ingegneria sismica
International Journal of Earthquake Engineering
Anno XLIII - Num. 1 - 2026

The innovative development path of industrial design under the combination of traditional craftsmanship and modern technology

Jinsong Huang[1] *and Jiawen Xu*[1,*]

[1] School of Industrial Design, Hubei University of Technology, Wuhan, Hubei, 430068, China

SUMMARY: *In the context of the integration of traditional craftsmanship and modern technology, this paper explores the path of industrial design innovation. Taking the iron drilling project of Baoji Petroleum Machinery Co., Ltd. as an example, it solves the problems of design evaluation and optimization, and enhances the competitiveness of product innovation. Using the key structure and process of the original product, generate three design schemes. Invite 20 professionals to score based on 12 indicators and establish a decision matrix. By combining the Analytic Hierarchy Process and Entropy Weight Method to determine the weights of indicators, and using the Grey Comprehensive Evaluation Method, the Grey Weighted Correlation Degree is calculated through the evaluation process and steps, and the optimal scheme is ranked and checked for consistency. The experimental results show that for the three design schemes A1, A2, and A3, A2 has the best overall performance in terms of operational convenience; In terms of safety, A2 design is superior; In terms of reliability, the gap between the three plans is small; In terms of innovation, A2 stands out with its highlights. Overall score, A2 (0.3720) is the highest, followed by A3, and A1 is the lowest. Compared with traditional methods, the proposed method has a higher A2 score, which verifies its effectiveness. The method proposed in this article can provide an effective path for the innovation and development of industrial design. After optimization design, the selected A2 scheme has significant advantages in enhancing product innovation competitiveness.*

KEYWORDS: *traditional craftsmanship; Industrial design innovation; Analytic Hierarchy Process; Entropy weight method; Grey comprehensive evaluation method; Optimal selection of solutions*

1 Introduction

With the continuous development of technology and socio-economic factors, social material products have become increasingly abundant. The concept of product design and production has shifted from "manufacturing oriented, product centered" to "market-oriented, user centered". The user's consumption concept has shifted from focusing on basic performance to emphasizing aesthetic features and user experience such as style and style [1]. Most consumers evaluate and choose most products from an aesthetic perspective, and their aesthetic taste and judgment ability have been double enhanced. In this context, the combination of design innovation and industrial design innovation for economic development is becoming the most important productive force for social development [2]. Industrial design refers to the use of training, technical knowledge, experience, and visual perception to endow materials, structures, constructions, forms, colors, surface treatments, and decorations with new qualities and

*15271871224@163.com
https://doi.org/10.65102/is2026252 Published: 30 April, 2026

specifications for mass-produced industrial products. It aims to solve complex and multifaceted problems. The design evaluation mainly includes two aspects [3]: one is to compare and evaluate the solutions to design problems during the design process, thereby determining the value of each solution, judging its advantages and disadvantages, in order to screen out the best design solution; The second refers to evaluating the quality of a product based on the concept of the entire product (substantive product, formal product, extended product), following certain evaluation criteria and evaluation items. The former plays a crucial role in the final design quality of the product. Therefore, this article proposes the theory and method of using Analytic Hierarchy Process to effectively evaluate industrial design schemes, providing a new approach for complex scheme evaluation problems in industrial design [4].

According to the four stages of national development proposed by American scholar Michael Porter in the theory of national competitive advantage, major developed countries in Europe and America experienced the innovation driven development stage in the 19th and 20th centuries [5]. Due to historical reasons, China's socio-economic development is not as advanced as that of European and American countries, but it also realized the importance of innovation earlier. Since the official proposal of the independent innovation strategy by the country in 2005, technological innovation and design innovation have been increasingly valued, and social development is in a stage of transition from investment orientation to innovation orientation [6]. Since the 18th National Congress of the Communist Party of China, innovation has been at the core of the country's overall development. The significant impact of design innovation on the economic structural transformation and sustainable development of developed countries and regions such as Europe, the United States, Japan, and South Korea is a joint venture. Although China's design innovation started late, many current policies and measures are providing a rare historical opportunity for the rapid development of design, especially industrial design, and also putting forward new and higher requirements for the innovation and development of enterprise products. In the development of the 13th Five Year Plan from the central to local governments, it is clearly stated to enhance the productive service industry, especially the development of industrial design. Mowery&Rosenberg proposed the "dual factor theory" in 1979, which states that supply and demand are important determinants of innovation success [7]. Currently, the country is vigorously promoting supply side reform in the hope of improving consumption sources and activating their driving forces. At the same time, Chinese companies that rely on contract manufacturing to obtain low profits are facing challenges from emerging Southeast Asian contract manufacturing companies with lower costs. Relying on design innovation to create value will become a topic that many enterprises have to face. In this environment, the value of industrial design innovation in product development cannot be limited to decorative design of appearance alone. How to integrate industrial design innovation development into product innovation, and even enhance the competitiveness of product innovation with the value of industrial design innovation development, is a problem that enterprises must pay attention to [8].

