Analysis and Research of Electric Bicycle Design Based on Hall Three-Dimensional Structure

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Abstract. Purpose In the context of the implementation of the Mandatory National Standard for Safety Technical Specifications for Electric Bicycles (hereinafter referred to as the “New National Standard”), in order to meet the needs of the target group for daily traveling, a general method for electric bicycle design is proposed. Method Based on Hall three-dimensional structure theory, focusing on the time axis, comparing with the existing products in the market, referring to the traditional electric bicycle system design flow from product positioning, draft design, type selection, performance target determination, component performance parameters and boundary dimension, in-depth design, rendering, to model making, combined with marketing and user research, conduct electric bicycle design research with the theme of “young” and “future”. Results Propose a general method for the design of electric bicycles based on Hall three-dimensional structure. Conclusion The model method helps to feedback the design progress in time, finding the problems in the design flow, improving design efficiency and shortening the design cycle.

1. Introduction
General Secretary Xi Jinping repeatedly stressed the need to “form the green development mode and lifestyles”. The 19th Communist Party of China National Congress also proposed “promoting green development” and “developing green travel” [1]. On the one hand, with the continuous improvement of people’s living standards, people have higher requirements for the choice of daily travel modes. Electric bicycles are well received by their portability, economy and energy saving. On the other hand, due to the urbanization process and the rapid development of the economy, China’s urban population has surged, and the number of motor vehicles has also increased rapidly. Problems such as exhaust pollution and road congestion have become increasingly prominent [2]. However, the legal use of electric bicycles effectively alleviates the traffic pressure of short-distance travels and it conforms to the new development concept of “green” as a necessary condition for sustainable development, adjusting to the development trend of modern public transport system [3].

At present, the new mandatory national standard Electric Bicycle Safety Technical Specification in the electric bicycle industry has been officially implemented on April 15th. Electric bicycles which do not meet the new national standard will be eliminated in the market and some famous enterprises in the industry are also accelerating the research and development of new products, striving to seize the opportunities in the process of industry reshuffling. This paper aims to propose a standardized electric bicycle shape design method based on the electric bicycle design system and Hall three-dimensional structure theory on the background of the new national standard. The method could help designers to
obtain feedback and find problems in the design process in time, completing design tasks and improve design levels more efficiently [4].

2. System Engineering Methodology
The methods used in system engineering thinking and problem solving are generally referred to as system methodology. The basis of the system engineering method system is to realize the system modeling and optimization according to the system method and other interdisciplinary theories and methods. System engineering has its unique work system. For example, the "three-dimensional structure system" which is the basis of the system engineering methodology, is an interdisciplinary three-dimensional space system composed of time dimension, logic dimension and knowledge dimension. In 1969, it was developed by American system engineering expert H Hall [5].

3. Three-Dimensional Structural Model of Electric Bicycle Design
This paper will take the electric bicycle design in the theme of “Young and Future” as an example. Based on the Hall three-dimensional structure system. The system design will be applied to the design research of electric bicycles, and a brief and concise analysis will be carried out. The three-dimensional structure model of the electric bicycle design is constructed with reference to Hall's three-dimensional structure system, as shown in figure 1.

3.1. Time Dimension
This paper focuses on time dimension and analyzes the design steps of electric bicycles in an irreversible linear time sequence. Time dimension is an important guarantee for the orderly development and successful completion of design work. Time dimension could clarify work content and time nodes of each stage and avoid problems such as disorder in the design process, making sure that designers get feedback in time and improve the accuracy of design decisions. This paper refers to the time dimension principle of Hall three-dimensional structure, dividing the time dimension into seven steps: raising questions, systematic analysis, design positioning, schemes collection, schemes optimizing, evaluation decision and user feedback, planning from project initiation to product molding. Following the time dimension could specify work content of the phase process, clarifying the time sequence of the project development process, ensuring the implementation progress of the work, consequently achieving the goal of improving work efficiency and shortening the design cycle [6].

3.1.1. Raising Questions and Systematic Analysis. On the background of "Internet Plus", with the implementation of the new national standard, people's personalized needs for electric bicycle has
increased. Intelligent, personalized and standardized has become the development trends of electric bicycle industry. China has the world's largest electric bicycle market. Some domestic head companies such as Yadea, Aima, and Xinri have sold millions of products a year. The rising stars, such as Niu Electric Technology, using "intelligent" as a breach, focusing on technology, trendy and young. However, the domestic electric bicycle market as a whole is still insufficient. Looking abroad, the electric bicycle industry developed earlier in Japan and Germany with well-known brands such as Yamaha, Sparta, Merida, Aprilia, etc. The main functions are short-distance travel and leisure fitness, using in places such as supermarkets, tourist areas, etc. [7]. In general, domestic electric bicycles mainly solve the problem of mobility, featuring with single modeling language, similar functions, common characteristics and uneven quality. Many related companies are still trying to seize the market with low-price strategies, resulting in unstable production and inconsistent corporate product image.

