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Evaluation Method of Modeling Beauty of Construction Machinery Products Based on Analytic Hierarchy Process

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ABSTRACT

Based on the current research on the beauty evaluation of construction machinery, the analytic hierarchy process is introduced to establish the evaluation system and method for the beauty of construction machinery. Build a hierarchical structure model, extract construction machinery beauty evaluation factors, such as proportion, structure, color, material, surface technology and brand image, which as the criterion layer of the hierarchical structure mode, and the criterion layer is divided into fourteen index layers. Experiments show that the extraction model of impact factors of construction machinery beauty is feasible, and the model is repeatable. With the help of AHP, the preference of users' perception of the beauty of construction machinery is obtained, which provides a theoretical basis for construction machinery design.

Keywords: Analytic hierarchy process, Construction machinery products, Model beauty, Evaluation

INTRODUCTION

As a typical complex industrial product, construction machinery products are different from traditional consumer products, and their appearance depends largely on their functions, structures and working environment. Appearance modeling, as a media channel for emotional communication between users and products, also serves as a bridge between users, designers and enterprises, which is very important for improving the market competitiveness of construction machinery products. However, the evaluation of construction machinery products is full of uncertainty and subjectivity, and it is often impossible to get objective and accurate evaluation results by relying entirely on the judgment of specialists. AHP (analytic hierarchy process) is suitable for dealing with multi-level, multi-factor and complex evaluation problems, and is widely used in product design evaluation at present. In this study, AHP is introduced to evaluate the modeling beauty of construction machinery products, which not only helps to improve design efficiency, but also helps to make more standardized, objective and accurate evaluation results.

EVALUATION MODEL OF MODELING BEAUTY OF CONSTRUCTION MACHINERY PRODUCTS

Principle of analytic hierarchy process. AHP (analytic hierarchy process) is a multi-objective evaluation method combining qualitative analysis with

quantitative analysis, which was put forward by American scholars in 1970s. The key point of the implementation of AHP is to compare different factors (Chen and Wu, 2007), so as to get their weight relations and establish a set of weight judgment matrix (Tan, 2012). Using AHP to analyze the problem, it is usually necessary to divide the judgment object into three levels, namely, the target level, the criterion level and the index level, which is called the evaluation system of this problem (Xu, 1988; Han et al., 2004). Among them, the target layer is the ultimate goal and summary of evaluation at all levels, the criterion layer is the further structural refinement of the target layer, and the index layer is the refinement and disassembly of each criterion layer. The determination of the evaluation system needs to be considered according to the actual problems in order to be objective and accurate. For the comparative judgment between different levels, it is necessary to carry out semantic quantization, thus obtaining the comparative weight and calculating the final evaluation matrix.

Construction Machinery Product Modeling Beauty Evaluation System

Determining an accurate and operational beauty evaluation system is the most important thing in AHP analysis and evaluation. Compared with other kinds of products, construction machinery products have more structural parts, and the functions of each part are clearly divided, which makes the modeling beauty system of construction machinery products more complicated. Chen Xi et al. (2015) proposed that users should establish the image cognition of mechanical products through visual perception of appearance, color and material. Dai Mingyuan (2016) believes that users perceive and understand the shape of mechanical products from the aspects of volume, shape, linearity and color. Yi Jun and Li Xue (2021) thinks that the field of construction machinery needs to solve the specific problems of product concept, modeling, color, structure, function, man-machine interface and so on. To sum up, proportion, structure, shape, color, coating and material are important factors to evaluate the beauty of construction machinery products. Based on the user's observation of construction machinery products, combined with the discussion with many industry experts, according to the principle of construction machinery product hierarchy, the evaluation system is shown in Table 1.

Evaluation Indicators

Proportional beauty index. Proportion refers to a ratio between measures such as length or area, that is, the relationship between parts or parts and the whole (Hu and Li, 2009). In product design, the beauty of proportion is usually the key consideration of designers, which is related to the contrast and coordination of overall modeling and detailed modeling. A good proportion can enhance the aesthetic feeling of modeling. The beauty of modeling proportion of construction machinery products can be expressed through the coordination and rationality of proportion. Proportional harmony reflects the volume ratio coordination of all parts in the overall modeling, which is related to the proportional aesthetic feeling of product modeling.