Design paradigm refers to a recognized or dominant system or paradigm in terms of design philosophy, design theory, design methods, and technological means during a certain historical period. A design paradigm is a foundation and platform for the design discipline community to conduct routine research; only on the basis of the formation of a design paradigm can the design community conduct more in-depth research and argue various issues raised by the design paradigm. In the first hundred years of the Industrial Revolution, social production was in a transitional stage between handicrafts and adaptation to mechanized mass production [9]. The establishment of Bauhaus in Germany marked the birth of the "product design" model based on manufacturing technology. After the 1980s, with the development of information technology, the "interactive design" model has become increasingly common. Nowadays, with the shift of the dominant force in socio-economic development from manufacturing economy to service economy. Widespread demand is the social driving force for design innovation. The different needs of characters in terms of quality and spirit will inevitably lead to rich and diverse product design forms. Although China is currently in an era where industrial society, information society, and experience economy society overlap due to uneven regional development and diverse consumer choices, product design, interaction design, service design, and integration design are all forms of product innovation. However, digitalization of product design has become mainstream and has developed towards networking and intelligence. In this context, product design innovation should not only be about innovation in form and decoration, and the manifestation of the value of industrial design innovation in product development cannot only be about the perception of audio-visual effects.

2 Related research

Although there are relatively few direct literature discussing the value of innovative development in product industrial design, there are many literature studies on this topic, covering multiple disciplines such as industrial design innovation development, design, economics, and management. The innovative development of product industrial design not only brings huge social and economic benefits, but also greatly promotes the interdisciplinary research of economics and industrial design innovation, especially the construction of the discipline of aesthetic economics.

Build model method. [10] constructed a matrix positioning diagram with "shape" and "technology" as the axes, believing that enterprises should pursue products with high technology, good shape, and thus high value. And propose seven value opportunities for the product, including emotions, ergonomics, industrial design innovation and development, characteristics, impact, core technology, and quality, each of which is composed of several sub items. The value of industrial design innovation and development includes five aspects: visual, tactile, auditory, gustatory, and olfactory. Prahalad, D. Sawhney, R. developed an innovative development diagram for psychological industrial design based on Maslow's hierarchy of needs theory. By dividing product design into four categories: basic quadrant, universal quadrant, artistic quadrant, and rich quadrant, companies can transfer a certain product and brand from one quadrant to another according to the situation, creating business miracles and brand reputation. Zhao [11] elaborated on the role of industrial design in enhancing product value, analyzed the coordinated relationship between industrial design added value and product technical value, and constructed an analysis model with "product technical value" as the horizontal axis from low to high and "industrial design added value" as the vertical axis. They proposed that enterprises should pursue products with high technology and added value.

Strategic approach. The transformation from product functional form to aesthetic form by [12] is an important content of styling and an important means to enhance the aesthetic value of products. [13] proposed that to enhance the practical aesthetic value of a product, the following eight points should be considered: clarifying the practical aesthetic goals of the product and improving the design level; Improve the industrial design innovation and development literacy of all employees and the technical level of skilled workers; Actively creating the best working conditions; Implement innovative development in labor industry design and civilized production; Improve the process flow and various processes; Select appropriate materials and improve technical equipment; strengthen management; Create high-quality branded products. And summarize the methods and approaches to enhance the added aesthetic value of products into eight points: improving the artistic design and style of products; Refine trademark and decoration design; Ensure proper packaging and transit storage of products; Promote and advertise effectively; Master the balance between pricing, transportation methods, and delivery methods; Carry out evaluation and exhibition activities; Beautify the shopping environment; Provide excellent business services. [14] proposed from a macro social perspective that establishing a scientific design concept, establishing an identification system, and establishing a modern design talent training system are three ways to enhance the overall value of product industrial design innovation and development in society. [15] believes that the beauty of a product is reflected through three levels: formal beauty, technical functional beauty, and social beauty. The first layer provides a pleasant experience with a reasonable and beautiful external design, coordinated colors, and friendly material texture. The second layer is designed with a reasonable interactive interface, including high recognition, low error judgment, ease of operation, maintainability, and high reliability in ergonomics; The third layer is the use of individual and group common pursuit goals, which is the realization of social common interests, and the three are in a progressive relationship.

Quantitative analysis method. Value Engineering is an organized and creative activity that focuses on the functional analysis of a product or job, with the aim of enhancing its value and achieving the necessary functions required by the product or job at the lowest possible life cycle cost. This theory is widely applied in product value analysis and enhancement activities. [16] believed that in order for a product to realize its value, it must have the realization of industrial design innovation and development functions. And applying the general principles and methods of value engineering, 23 steps of the value engineering program for industrial design innovation and development were proposed, and demonstrated through practical cases. Ling Jiyao's research group analyzed the current situation of aestheticization in China's regional and industrial economies around 2007, and pointed out their development characteristics. At the same time, they conducted in-depth research on the independent innovation activities of manufacturing enterprises, focusing on various aspects of product aestheticization: beautifying the appearance of goods, improving the material of goods, enhancing the craftsmanship of goods, unifying technology and art, developing a series of designer quality biochemistry, reflecting the social and cultural value of designers, product promotion plans, design funds, publicity and information dissemination, product promotion plans, planning, etc. At the same time, a diagnostic model for the innovative development of enterprise industrial design was designed from three aspects: the four major element system, the three-level indicator system, and the operating system that combines quantitative and qualitative methods.

3 Problem description

3.1 Industrial Design Evaluation Issues

Design schemes in industrial design can take various forms, such as principle schemes, structural schemes, and modeling schemes. From their carriers, they can be component or assembly drawings, as well as models, prototypes, products, etc [17]. Generally speaking, the solution referred to in the evaluation essentially refers to the solution to the problems encountered in the design. Whether it is in the form of a physical entity or a conceptual form, these schemes can serve as objects of evaluation.

