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Prioritization of User Needs for Spinning Bikes Based on the Analytic Hierarchy Process

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Abstract: This study systematically analyzes the design of spinning bikes using the Analytic Hierarchy Process (AHP). User requirements are classified into four main categories: functional and interactive needs, safety and durability needs, aesthetic and personalized needs, and environmental and maintenance needs. These are further refined into specific indicators. By constructing a hierarchical model and employing pairwise comparisons to determine the weight priorities, the final weight values for each design factor are obtained, leading to a prioritized ranking of user requirements that provides practical design guidance for engineers. The research also emphasizes the importance of aligning design features with real user expectations. By incorporating expert insights and empirical data, the approach ensures logical consistency and highlights critical areas for innovation. The findings offer a comprehensive evaluation of user needs, enabling designers to make informed decisions that enhance both functionality and overall user satisfaction. Furthermore, the study demonstrates the value of applying AHP to complex design problems by providing a replicable framework for evaluating competing alternatives. It offers insights to guide future research and product development in the fitness equipment industry, contributing to continuous improvement and market competitiveness.

Keywords: Analytic Hierarchy Process (AHP), Design Factors, Spinning Bike.

1. Introduction

With the diversification of fitness demands, spinning bikes have emerged as gym equipment that combines efficient training with space adaptability, making design optimization a key factor in product competitiveness. As users increasingly demand enhanced functional performance and interactive experiences, quantifying multidimensional requirements and establishing their priorities during the design process remains challenging. The Analytic Hierarchy Process (AHP) provides an effective tool for balancing multi-objective design requirements by decomposing complex issues into a structured hierarchy and quantifying subjective judgments. This study integrates AHP with user needs analysis to construct an evaluation system for spinning bike design, thereby offering a quantifiable scientific basis for design decision-making.

2. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), introduced by American operations researcher Thomas L. Saaty in the 1970s, is a systematic, hierarchical multi-criteria decision analysis method. It decomposes complex problems into several layers—namely the goal level, criteria level, and alternative level—and combines qualitative and quantitative techniques to determine the weights of each factor, thereby providing decision-makers with a scientific evaluation basis [1]. Its core idea is to quantify the relative importance of factors at the same level via pairwise comparisons and to ensure logical consistency through a consistency check, ultimately achieving the prioritization of alternatives by synthesizing these weights.

The methodological process and key steps include:

(1) Defining the decision-making objective, delineating the criteria, and constructing the hierarchical structure.

(2) Consulting industry experts to establish judgment matrices for secondary and tertiary indicators, and performing pairwise comparisons using the 1–9 scale [2].

(3) Solving for the weight vector of the judgment matrix—using either the eigenvector method or the geometric mean method—to obtain the weight values of each factor. A consistency ratio is then calculated to verify the logical soundness of the judgments.

(4) Aggregating the weights layer by layer to compute the total score for each alternative, followed by ranking the alternatives to select the optimal solution.

AHP has been widely applied in resource allocation, alternative selection, and policy analysis owing to its clear structure and ability to handle multidimensional issues.

3. Model Construction and Application

Based on the theoretical framework of AHP and addressing the design optimization of spinning bikes, a hierarchical structure model comprising the goal level, criteria level, and alternative level was developed. The criteria level is divided into four dimensions: Functional and Interactive Needs; Safety and Durability Needs; Aesthetic and Personalized Needs; Environmental and Maintenance Needs. The alternative level is further detailed into 15 specific indicators, as shown in Table 1.

Table 1. User Requirements

Criteria Level	Alternative Level
Functional and Interactive Needs	Resistance Adjustment Data Tracking Voice Control Entertainment Support
Safety and Durability Needs	Anti-Slip Design Emergency Braking Durable Structure
Aesthetic and Personalized Needs	Aesthetic Design Material and Color Matching User Profile Customization Options
Environmental and Maintenance Needs	Low Noise Temperature Adaptability Easy to Clean Modular Maintenance

By integrating user survey data, the evaluation system is ensured to cover the core dimensions of user requirements and the actual design context. In applying the model, the 1–9 scale was used to perform pairwise comparisons among the criteria level elements, thus constructing the judgment matrix.

