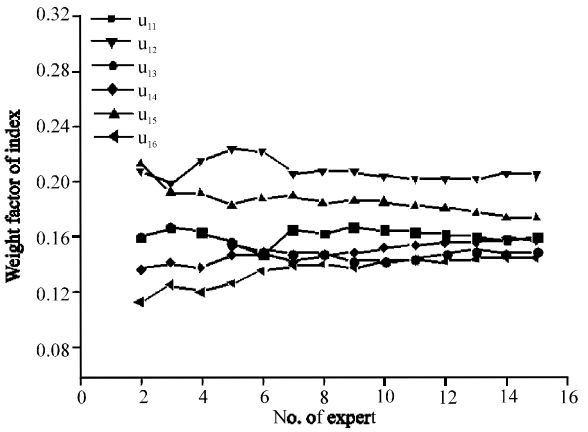

Fig. 2: Comparison of weight factors of indexes in set U_1

{w_{u11}, w_{u12}, w_{u13}, w_{u14}, w_{u15}, w_{u16}} = {0.1615, 0.1507, 0.1744, 0.2059, 0.1600, 0.1476}

{w_{u21}, w_{u22}, w_{u23}, w_{u24}, w_{u25}, w_{u26}, w_{u27}, w_{u28}} = {0.1227, 0.1280, 0.1251, 0.1242, 0.1021, 0.1702, 0.1071, 0.1206}

{w_{u31}, w_{u32}, w_{u33}, w_{u34}, w_{u35}, w_{u36}, w_{u37}} = {0.1832, 0.1273, 0.1670, 0.1205, 0.1212, 0.1449, 0.1359}

{w_{u41}, w_{u42}, w_{u43}, w_{u44}, w_{u45}} = {0.1992, 0.1889, 0.2360, 0.1867, 0.1892 }

{w_{u51}, w_{u52}, w_{u53}, w_{u54}, w_{u55}, w_{u56}, w_{u57}} = {0.1354, 0.1654, 0.1569, 0.1572, 0.1461, 0.1228, 0.1163}

{w_{u61}, w_{u62}, w_{u63}, w_{u64}, w_{u65},} = {0.1827, 0.1750, 0.2156, 0.2134, 0.2133}

In order to analyze the reliability of weight factors of evaluation indexes, the variation tendency of weight factors of indexes with the increasing number of experts was caculated, see Fig. 1-7.

From the Fig. 1-7 the conclusion can be obtained that when the number of experts reach to a designated number, the calculated weight factors tend to be stable. It indicates

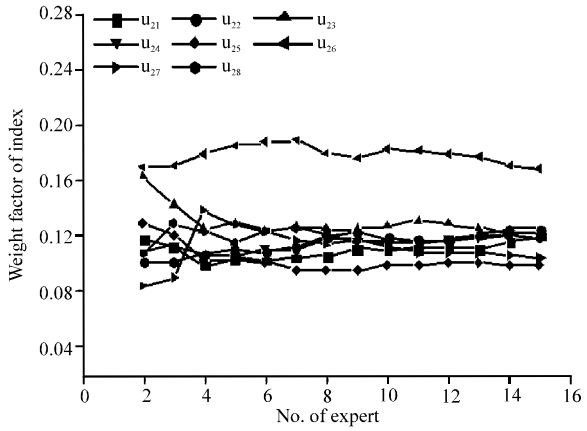

Fig. 3: Comparison of weight factors of indexes in set U_2

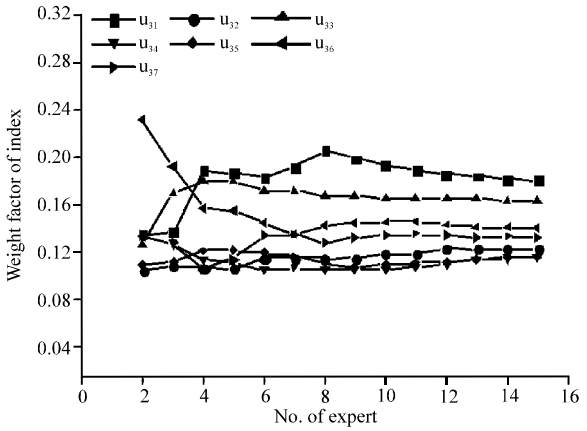

Fig. 4: Comparison of weight factors of indexes in set U_3

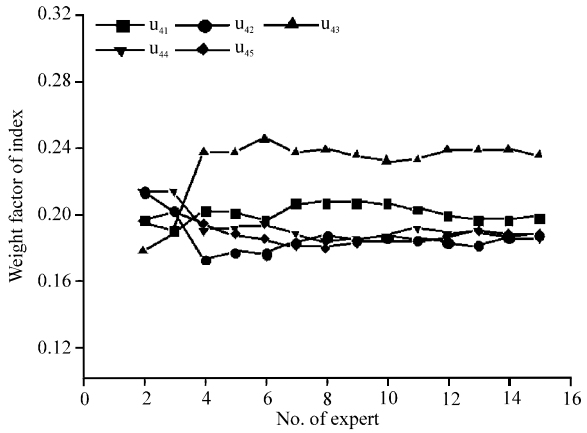

Fig. 5: Comparison of weight factors of indexes in set U_4

that the weight factors which were calculated by the order relation analysis method in this study are reliable.

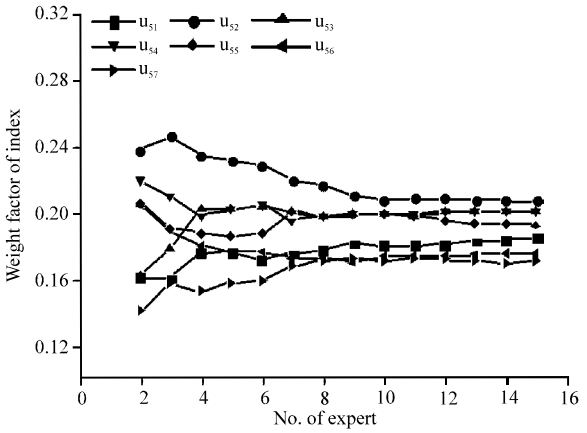

Fig. 6: Comparison of weight factors of indexes in set U_5

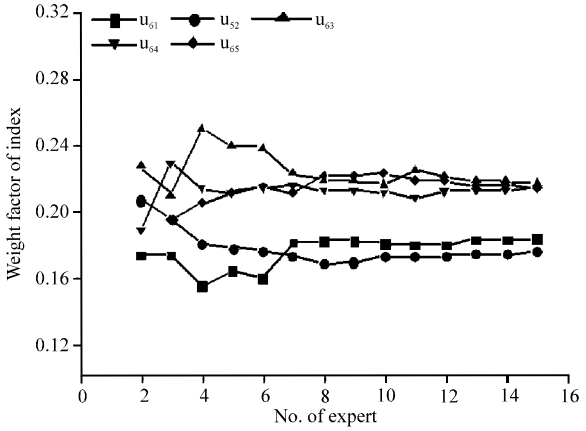

Fig. 7: Comparison of weight factors of indexes in set U_6

CONCLUSION

The research in this study indicates that the order relation analysis method to determine weight factors is characterized as the strong maneuverability.

As to the recruited experts, it should be recruited those person who are experienced and volunteered and the number of experts should be more than 10.

This research can provide guidance to the engineering department in design and evaluation work and also can offer reference to the correlation study in other areas.

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