The basis for scheme evaluation is the evaluation objective. The self-evaluation of industrial design generally includes several aspects such as appearance, function, quality, safety, environmental friendliness, practicality, economy, and emphasis on ergonomics. Therefore, the overall objective can be refined into some sub objectives, namely [18]:

$$G_w = w_1 G_1 + w_2 G_2 + w_3 G_3 + \Lambda + W_n G_n \tag{1}$$

where, $G_w, G_1, G_2, \cdots, G_n$ represents the overall goal, sub goal 1, sub goal 2, ···, sub goal n, while $w_1, w_2, w_3, \cdots, w_n$ represents the weighted coefficients that indicate the importance of each sub goal. Each sub goal can be further subdivided into sub goals at a lower level, that is, the evaluation of the overall goal can be converted into the evaluation of each specific goal.

3.2 Industrial Design Evaluation Criteria

At present, the selection criteria for industrial design competitions led by enterprises at home and abroad are complex, and the evaluation focuses are also different. Through statistical analysis and sorting of the design evaluation criteria for 50 industrial design competitions led by enterprises at home and abroad, starting from enterprises and excluding low-frequency indicators, four evaluation criteria for industrial design competitions have been summarized, including commercial characteristics, technical characteristics, presentation characteristics, and artistic characteristics [19, 20].

The evaluation system is based on 12 sub indicators, including technological implementation, mass production capability, market value, low economic cost, sustainable development, functional innovation, exquisite craftsmanship, environmentally friendly materials, visual recognition, forward-looking application, expression of design ideas, application of design methods, aesthetic appearance, and color matching, as shown in Table 1.

Table 1: Evaluation Criteria for Industrial Design Competition Evaluation System

Review target layer	Evaluation criteria layer	Evaluation indicator layer	The frequency of occurrence of related words
Comprehensive evaluation of the evaluation system for industrial design competitions	Commercial features (U1)	Technical implementation (U11)	20
		Can be mass-produced (U12)	19
		Low economic cost (U13)	19
	Technical features (U2)	functional innovation (U21)	14
		Eco-friendly materials (U22)	17
		Appearance recognition (U23)	14
	Present features (U3)	Design Ideas Table (U31)	19
		Sustainable development (U32)	18
		Application of Design Methods (U33)	20
	Artistic characteristics (U4)	elegant design (U41)	19
		exquisite craftsmanship (U42)	10
		color matching (U43)	18

For the convenience of understanding the meaning of evaluation indicators, explanations and clarifications are provided for each indicator, as shown in Table 2.

Table 2: Explanation of Evaluation Indicators for Industrial Design Competition Evaluation System

Evaluation indicator	Indicator Description
Technical implementation	Has the evaluation system evaluated the product based on existing production technology
Can be mass-produced	Is there an evaluation of the difficulty level of batch production for the evaluated products in the evaluation system
market value	Does the evaluation system assess the commercial value of the evaluated products based on market demand
Low economic cost	Does the evaluation system estimate the cost of purchasing, producing, selling, and transporting various materials for the product
Sustainable development	Is there a review of the extended design and continuous improvement potential of the evaluated products in the evaluation system
functional innovation	Is there a review of the product's features that differentiate it from other products in the market
exquisite craftsmanship	Does the evaluation system require participating products to adopt new processing techniques and be exquisite
Eco-friendly materials	Does the evaluation system meet the standards of green and environmental protection for the materials of each component of the evaluated products
Appearance recognition	Is it required for the product to have strong shape recognition and novel design features
Forward looking applications	Whether the overall design requirements of the product foresee future usage and application scenarios
Design Ideas Table	Does the review system evaluate the completeness of the overall design process of the evaluated products
Application of Design Methods	Does the evaluation system require participating products to be designed through the application of clever design methods
elegant design	Does the evaluation system review the proportion and overall style of product form design for evaluation
color matching	Review whether the evaluated products conform to the current aesthetic trends and color coordination

3.3 Calculation of Judgment Matrix and Criterion Weight Values

After determining the evaluation criteria, the 1-9 level scaling method shown in Table 3 was used. Three design directors from enterprises that have held multiple industrial design competitions were invited as experts to compare the four criteria pairwise and construct a judgment matrix to quantify the judgment of the evaluation criteria. The importance of the evaluation indicators was reflected by the magnitude of their values [21, 22].

According to the comprehensive analysis of the judgment matrices of three experts, a fourth-order judgment matrix was constructed for technical features, commercial features, artistic features, and presentation features. The sum product method was used to calculate the eigenvectors, which were (1.140, 1.669, 0.358, 0.883) [23]. The weight values corresponding to the four items were 28.502%, 41.733%, 8.944%, and 20.821%, respectively.

Table 3: Scale and Meaning

Scale	Meaning
1	Indicating that two factors have the same importance when compared
3	Comparing two factors, a is slightly more important than b
5	Comparing two factors, a is significantly more important than b
7	Comparing two factors, a is more important than b
9	Comparing two factors, a is extremely important compared to b
2,4,6,8	The median of the adjacent judgments mentioned above
countdown	Compare b and a to the same extent

4 Grey comprehensive evaluation method

4.1 Evaluation Process

The multi-level grey comprehensive evaluation and optimization method integrates the advantages of grey correlation analysis in handling multi factor statistical analysis problems, AHP in handling non independent hierarchical evaluation fields, and entropy weight method for objective weight correction. Applying it to the evaluation and optimization process of industrial product design schemes can better increase the scientificity of the evaluation process [24, 25]. The grey relational analysis method is used as the main evaluation strategy, supplemented by AHP and flame weight method to comprehensively construct the industrial product design scheme evaluation process as shown in Figure 1.

