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Ergonomics in Bicycle Saddle Design: Application of TRIZ Innovation System Method with IPA-Kano Model Validation

Kai-Chao Yao [1,2,3], Ya-Nan Chang [1,3], Li-Yun Chen [1,3], Kuo-Yi Li [4,5], Jing-Ran Xu [1,3,6], Wei-Sho Ho [1,3,7,8,*], Wei-Lun Huang [1,3,9,10], Cheng-Yang Chung [1,3,11] and Yao-Ting Chen [1,3,12]

[1] Department of Industrial Education and Technology, National Changhua University of Education Bao-Shan Campus, No. 2, Shi-Da Rd., Changhua City 500208, Taiwan; kcyao@cc.ncue.edu.tw (K.-C.Y.); d1231004@mail.ncue.edu.tw (Y.-N.C.); d1031019@mail.ncue.edu.tw (L.-Y.C.); a047224716@gmail.com (J.-R.X.); u107075701@cmu.edu.tw (W.-L.H.); c8031356@gmail.com (C.-Y.C.); martin.yt.chen@gmail.com (Y.-T.C.)
[2] Kenda Cultural and Educational Foundation, No. 146, Sec. 1, Zhongshan Rd., Yuanlin City 510037, Taiwan
[3] Department of Electrical and Mechanical Technology, National Changhua University of Education Bao-Shan Campus, No. 2, Shi-Da Rd., Changhua City 500208, Taiwan
[4] Department of Industrial Engineering and Management, National Chin-Yi University of Technology, No. 57, Sec. 2, Zhongshan Rd., Taiping Dist., Taichung City 411030, Taiwan; kyli@ncut.edu.tw
[5] Society of Innovative Education and Technology, No. 164-1, Yanji St., Da'an Dist., Taipei City 106062, Taiwan
[6] Sheng Jen Industrial Co., Ltd., No. 49, Aly. 2, Ln. 226, Sec. 1, Zhongzheng Rd., Changhua City 500004, Taiwan
[7] NCUE Alumni Association, National Changhua University of Education Jin-De Campus, No. 1, Jinde Rd., Changhua City 500207, Taiwan
[8] Graduate Institute of Technological and Vocational Education, National Changhua University of Education Bao-Shan Campus, No. 2, Shi-Da Rd, Changhua City 500208, Taiwan
[9] Medical Affairs Office, National Taiwan University Hospital, No. 7, Zhongshan S. Rd., Zhongzheng Dist., Taipei City 100225, Taiwan
[10] Department of Health Services Administration, China Medical University, No. 100, Sec. 1, Jingmao Rd., Beitun Dist., Taichung 406040, Taiwan
[11] The Affiliated Experimental Elementary School, National Tsing Hua University, No. 47, Siwei Rd., North Dist., Hsinchu City 300192, Taiwan
[12] Iscom Online International Information Inc., No. 33, Hanxiang E. Rd., Xitun Dist., Taichung City 407031, Taiwan
* Correspondence: homaintain@gmail.com

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Abstract: This study investigates the innovative design of a bicycle saddle by incorporating sustainable ergonomics, universal design principles, and systematic innovation methods. Initially, the literature related to bicycle saddle design and its impact on the human body during riding was analyzed. The TRIZ contradiction matrix was then used to identify relevant invention principles, which served as references for the innovative design of the bicycle saddle. Biomechanics and the human–machine system analysis within human factors engineering were applied to ensure the innovative design is ergonomic and user-friendly. The design features a horizontally expandable and foldable bicycle saddle, enhancing its adaptability and sustainability. Universal design principles were applied to make the innovative design more accessible to the general public, and the prototype was simulated using Inventor drawing software. The research results include: (1) An innovative bicycle saddle design with horizontal expansion and folding functions is proposed. This design divides the saddle into three components, enabling the left and right parts to expand or retract based on user preferences. (2) A bicycle backrest design featuring vertical adjustability is introduced. It incorporates a quick-release adjustment mechanism at the junction of the backrest and saddle, allowing users to freely adjust the backrest height. (3) A quick-operation bicycle saddle design is presented, utilizing quick-release screws to facilitate the swift operation of the horizontal expansion and folding mechanisms. This validation method confirmed that the innovative design meets both sustainable ergonomic standards and user expectations. The systematic innovation approach used in this study can serve as a valuable reference for future research and design applications.