Table 1. Construction machinery product modeling beauty evaluation system.

Target Level	Criterion Level	Index Level
Modeling beauty	Proportion Beauty(C1)	Proportional coordination(F1)
		Reasonable proportion(F2)
	Structural Beauty(C2)	Functional structure(F3)
		Simple and feasible structure(F4)
		Coordinated structure(F5)
	Shape and Surface Beauty(C3)	Smooth surface(F6)
		Coordinated surface(F7)
		Appropriate surface density(F8)
	Color Beauty(C4)	Unobtrusive color(F9)
		Beautiful colors(F10)
	Coating Beauty(C5)	Coating conforms to the overall style(F11)
		Simple coating(F12)
		Steady coating(F13)

Structural beauty index. Structural beauty is the external modeling expression of the internal structure of construction machinery products, and it is the basis of the modeling beauty of construction machinery products. The structure of construction machinery products is not always reflected in the external modeling, but some exposed structure has a significant impact on the overall aesthetic feeling. Structural beauty has multiple aesthetic levels, and the evaluation corresponding to structural beauty can be decomposed into functional rationality, formal appropriateness, feasibility and coordination of structure.

Shape and surface beauty index. Form surface. Shape feature is the most direct way to convey the information of modeling (Hsiao and Huang, 2002). The shape and surface characteristics of construction machinery products refer to the ups and downs of the external structure coverage and the connection between surfaces. The size, curvature and shape changes of the surface give users different visual impacts and feelings, which affect the user's perception experience in the most intuitive way. The shape of construction machinery products is largely determined by their functional structure. However, as construction machinery products tend to be large-scale, light-weight and intelligent, users' perception needs for shape are more diverse.

Color beauty index. Color is one of the important elements of construction machinery products modeling design, which affects users' judgment on the beauty of modeling. It can change the living environment, create different atmosphere, and create different design styles by combining different elements (Li, 2006). Different colors of construction machinery products have different visual feelings under the same appearance. Successful construction machinery products color design is characterized by beautiful and harmonious colors, that is, colors are not abrupt.

Coating beauty index. Coating of construction machinery products includes color coating and pattern coating (Zhang et al., 2018). As the first element of users' visual perception, the different types and areas of colors trigger different visual impact, which in turn affects users' psychological feelings and

emotional reactions. Due to the particularity of the working environment of construction machinery, reasonable color configuration can coordinate the relationship between the machine and users, alleviate the fatigue and boredom caused by users' long-term operation in harsh environment, and at the same time improve work efficiency and ensure safety. The purpose of pattern characters is to convey information, and whether users can accurately perceive information will also affect the safety of the operation process. The particularity of the operation type of construction machinery products determines that its coating design can not blindly pursue novelty, ignoring the objective needs of the environment and users.

Material beauty index. Material is the material basis of form. The user's perception of the material forms the texture, which is the psychological response made by the user to the physiological stimulation caused by the visual and tactile perception of the material's attributes. Different materials have different perceptual characteristics, and different surface treatments will bring different visual effects and psychological feelings to users. The main material of construction machinery products is steel, which not only meets the structural and functional requirements, but also enhances the user's sense of security; Auxiliary materials are mostly glass, rubber, plastic, etc., which enhances the overall sense of science and technology and modernity.

Calculation of Evaluation Index Weight

AHP constructs a hierarchical analysis structure model by analyzing the factors and related relationships contained in a complex system. By comparing the elements of each level with each other according to a certain scaling theory, a comparison scale of relative importance degree is obtained, and a judgment matrix is established to calculate the maximum eigenvalues and eigenvectors of the judgment matrix, so as to obtain the importance order of the elements of each level to a certain element of the upper level, and then a weight vector is established. The main steps are as follows:

According to scaling theory, a pairwise comparison judgment matrix A is constructed:

$$A = (aij)\ n \times n\ (i, j = 1, 2, \ldots, n)$$

in the formula, $aij = 1, aij = 1/aji$.