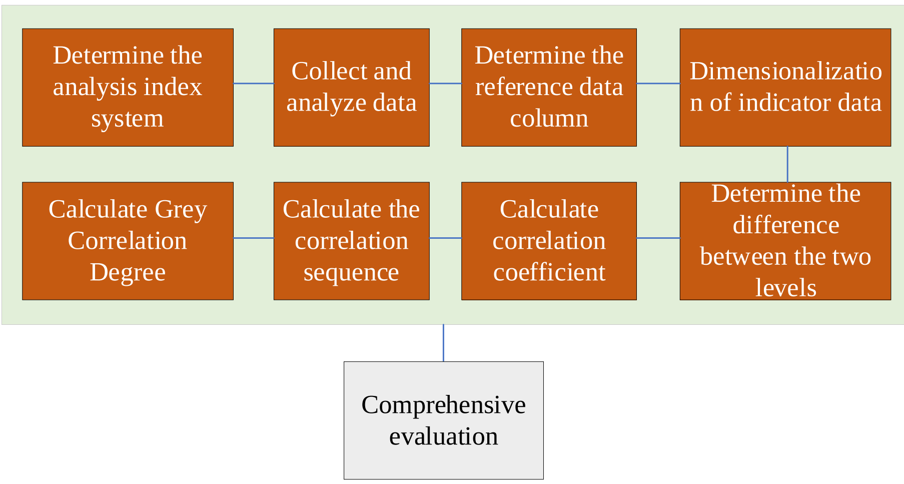

Figure 1: Evaluation Process of Industrial Product Design Scheme

4.2 Evaluation steps

According to the established evaluation system for industrial products, the evaluated scheme is $D(D=1,2,\cdots,n)$, X' is the set of primary indicators $X'=\{X_i'\}$, and X_i' is the set of secondary indicators $X_i'=\{X_{ik}'\}$. The evaluation process is as follows:

Step 1. Collect and analyze data to form a comparison matrix, namely:

$$\left(X_1^{'}, X_2^{'}, \cdots, X_n^{'}\right) = \begin{bmatrix} x_{11}^{'} & x_{21}^{'} & \cdots & x_{n1}^{'} \\ x_{12}^{'} & x_{22}^{'} & \cdots & x_{n2}^{'} \\ \vdots & \vdots & \ddots & \vdots \\ x_{1m}^{'} & x_{2m}^{'} & \cdots & x_{nm}^{'} \end{bmatrix} \tag{2}$$

where, n is the number of design schemes that need to be evaluated; m is the number of evaluation indicators.

Step 2. Determine the reference data column. It is an ideal comparison standard, usually consisting of the optimal values of each indicator to form a reference data column, or other reference values can be selected according to the evaluation purpose. The reference data column is:

$$X_0^{'} = \left(X_{01}^{'}, X_{02}^{'}, \cdots, X_{0m}^{'}\right) \tag{3}$$

Step 3. Non dimensionalization of indicator data. Due to the different meanings and physical meanings represented by each evaluation index, the data has different dimensions and orders of magnitude. Therefore, before calculating the grey correlation degree, dimensionless data processing is required, namely:

$$X_{ik} = \frac{(n+1)X_{ik}^{'}}{\sum_{k=0}^{m} X_{ik}^{'}} \tag{4}$$

where, $i = 0,1,2,\cdots,n$; $k = 1,2,\cdots,m$.

The dimensionless data sequence consists of:

$$\left(X_1, X_2, \cdots, X_n\right) = \begin{bmatrix} x_{11} & x_{21} & \cdots & x_{n1} \\ x_{12} & x_{22} & \cdots & x_{n2} \\ \vdots & \vdots & \ddots & \vdots \\ x_{1m} & x_{2m} & \cdots & x_{nm} \end{bmatrix} \tag{5}$$

Step 4. Determine the difference between the two levels. Calculate the absolute difference between each evaluated scheme indicator comparison sequence and the corresponding element of the reference data column one by one, that is, $\left|X_{0k} - X_{ik}\right|$.

Determine the maximum and minimum differences as follows:

$$\begin{cases} f_{\max} = \min_{i=1}^{n} \min_{k=1}^{m} \left|X_{0k} - X_{ik}\right| \\ f_{\min} = \max_{i=1}^{n} \max_{k=1}^{m} \left|X_{0k} - X_{ik}\right| \end{cases} \tag{6}$$

Step 5. Calculate the correlation coefficient. Calculate the correlation coefficient between each comparison sequence and the corresponding element of the reference sequence using equation (7), that is:

$$\zeta_{ik} = \frac{\min_i \min_k |X_{0k} - X_{ik}| + \rho \max_i \max_k |X_{0k} - X_{ik}|}{|X_{0k} - X_{ik}| + \rho \max_i \max_k |X_{0k} - X_{ik}|} \tag{7}$$

where, ρ is the resolution coefficient, $0 < \rho < 1$. If the ρ is smaller, the difference between the correlation coefficients will be greater, and the discriminative ability will be stronger. Conversely, if the ρ is smaller, the discriminative ability will be weaker.