(1) Criteria Level Judgment Matrix

$$\begin{vmatrix} 1 & 1 & 3 & 4 \\ 1 & 1 & 2 & 4 \\ 1/3 & 1/2 & 1 & 2 \\ 1/4 & 1/4 & 1/2 & 1 \end{vmatrix}$$

(2) Normalized Matrix

$$\begin{vmatrix} 0.387 & 0.364 & 0.462 & 0.364 \\ 0.387 & 0.364 & 0.308 & 0.364 \\ 0.129 & 0.182 & 0.154 & 0.182 \\ 0.097 & 0.091 & 0.077 & 0.091 \end{vmatrix}$$

(3) Calculation of Criteria Level Weights

Functional and Interactive Needs:

$$(0.387+0.364+0.462+0.364)/4 \approx 0.4$$

Safety and Durability Needs:

$$(0.387+0.364+0.308+0.364)/4 \approx 0.35$$

Environmental and Maintenance Needs:

$$(0.129+0.182+0.154+0.182)/4 \approx 0.15$$

Aesthetic and Personalized Needs:

$$(0.097+0.091+0.077+0.091)/4 \approx 0.1$$

(4) Consistency Check

Calculation of Maximum Eigenvalue (λ_{max})

$$\lambda_{\max}=\frac{1}{4}\left(\frac{1.592}{0.4}+\frac{1.430}{0.35}+\frac{0.649}{0.15}+\frac{0.357}{0.1}\right)\approx 4.0225$$

Consistency Index (CI)

$$CI=\frac{\lambda_{\max}-n}{n-1}=\frac{4.0225-4}{3}\approx 0.0075$$

Random Consistency Index (RI): n=4，RI=0.90

Consistency Ratio (CR):

$$CR=\frac{CI}{RI}=\frac{0.075}{0.90}\approx 0.0083<0.1$$

The consistency ratio (CR) calculated using the Analytic Hierarchy Process is 0.0083, which satisfies the criterion (CR < 0.1). Accordingly, the weights for Functional and Interactive Needs, Safety and Durability Needs, Aesthetic and Personalized Needs, and Environmental and Maintenance Needs are determined to be 0.40, 0.35, 0.15, and 0.10, respectively, with Functional and Interactive Needs having the highest priority.

(5) Judgment Matrix for the Alternative Level under Functional and Interactive Needs

$$\begin{vmatrix} 1 & 3 & 5 & 7 \\ 1/3 & 1 & 3 & 5 \\ 1/5 & 1/3 & 1 & 3 \\ 1/7 & 1/5 & 1/3 & 1 \end{vmatrix}$$

(6) Normalized Matrix

$$\begin{vmatrix} 0.597 & 0.662 & 0.536 & 0.438 \\ 0.198 & 0.221 & 0.321 & 0.313 \\ 0.119 & 0.074 & 0.107 & 0.188 \\ 0.085 & 0.044 & 0.036 & 0.063 \end{vmatrix}$$

(7) Calculation of Alternative Level Weights

Resistance Adjustment:

$$(0.597+0.662+0.536+0.438)/4 \approx 0.56$$

Data Tracking:

$$(0.198+0.221+0.321+0.313)/4 \approx 0.26$$

Voice Control:

$$(0.119+0.074+0.107+0.188)/4 \approx 0.12$$

Entertainment Support:

$$(0.085+0.044+0.036+0.063)/4 \approx 0.06$$

(8) Consistency Check for the Alternative Level

$$\lambda_{max} \approx 4.115$$

Consistency Index (CI):

$$CI=\frac{4.115-4}{3}\approx 0.038$$

Consistency Ratio (CR):

$$CR=\frac{CI}{RI}=\frac{0.038}{0.90}\approx 0.042<0.1$$

The consistency ratio (CR) calculated using AHP is 0.042, which satisfies the requirement (CR < 0.1). Consequently, the weights for Resistance Adjustment, Data Tracking, Voice Control, and Entertainment Support are determined to be 0.56, 0.26, 0.12, and 0.06, respectively. Clearly, Resistance Adjustment carries the highest weight, followed by Data Tracking.