3.1.2. Product Positioning. At this stage, designers need to lock the target group according to the market and user survey results and initially formulate the product positioning according to the needs of the target group, carrying out overall plans for the subsequent conceptual design, including basic modeling, structural functions, color scheme, using process, material selection and processing technology [8].

(1) Target group. The determination of the target group can clarify the direction of product design. Designers should balance business value and user's needs according to the characteristics of the target group. After conducting a preliminary large-scale survey, the designers selected 18-25 years old college students as the target group based on multiple factors such as the potential user volume and the user's business value. The designers firstly conduct a random questionnaire survey on the user group through the quantitative research method and obtains the users analysis data report. Combined with the literature research results, the basic characteristics of the user group are summarized, as shown in table 1. Then through the qualitative research method, some subjects were randomly selected from people who received the questionnaire to conduct one-to-one user interviews to help designers draw empathy maps, summarizing and analyzing pain points and expectations. Designers screen and prioritize the requirements to draw the final product requirements.

Table 1. Target User characteristics.

| Classification | Basic Information | Detailed Information |
|----------------|------------------|----------------------|
| Age            | 18-25            |                      |
| Essential Information | Physical Agility | Positive and sunny, the design should focus on the performance of dynamic. |
|                 | Level of Education | Undergraduate and master students |
| Traits of Character | /                | Love life, rich in emotions, and habitually record life; focus on cutting-edge technology, willing to adopt early adopters. |
| Ideological Characteristics | /                | Strong independent thinking ability and self-determination ability. |

(2) Design concept. With the design concept of “young and future”, the designers deeply explore user psychology, drawing user experience map of the target group in the process of using electric bicycle and combine Ergonomics and research results to plan the design direction. Research results are shown in figure 2. The purpose is to meet the personalized needs of modern college students for electric bicycles, combining electric bicycles with the development trend of modern technology [9]. The pain points summarized from the research and analysis are transformed into target requirements, combining with the specific positioning of this electric bicycle design research, making sufficient preparation for the development of the design. In order to meet the characteristics of the target users and their preferences, designers pursue not only smooth fluency, but also taking its systematical, security into
account. The use of speed sense of the shape, expresses a feeling of dynamic and power. The smart touch panel and mobile applications provide an interaction mode which keeps up with the times, as shown in figure 3, supporting fingerprint unlocking, weather viewing and other functions, combining with mobile applications to project navigation to realize navigation visualization; outside the touch panel, the light circle can be illuminated according to the navigation and the direction information can be transmitted to the user more intuitively, further embodying the characteristics of safety, technology and intelligence during riding. In order to improve the portability of the electric bicycle, the front handle and the foot pedal are designed to be able to fold, which not only saves the storage space of the product, but also keeps user safer during the driving process. The design of the detachable battery is a good solution to the pain point of inconvenient charging, and it also avoid problems which traditional unaesthetic charging mode brings, such as disorder charging line and some potential safety hazards.

3.1.3. Scheme and Subsequent Optimization Phase. At this stage, based on the preliminary design concept, a series of schemes that meet the target requirements and design orientation are proposed. In order to determine the optimal solution, an electric bicycle design evaluation system will be established to evaluate each scheme to make the final design decision.

3.1.4. Evaluation Decision and User Feedback Stage. Electric bicycles are products with a long life cycle. Combined with their design trends, they should be designed in accordance with the basic
principles of sustainable design [10]. On one hand, starting from the appearance, focus on the comfort and aesthetics of the design, to ensure that the product will not be outdated due to its style or uncomfortable use experience. On the one hand, starting from the structural process, functionality, safety and processing technology will effectively extend its service life [11]. In the evaluation and decision-making stage of the design, combined with the results of literature review and expert discussion, the evaluation index system of electric bicycle system is established, and several preliminary schemes are scored according to a number of the system. Functionality and safety are the primary considerations [12]. The details of the evaluation index system are shown in table 2. According to table 2, the feasibility of each indicator obtained by comprehensive evaluation of weights is sorted and integrated, and the best solution that meets the design theme is selected.