Step 6. Calculate the correlation sequence. Calculate the mean correlation coefficient between each indicator of the comparison sequence and the corresponding element of the reference sequence to reflect the correlation between each evaluation object and the reference sequence, and call it the correlation order, denoted as:

$$r_{0i} = \sum_{k=1}^{m} \zeta_{ik} \Big/ m \tag{8}$$

where, ζ_{ik} is the correlation between the *k*-th indicator of the *i*-th product and the reference sequence; *m* is the number of evaluation indicators.

4.3 Determination of comprehensive weights

In the process of calculating weights, a combination of qualitative and quantitative methods, as well as subjective and objective methods, are used to increase the credibility of the data [26]. This article uses a combination of AHP and entropy weight method to obtain the weights of various evaluation indicators. Due to the mature process of calculating weights, it will not be described in detail. The specific steps are shown in Figure 2, and the final comprehensive weight is calculated using $\omega = \tau\omega_1 + (1-\tau)\omega_2$.

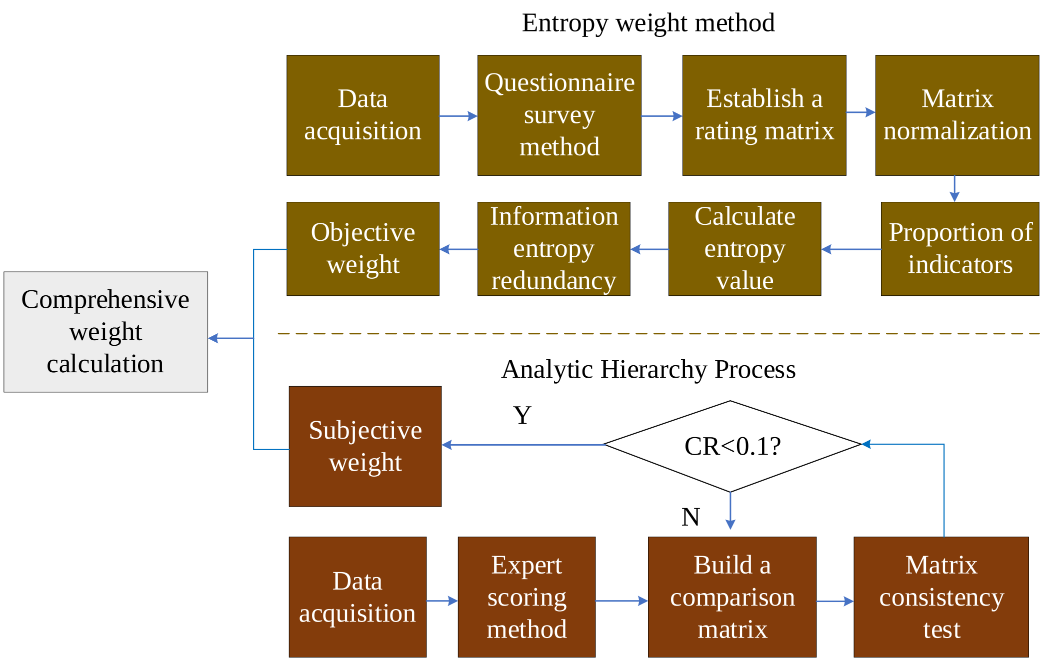

Figure 2: Comprehensive weight calculation steps of Analytic Hierarchy Process and Entropy Weight Method

4.4 Evaluation optimization

According to equation (8), calculate the grey weighted correlation degree. As each evaluation index has different weight sizes in the evaluation system, it is necessary to weight the obtained correlation order to obtain the grey weighted correlation degree, that is:

$$r_{0i}^{'} = \sum_{k=1}^{m} \omega_k \zeta_{ik} \Big/ m \tag{9}$$

where, ω_k is the weight of the k-th evaluation indicator; ζ_{ik} is the correlation value between the k-th indicator of the i-th product and the reference sequence.

Sort the calculated grey weighted correlation results in descending order, with the top ranked design schemes being more suitable for optimization and further design. The selected design scheme determines the parts that need further optimization based on the weight and score of the indicators. The higher the weight of the indicators in the design scheme and the lower the score, the higher the priority of optimization [27].

4.5 Consistency check

Each criterion element in the hierarchical structure model corresponds to a maximum eigenvalue $\lambda_{\max}$ and eigenvector in its judgment matrix. After normalization, it becomes the ranking weight of the relative importance of the same level dominated element to the previous level dominated element. This process is called hierarchical single ranking.

1) Calculate the eigenvector W

The relative ranking weight $B_1, B_2, \cdots, B_n$ of n elements $w_1, w_2, \cdots, w_n$ for the judgment matrix A of criterion A is represented as a vector:

$$W = \left(w_1, w_2, \cdots, w_n\right)^T \tag{10}$$

Since the judgment matrix is a positive reciprocal matrix, the column vectors of A can be normalized using the root mean method of geometric mean, and the resulting column vectors can be approximated as weighted vectors:

$$w_\imath = \left(\prod_{j=1}^{n} a_{ij}\right)^{\frac{1}{n}} \Bigg/ \sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{kj}\right)^{\frac{1}{n}} \tag{11}$$

$W = \left(w_1, w_2, \cdots, w_n\right)^T$ is the desired eigenvector.