4. Design Strategies

(1) Data-Driven Optimization of the Resistance Adjustment Function

At the alternative level, Resistance Adjustment is identified as the most crucial sub-function, with a weight of 0.56. This indicates that users have very high expectations for precision, smoothness, and intelligent control in resistance adjustment. Consequently, this study proposes a multi-level magnetic control resistance system that combines electromagnetic control technology to achieve continuously variable adjustment. Specifically, the system collects real-time exercise data from the user to dynamically match resistance levels, ensuring that the resistance feedback is both precise and smooth. Adaptive resistance modes can be developed for different fitness levels and training objectives—for example, automatically reducing resistance in beginner mode to prevent excessive fatigue, while offering a more challenging resistance curve in high-intensity training mode to help users overcome plateaus. This intelligent mechanism not only enhances exercise effectiveness but also boosts user satisfaction and retention. Additionally, to meet long-term use requirements, the mechanical design must balance durability with noise reduction. By selecting high-quality materials, optimizing gear meshing precision, and incorporating damping devices, operational noise can be minimized and equipment lifespan extended, thereby further enhancing the overall user experience.

(2) Multi-Dimensional Sensor Fusion Data Tracking System

In addition to resistance adjustment, the data tracking function (weight 0.26) is also a key area of user interest. Modern consumers increasingly value data visualization and feedback during workouts; hence, it is essential to build a comprehensive multi-dimensional sensor fusion system. This system should be capable of collecting real-time data on power output, pedaling frequency, heart rate, and calorie consumption, and of generating detailed, intuitive training reports. By connecting to a smartphone app via Bluetooth or Wi-Fi, users can monitor their exercise trajectories, calorie consumption trends, and progress toward their goals at any time. Moreover, leveraging big data analysis algorithms, the system can provide personalized workout recommendations—for example, suggesting endurance training plans tailored to the user's exercise habits and preferences to help establish more scientific fitness objectives. It is also imperative that data tracking incorporates robust privacy protection measures: all user data should be encrypted and accessible only to the individual, while open API interfaces may allow synchronization with third-party health management platforms to broaden application scenarios.

(2) Ergonomic Design and Safety Considerations

Although functional and interactive needs dominate, safety and durability needs (weight 0.35) cannot be neglected. Research indicates that if an exercise bike's design does not adhere to ergonomic principles—if its proportions do not align with human dimensions—it may cause discomfort or even physical injury [3]. During the design phase, it is essential to consider user characteristics such as height, leg length, and arm span, and to adjust seat height, handlebar position, and pedal angles accordingly to ensure a natural and comfortable riding posture. To further enhance safety, it is recommended to apply anti-slip coatings on critical surfaces and to install an emergency brake button for rapid shutdown in case of an accident. For home users, stability and space efficiency are also important factors. Optimizing the base structure can ensure stability during high-intensity workouts while minimizing the equipment's footprint, making it suitable for various home environments.

(3) Lightweight Voice Interaction and Entertainment Expansion

Although voice control (weight 0.12) and entertainment support (weight 0.06) are relatively less critical, they nevertheless serve as important supplements to improve the overall user experience. Considering the potential complexity of operations, this study suggests the selective integration of a lightweight voice interaction module using a low-power voice chip to support basic commands such as "start," "pause," and "switch mode". This not only simplifies the user interface but also avoids confusion caused by redundant functions. Moreover, a modular design that reserves expansion interfaces can enable compatibility with external music devices or third-party fitness applications, thereby accommodating additional light entertainment scenarios. For instance, users might play their favorite music or watch instructional videos during workouts to break the monotony and enhance training enjoyment. Such flexible expansion not only reduces development costs but also paves the way for future product iterations.

5. Conclusion

This study systematically analyzed the design requirements for spinning bikes using the Analytic Hierarchy Process (AHP). By constructing judgment matrices, calculating weights, and performing consistency checks, the importance of various functional modules was quantitatively assessed. The results indicate that at the criteria level, Functional and Interactive Needs (weight 0.40) dominate, significantly exceeding Safety and Durability Needs (0.35), Environmental and Maintenance Needs (0.15), and Aesthetic and Personalized Needs (0.10). At the alternative level, Resistance Adjustment (0.56) and Data Tracking (0.26) are identified as the core sub-functions under Functional and Interactive Needs, with much higher weights than Voice Control (0.12) and Entertainment Support (0.06). The AHP analysis not only validates the high priority of essential functions demanded by users but also provides a scientific basis for product development. The methodology and conclusions presented herein are applicable not only to the design of spinning bikes but also serve as a reference for the development of other fitness equipment. Future work could integrate empirical user data to further optimize the allocation of functional weights, thereby better aligning products with market demands.

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