Normalizing each column of the judgment matrix A:

$$\overline{a}_{ij} = a_{ij} / \sum_{k=1}^{n} a_{kj}\ (i,j\ \ = 1,2,\ldots,n)$$

Find the sum of the elements in each row of the judgment matrix A:

$$\overline{w}_i = \sum_{j=1}^{n} \overline{a}_{ij}\ (i = 1,2,\ldots,n)$$

Normalizing $\overline{w}_i$ to obtain wi:

$$w_i = \overline{w}_i / \sum_{i=1}^{n} \overline{w}_i \ (i = 1,2,\ldots,n)$$

According to $Aw=\lambda_{max}w$, the maximum characteristic root and its characteristic vector are obtained.

Consistency test:

1) calculate the consistency index $C.I=(\lambda_{\max} - -n)/(n-1)$;
2) Find out the corresponding average random consistency index $R.I$;
3) calculating the consistency ratio $C.R=C.I/R.I$;

When $C.R < 0.1$, the consistency test can be accepted, otherwise, A is corrected.

Because there are generally many indicators in indicator layer F, it is too much to compare all indicators in pairs. Therefore, in practice, the weight of the index layer is often calculated under a single criterion. Proceed one by one until it is completed, and the specific calculation steps are the same as those in the previous section. It should be noted that if there are too few indicators under a certain criterion, such as only two indicators, it can also be directly normalized according to the weight relationship of the questionnaire as a weight vector. Second order orthogonal Matrix can pass the consistency test.

Practical Research on Modeling Beauty of Construction Machinery Products

In this study, user evaluation data are collected by issuing questionnaires, and the weight of each evaluation index is determined by using the calculation method of analytic hierarchy process. The topic of the questionnaire adopts semantic differentiation method to help users compare the important relationships of indicators in the evaluation system (Li et al., 2018). More than half of the respondents are college experts related to the construction machinery industry, practitioners in the product design industry, and graduate students and undergraduates majoring in design. They have a better understanding of the modeling design process of construction machinery products and can better understand the product concepts contained in the semantics of the evaluation system. The important relationship of each index can be obtained by collecting user evaluation data and analyzing the weight by AHP method.

AHP Method to Determine the Weight of Criterion Level

According to the survey results, the orthogonal Matrix is obtained (as shown in Table 2).

Maximum eigenvalue $\lambda = 6.152$,

Weight vector (feature vector):

$$w = (0.1718, 0.2699, 0.1178, 0.2582, 0.1178, 0.0647)$$

Let's check the consistency, where $n = 6$, and the consistency index:

Table 2. Orthogonal matrix.

	Proportion Beauty	Structural Beauty	Shape and Surface Beauty	Color Beauty	Coating Beauty	Material Beauty
Proportion Beauty	1.0000	0.5000	2.0000	0.3330	2.0000	3.0000
Structural Beauty	2.0000	1.0000	2.0000	1.0000	2.0000	3.0000
Shape and Surface Beauty	0.5000	0.5000	1.0000	0.5000	1.0000	2.0000
Color Beauty	3.0000	1.0000	2.0000	1.0000	2.0000	4.0000
Coating Beauty	0.5000	0.5000	1.0000	0.5000	1.0000	2.0000
Material Beauty	0.3330	0.3330	0.5000	0.2500	0.5000	1.0000

Table 3. RI table.

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

$$C.I=\frac{\lambda_{\max}--n}{n-1}=0.0300$$

Saaty's random consistency index RI table (as shown in Table 3).

The consistency ratio is:

$$C.R=C.I/R.I=0.0240<0.1$$

The consistency test shows that the data obtained in this study are more accurate and the judgment matrix of the evaluation index is reliable.

According to the calculation of index weight vector in the criterion layer, six criteria can be obtained: structure, color, proportion, shape, coating and material.

In the bid, the structural beauty has the highest weight value, and the others are in descending order: color beauty, Proportion beauty, shape and surface beauty, coating beauty and material beauty.