2) Calculate the maximum eigenvalue and input it into $\lambda_{\max}$

The maximum eigenvalue $\lambda_{\max}$ of the judgment matrix can be approximated by the following equation:

$$\lambda_{\max} \approx \sum_{i=1}^{n} \frac{(Aw)_i}{nw_i} = \frac{1}{n} \sum_{i=1}^{n} \sum_{i=1}^{n} a_{ij} w_j \Big/ w_i \tag{12}$$

where, $(Aw)_i$ represents the i-th component of vector Aw, so that it can be checked whether matrix A is a consistent matrix by whether $\lambda_{\max}$ is equal to n.

From equation (11), it can be seen that the eigenvalue $\lambda_{\max}$ is continuously dependent on a_{ij}. Therefore, the larger the ratio of $\lambda_{\max}$ to n, the more severe the inconsistency of A, and the standardized eigenvector corresponding to $\lambda_{\max}$ cannot truly reflect the proportion of $B=\{b_1,b_2,\cdots,b_n\}$ in the impact on target A. Therefore, it is necessary to conduct a consistency test on the judgment matrix provided by experts to determine whether it can be accepted. Consistency testing can be judged by the value of the consistency ratio CR. When CR<0.10, the consistency of the judgment matrix is considered acceptable. Otherwise, appropriate modifications should be made to the judgment matrix. The consistency ratio CR is:

$$CR = CI / RI \tag{13}$$

Among them, CI is the consistency indicator:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{14}$$

RI is the average random consistency index. Construct 1000 sample matrices using random methods, that is, randomly select numbers from 1 to 9 and their reciprocal to construct a positive reciprocal matrix, and obtain the average value $\lambda'_{\max}$ of the maximum eigenvalue, thus obtaining RI as:

$$RI = \frac{\lambda'_{\max} - n}{n-1} \tag{15}$$

5 Experimental analysis

This is based on the design practice of the steel drilling project of Daqing Petroleum Machinery Co., Ltd. On the basis of the existing products of the company, the scheme design is carried out, using the key structure and form of the original product, adopting mature processes and technologies, meeting HSE related requirements, and designing the scheme according to various evaluation indicators in the steel drilling scheme evaluation model. After on-site research and a series of design schemes deduction, three steel driller design schemes that meet the above requirements were designed and generated.

According to the established evaluation index system for steel drilling industry design schemes, 20 professionals from relevant fields (including 5 engineers, 2 corporate executives, 3 university teachers, and 10 university students) were invited to form a scheme evaluation team. A 9-point scale was used to evaluate and score the 3 design schemes based on 12 evaluation indicators. Calculate the arithmetic mean of the ratings for each indicator for each alternative plan, and establish an evaluation decision matrix for the alternative plan. Calculate the objective weights of the industrial design evaluation index layer for steel drilling workers, as shown in Table 4.

Table 4: Weight Calculation by Weight Method

Sub criteria layer	P_{1i}	P_{2i}	P_{3i}	e_i	W_i^0
*U*11	0.306	0.324	0.338	0.999	0.017
*U*12	0.294	0.349	0.334	0.998	0.041
*U*13	0.285	0.376	0.305	0.993	0.156
*U*21	0.283	0.360	0.324	0.996	0.100
*U*22	0.284	0.364	0.319	0.995	0.111
*U*23	0.301	0.347	0.319	0.998	0.036
*U*31	0.306	0.331	0.331	0.999	0.014
*U*32	0.337	0.308	0.321	0.999	0.014
*U*33	0.316	0.321	0.330	0.999	0.003
*U*41	0.270	0.392	0.305	0.989	0.266
*U*42	0.300	0.377	0.290	0.994	0.150
*U*43	0.313	0.362	0.293	0.996	0.084

According to the experimental data in Table 3, in terms of operational convenience (U1 series indicators), P3i scores relatively outstanding under U11, U12, and U13 indicators. For example, its weight calculation value of 0.338 under U11 indicator is higher than P1i's 0.306 and P2i's 0.324, indicating that P3i is more ergonomic in its operational process design and has simpler operating steps. In terms of safety (U2 series indicators), P2i performs well under U21 and U22 indicators. The weight of U21 indicator is 0.360, which is higher than P1i's 0.283 and P3i's 0.324, indicating that P2i has more complete safety protection device settings and safety warning sign design, which can effectively reduce operational risks. In terms of reliability (U3 series indicators), P1i and P3i perform similarly, and there is not much difference in weight values under U31, U32, and U33 indicators, indicating that both are relatively reliable in component selection, structural stability design, and can ensure long-term stable operation of steel drills. In terms of innovation (U4 series indicators), P2i has a significant advantage with a weight of 0.392 under U41 indicators, indicating that it has unique innovative points in appearance design or functional expansion, which can enhance the product's market competitiveness. By comparing various indicators comprehensively, the advantages and disadvantages of each plan can be evaluated comprehensively, providing a strong basis for the final selection of the plan.

Evaluate and score each scheme based on comprehensive weights. The detailed evaluation results and final scores are shown in Table 5, and the comparison with traditional methods is shown in Table 6.