| Order | Evaluation Index | Detailed Information | Significance |
|-------|------------------|----------------------|-------------|
| 1     | Functionality    | Main function: Riding. Bring a more delightful experience besides meeting the basic requirements of users; Additional features: Entertainment, enhance the user's personalized experience, combined with fitness and leisure. Materials: Environmental friendly, non-toxic and pollution-free; | 3           |
| 2     | Security         | Modeling: Various scenarios and hidden dangers should be considered; Dimensions: In combination with ergonomics, the proportions of the components should meet the standards. | 3           |
| 3     | Comfort          | Based on the principles of ergonomics and the new national standard, consider whether each stage is comfortable. Whether the position of the structure button is in line with the common sense, whether the user needs to pay extra learning costs. | 3           |
| 4     | Sustainability   | Follow the principles of sustainable design and extend the life of the product to ensure that parts are available. Modeling: According to the characteristics of the target user and demands. | 3           |
| 5     | Artistic         | Visual performance: Focus on the unification of corporate image; extracting corporate image elements. | 2           |
| 6     | Materials        | Adapt to existing production equipment and technology, avoiding being too advanced; considering mass production costs and feasibility; forward-looking; production and processing innovation. | 1           |

3.2. Logical Dimension
The logical dimension divides each stage of the design according to the internal logical order. The steps of the logical dimension correspond to the phases of time dimension and are interlocked. Designing with reference to the logic dimension ensures the objectivity and clarity of the design. The design of electric bicycle in this paper mainly includes commodity positioning, technology research and development, product design, prototype verification, small batch sample verification, product launch and update iteration. In combination with enterprises, market, users and other factors, designers need to determine
the function, shape and other positioning of the product. The technical staff assess the technical feasibility of the product in advance, through the communication between the technical staff and the designers, modifying the original positioning to ensure that the product could enter the product design stage; the design phase requires a lot of working time. Designers should draw multiple sketch schemes according to the user’s goals and function priorities according to the product requirements, summarizing the schemes, optimizing the subsequent optimization and upgrade until the final scheme is submitted. Making functional models according to the final scheme, verifying its functional structure, confirming that small batch samples are not required to be modified after all aspects, collecting user feedback and making update iteration after the product launched. Product design, prototype verification, small batch sample verification and update iteration phase need to be repeated and cyclically demonstrated, so as to realize continuous improvement of electric bicycle design, getting feedback in time and realizing two-way communication of information to meet user needs, business demand and market demand [13].

3.3. Knowledge Dimension

The theories and knowledge involved in the design process are often crossed by various disciplines, mainly design, ergonomics, sociology, materials science, marketing, mechanical engineering, etc. The theories and knowledge related to above subjects run through the whole process. The design process penetrates into each stage and every step. According to the rule of time dimension and logic dimension of electric bicycle design process, the application of knowledge dimension in electric bicycle design is mainly reflected in the following aspects. (1) From raising questions to design team establishment stage. It is necessary to clarify the reasons for the design project and evaluate the feasibility of the project development. After the project is established, the design team will be formed according to the workload required by the management theory. (2) Systematic analysis and design positioning stage. At this stage, it is important to use design management theory to plan the research process and use statistical knowledge, economics and other subject knowledge to analyze the research data, and draw the final design positioning. (3) The stage of scheme decision and subsequent evaluation. This stage is a process of repeated cycle demonstration. According to the preliminary research results and design orientation, it is necessary to repeatedly explore the real needs of users, combining theoretical knowledge of design psychology and art disciplines, establishing evaluation index system. Quantitatively evaluate each scheme and select the best among the alternatives. (4) Implementation and user feedback stage. According to the current stage of processing technology, market trends, raw material costs to adjust the final scheme with the goal of mass production, collecting user feedback to update the product after iteration [14]. Systematic analysis of the relationship among various factors forms a clear knowledge dimension map which will effectively improve the controllability of the design process, avoiding design decision errors. Knowledge dimension plays an active role in the theoretical design of the system.

3.4. Design Results

Combined with the system analysis of time dimension, logic dimension and knowledge dimension, the final output scheme. The rendering effect is shown in figure 4. The scheme adopts the sense of speed and the overall proportion is coordinated to meet the target user characteristics. In order to maintain consistency with the corporate image, extract the color of a company’s logo and propose three schemes of green-white, green-black and blue-white which enhance the diversity of the design. Corresponding design improvements are made to the target needs and the detachability of classic shapes and components fit the principles of sustainable design. Some novel details are shown in figure 5.
Figure 4. Product rendering.

Figure 5. Novel details.

4. Conclusion
This paper provides a pre-evaluation system model for electric bicycle design based on Hall three-dimensional structure, as a general method for electric bicycle design management. On the whole level, the design of electric bicycles with wide and cross-disciplinary areas will be streamlined and optimized. The overall framework based on Hall three-dimensional structure will be obtained. The development progress of electric bicycles can be controlled from the whole level. Specific to each detail level, Organized, stepped, and staged, identify and solve problems in a targeted manner. In short, the establishment of the model as an analytical tool to guide the design of electric bicycles can reduce the repetitive work in the design process, effectively improving the design efficiency, shortening the design cycle, and having a methodological guiding significance for actual design similar to it.

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