Calculation of Relative Weight of Index Level Under a Single Criterion

Calculate the weight of the index layer under a single criterion layer, and the weight of each index layer can be obtained as shown in Table 4. The results after normalization are shown in Table 5. Comparing the weights of the third-level indicators, the following conclusions can be drawn:

Under the single criterion of proportional beauty, the weight of "proportional coordination" is greater than that of "reasonable proportion"; Under the single criterion of structural beauty, the weight of "reasonable function of structure" is the highest, followed by "simple and feasible structure" and "coordination of structure" is the lowest; Under the single criterion of beauty

Table 4. Weight of index level under a single criterion.

	Index score		
Proportion Beauty	4.2500	4.0000	
Structural Beauty	4.3500	4.1500	4.2000
Shape and Surface Beauty	4.1000	3.9500	3.9000
Color Beauty	4.1000	4.2500	
Coating Beauty	3.9500	4.0500	4.0000
Material Beauty	3.9000	3.9500	

Table 5. Index layer weights under a single criterion after normalization.

	Index score		
Proportion Beauty	0.5150	0.4850	
Structural Beauty	0.3430	0.3270	0.3300
Shape and Surface Beauty	0.3430	0.3300	0.3260
Color Beauty	0.4910	0.5090	
Coating Beauty	0.3290	0.3370	0.3330
Material Beauty	0.4970	0.5030	

of form and surface, "smoothness of form and surface" has the highest weight, followed by "combination and coordination of form and surface" and "proper density of form and surface". Under the single criterion of color beauty, the weight of "beautiful color" is greater than that of "unobtrusive color"; Under the single criterion of coating beauty, "simple coating" has the highest weight, followed by "stable coating" and "coating conforms to the overall style". Under the single criterion of material beauty, the weight of "reasonable material distribution" is greater than that of "exquisite material".

Comprehensive Index Weight Value and Evaluation Results

After combining and normalizing the above calculated criteria and index weights, the final index weight calculation result is obtained: the weight of each indicator on the same evaluation level can be obtained, that is, the indicators under different criteria layers can also be compared with each other according to the weight values (Table 6).

Table 6. Comprehensive index weight.

	Weight after indicator combination			Comprehensive weight of criterion layer
Proportion Beauty	0.0886	0.0834		0.1720
Structural Beauty	0.0926	0.0883	0.0891	0.2700
Shape and Surface Beauty	0.0405	0.0389	0.0385	0.1179
Color Beauty	0.1268	0.1315		0.2583
Coating Beauty	0.0388	0.0397	0.0393	0.1178
Material Beauty	0.0322	0.0325		0.0647

From the comparison of the weights of the criterion layer, it can be seen that the comprehensive weight of structural beauty is the largest, so special attention should be paid to the reasonable function, simplicity and coordination of the structure in the modeling design of construction machinery products. Secondly, the beauty of color and the beauty of proportion are the higher weights, which shows that beautiful colors and reasonable and coordinated proportion can greatly improve the modeling beauty of construction machinery products. The comprehensive weight value of material beauty is the smallest, which shows that the influence of material is weaker than the proportion, structure, shape, color and coating of appearance in the modeling of construction machinery products, and it is the most unimportant consideration index in the modeling design of construction machinery products. From the comparison of the weights of the index layers, it can be seen that "beautiful color" and "unobtrusive color" are the most important indexes, which are the details that need to be given priority in the modeling design of construction machinery products; "reasonable function of structure" in the beauty of structure is also the important index, which reflects the important influence of the function of construction machinery products on modeling, while "exquisite material" is the least important index, which is relatively less considered in the modeling design of construction machinery products.

CONCLUSION

Based on AHP, this paper explores a new method for modeling evaluation of construction machinery products, establishes an evaluation system for modeling beauty of construction machinery products, and calculates the weight values of each index, which can be directly applied to the modeling evaluation practice of construction machinery products. Comprehensive analysis of the final calculated index weights at all levels shows that the evaluation system conforms to the design experience and can accurately reflect the real evaluation results. In this paper, the evaluation system based on the beauty of construction machinery product modeling can be expanded according to the continuous development of construction machinery product modeling, with strong maneuverability and transformation. The application of analytic hierarchy process improves the design efficiency and helps designers to design construction machinery products that are more in line with consumers' favorite.

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