Table 5: Scores of various indicators for alternative solutions

Scheme	A_1	A_2	A_3
*U*11	0.0231	0.0241	0.0251
*U*12	0.0265	0.0306	0.0296
*U*13	0.0357	0.0462	0.0387
*U*21	0.0346	0.0439	0.0394
*U*22	0.0280	0.0367	0.0325
*U*23	0.0154	0.0172	0.0163
*U*31	0.0141	0.0154	0.0157
*U*32	0.0256	0.0238	0.0243
*U*33	0.0119	0.0115	0.0119
*U*41	0.0465	0.0659	0.0517
*U*42	0.0293	0.0374	0.0286
*U*43	0.0176	0.0193	0.0169
Total	0.3083	0.3720	0.3307

From the data in Table 5, it is possible to conduct a comprehensive comparative analysis of the performance of the three alternative solutions in various indicators. In terms of operational convenience related indicators (U1 series), A3 scored slightly higher at 0.0251 in the U11 indicator than A1's 0.0231 and A2's 0.0241; A2 has the highest score of 0.0306 on the U12 indicator, and its score of 0.0462 on the U13 indicator far exceeds A1's 0.0357 and A3's 0.0387, indicating that A2 has the best comprehensive performance in terms of operational process design and convenience. In the safety indicators (U2 series), A2 scored 0.0439 and 0.0367 in U21 and U22 indicators, respectively, both higher than A1 and A3, indicating that A2 has better design in safety protection and risk control. In terms of reliability indicators (U3 series), the difference between the three schemes is relatively small, with A3 scoring slightly higher in U31 and U33 indicators, and A1 leading in U32 indicators, indicating comparable overall reliability. In the innovation index (U4 series), A2 has a significant advantage with a score of 0.0659 in U41 index, indicating that it has outstanding highlights in product innovation design. Based on the overall score, A2 has the highest score of 0.3720, followed by A3, and A1 has the lowest score, further verifying that the A2 scheme has the best overall performance.

Table 6: Comparison of Method Scores

Scheme	AHP	Entropy weight method	Proposed method
A_1	0.3067	0.3083	0.2987
A_2	0.3571	0.3720	0.3808
A_3	0.3332	0.3307	0.3183

On the basis of retaining the A2 rotary clamp cover and the double hydraulic bi-directional twisting scheme of the punching clamp, protective plates were added to the front and side of the steel driller to isolate the exposed cables from oil stains. Optimization design has been carried out on multiple parts such as the installation seat of the drilling fluid box, the oil coating device, and the sliding pipe clamp for easy maintenance and protection. The scheme has also been repainted to enhance the overall appearance.

6 Conclusion

In the context of the deep integration of traditional craftsmanship and modern technology, innovative development of industrial design has become a key force in promoting industrial upgrading and enhancing product competitiveness. This article focuses on exploring the innovation path of industrial design, taking the steel drilling project of Daqing Petroleum Machinery Co., Ltd. as the specific research object, aiming to solve the core problem of design evaluation and optimization, and provide a scientific, systematic and practical innovation method for the field of industrial design. The main work of this article is reflected in the following aspects: Firstly, a comprehensive and detailed evaluation index system for industrial design schemes has been constructed. This system covers multiple key dimensions such as operational convenience, safety, reliability, and innovation, and is refined into 12 specific indicators, providing a solid foundation for subsequent design evaluation. Secondly, an innovative comprehensive weight determination method combining Analytic Hierarchy Process and Entropy Weight Method was proposed. This method not only fully utilizes the advantages of Analytic Hierarchy Process in handling non independent hierarchical evaluations, but also utilizes Entropy Weight Method to achieve objective weight correction, effectively improving the accuracy and scientificity of weight determination. Furthermore, the grey comprehensive evaluation method is introduced and applied to the evaluation and optimization process of industrial product design schemes. By constructing a scientifically reasonable evaluation process and steps, calculating the grey weighted correlation degree, the quantitative ranking of design schemes has been achieved, providing a strong basis for the optimal selection of schemes. In addition, this article also conducted consistency checks on the selected solutions to ensure the reliability and stability of the evaluation results.

The innovation and development of industrial design is a constantly evolving and exploratory process, and there are still many unknown areas that need to be further studied. The future research directions mainly include: firstly, further optimizing the evaluation index system. With the continuous advancement of technology and the increasing diversity of user needs, the evaluation index system needs to keep up with the pace of the times and introduce new evaluation indicators in a timely manner, such as intelligence level, environmental sustainability, etc., to more comprehensively and accurately evaluate design schemes. The second is to expand the application scope of evaluation methods. At present, the method proposed in this article is mainly applied to steel drilling projects, and in the future, it can be attempted to be promoted to other industrial product fields to verify its universality and effectiveness, providing strong support for industrial design innovation in different industries. The third is to conduct in-depth research on the mapping relationship between user needs and design solutions. By establishing a more accurate user demand model and directly integrating user needs into the design evaluation and optimization process, true user centered design innovation can be achieved, further enhancing the market adaptability and user satisfaction of the product.

References

[1] Conti E, Chiarini A. Design-driven innovation: exploring new product development in the home appliances and furniture industry[J]. The TQM Journal, 2021, 33(7): 148-175.

[2] Dokter G, Thuvander L, Rahe U. How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy[J]. Sustainable Production and Consumption, 2021, 26: 692-708.

[3] Patil K, Athavankar U. Design precedents to design innovation: Category-based reasoning in problem-solving[J]. The Design Journal, 2022, 25(1): 62-85.

[4] Haq N U. Impact of FDI and its absorption capacity on the national innovation ecosystems: evidence from the largest FDI recipient countries of the world[J]. Foreign Trade Review, 2023, 58(2): 259-288.

[5] Auernhammer J, Roth B. The origin and evolution of Stanford University’s design thinking: From product design to design thinking in innovation management[J]. Journal of Product innovation management, 2021, 38(6): 623-644.

[6] Yaghi A Z A, Tomaszewski T. Measuring the impact of R&D&I subsidies on innovative inputs and outputs in Polish manufacturing firms[J]. Journal of the Knowledge Economy, 2024, 15(1): 3792-3823.

[7] Krutova I A, Stefanova G P, Dergunova O Y, et al. Training university students for the development of innovative products and technologies[C]//AIP Conference Proceedings. AIP Publishing LLC, 2022, 2647(1): 020021.

[8] Viviani S, Gulino M S, Rinaldi A, et al. An Interdisciplinary Double-Diamond Design

Thinking Model for Urban Transport Product Innovation: A Design Framework for Innovation Combining Mixed Methods for Develo** the Electric Microvehicle “Leonardo Project”[J]. Energies, 2024, 17(23): 5918.

[9] Hajeniati N, Kaharuddin A. Innovation of the problem based learning model with contextual teaching learning in mathematics learning in the Industrial Revolution 4.0 era: A comparative case studies[J]. International Journal of Trends in Mathematics Education Research, 2022, 5(2): 222-227.

[10] Valackienė A, Nagaj R. Shared taxonomy for the implementation of responsible innovation approach in industrial ecosystems[J]. Sustainability, 2021, 13(17): 9901.

[11] Taques F H, López M G, Basso L F, et al. Indicators used to measure service innovation and manufacturing innovation[J]. Journal of Innovation & Knowledge, 2021, 6(1): 11-26.

[12] Krutova I A, Stefanova G P, Dergunova O Y, et al. Training university students for the development of innovative products and technologies[C]//AIP Conference Proceedings. AIP Publishing LLC, 2022, 2647(1): 020021.

[13] Juniani A I, Singgih M L, Karningsih P D. Design for manufacturing, assembly, and reliability: An integrated framework for product redesign and innovation[J]. Designs, 2022, 6(5): 88.

[14] Charosky G, Hassi L, Papageorgiou K, et al. Develo** innovation competences in engineering students: a comparison of two approaches[J]. European Journal of Engineering Education, 2022, 47(2): 353-372.

[15] Rahmanzadeh S, Pishvaee M S, Govindan K. Emergence of open supply chain management: the role of open innovation in the future smart industry using digital twin network[J]. Annals of Operations Research, 2023, 329(1): 979-1007.

[16] Nyagadza B, Pashapa R, Chare A, et al. Digital technologies, Fourth Industrial Revolution (4IR) & Global Value Chains (GVCs) nexus with emerging economies’ future industrial innovation dynamics[J]. Cogent Economics & Finance, 2022, 10(1): 2014654.

[17] Bonnet S, Teuteberg F. Impact of blockchain and distributed ledger technology for the management of the intellectual property life cycle: A multiple case study analysis[J]. Computers in Industry, 2023, 144: 103789.

[18] Taques F H, López M G, Basso L F, et al. Indicators used to measure service innovation and manufacturing innovation[J]. Journal of Innovation & Knowledge, 2021, 6(1): 11-26.

[19] Polyanin A V, Tat'iana A G. The concept of innovation management of industrial systems based on digital twin technology[J]. St. Petersburg State Polytechnical University Journal. Economics, 2021, 14(5): 7.

[20] D'Urzo M, Campagnaro C. Design-led repair & reuse: An approach for an equitable, bottom-up, innovation-driven circular economy[J]. Journal of Cleaner Production, 2023, 387: 135724.

[21] Verma P, Kumar V, Daim T, et al. Design thinking framework toward management control

system in environmental dynamism: An innovation perspective[J]. IEEE Transactions on Engineering Management, 2023, 71: 4955-4970.

[22] Shekarian E, Ijadi B, Zare A, et al. Sustainable supply chain management: a comprehensive systematic review of industrial practices[J]. Sustainability, 2022, 14(13): 7892.

[23] Tiran J, Bole D, Kozina J. Industrial culture as an agent of social innovation: reflections from Velenje, Slovenia[J]. Innovation: The European Journal of Social Science Research, 2023, 36(2): 333-356.

[24] Parthiban K T, Fernandaz C C, Sudhagar R J, et al. Industrial agroforestry—A sustainable value chain innovation through a consortium approach[J]. Sustainability, 2021, 13(13): 7126.

[25] Antipina O, Rasputina A. Scientific support of the innovative development of agriculture in the Russian Federation: Problems and solutions[C]//BIO Web of Conferences. EDP Sciences, 2023, 71: 02012.

[26] Sapkota B, Palaian S, Shrestha S, et al. Gap analysis in manufacturing, innovation and marketing of medical devices in the Asia-Pacific region[J]. Expert Review of Pharmacoeconomics & Outcomes Research, 2022, 22(7): 1043-1050.

[27] Mariani M M, Nambisan S. Innovation analytics and digital innovation experimentation: the rise of research-driven online review platforms[J]. Technological Forecasting and Social Change, 2021, 172: 121009.