Keywords: bicycle saddle; TRIZ; ergonomics; universal design

1. Introduction

With the advancement of technology and the improvement of living standards, people's attention to exercise and health has increased significantly. Additionally, leisure and environmental issues have become increasingly important to both the government and the public. Against the backdrop of widespread energy-saving and carbon-reduction awareness, cycling has gradually become a popular choice, with the number of participants increasing year by year. According to the Ministry of Transportation's statistics from 2018, 24.2% of the population over the age of 12 in the country cycles regularly each week. Among those who cycled in the past two weeks, the most common activity was leisure and exercise (41.8%), followed by personal activities such as shopping (36.6%) and commuting (21.1%) [1].

The bicycle saddle is a crucial component for cyclists, as it directly affects the support and comfort during riding. For users, saddle selection is based on three factors: pelvic tilt angle, saddle width, and saddle length. The pelvic tilt angle refers to the angle between the spine and the femur during riding, generally categorized into "forward tilt" and "upright" riding positions. Among these factors, saddle width and length most directly impact comfort; a larger saddle provides more support for the hips, enhancing comfort. However, an overly large saddle may conflict with the overall aesthetics of the bicycle.

Therefore, this study aims to use the TRIZ method to analyze the functions of the bicycle saddle and design an innovative saddle. By integrating ergonomic principles, the design seeks to offer comfort during riding while incorporating a deformable feature to maintain aesthetic and storage functions. Additionally, universal design principles will be applied to ensure the saddle is suitable for various bicycles and users on the market.

2. Literature Review

2.1. Product of Bicycle Saddle

Previous research has classified bicycle saddles in various ways, including by shape, material, firmness, and elasticity. Since cycling is an activity often performed for extended periods, the compatibility of the saddle shape with the rider's pelvic region significantly affects subjective comfort. Bicycle saddles come in many types, tailored to different purposes, but they can generally be categorized based on the presence or absence of a saddle nose and the width of the saddle. Traditional saddles typically feature a protruding nose to maintain stability while riding, whereas modified nose-less designs primarily aim to reduce pressure on the perineal and groin areas [2–5].

Research has broadly classified traditional saddle types into four categories [6,7]:

1. Saddles with a long protruding nose, commonly used for racing or flat-handlebar bicycles.
2. Nose-less saddles, designed to avoid perineal pressure by distributing the rider's weight onto the ischial tuberosities.
3. Nose-less and wider saddles, intended to enhance support for the hips and distribute pressure away from the ischial area.
4. Saddles with a traditional nose length but wider, suited for bicycles with higher handlebars.

While these four saddle types differ in design, they primarily focus on the length of the nose and the width of the saddle. Nose-less saddles, lacking a protruding front, may result in instability during riding [8]. Traditional saddles balance the body and guide the bicycle's movement, but nose-less designs, lacking front support, can affect handling. Therefore, additional equipment to reduce hand pressure is necessary. However, these nose-less designs exert the least pressure on the perineal area [9,10].

The analysis highlights that while traditional saddles with a protruding nose ensure stability and control, nose-less designs prioritize reducing pressure on sensitive areas, presenting a trade-off between comfort and stability. This ongoing development in saddle design reflects an effort to enhance rider comfort and address ergonomic challenges in cycling.

2.2. Investigation of Bicycle Saddle-Related Injuries and Comfort

Previous studies have identified musculoskeletal injuries associated with cycling, primarily including neck and shoulder pain, lower back pain, and soft tissue injuries around the buttocks. These issues can extend to causing infertility in women and sexual dysfunction in men. Poor bike fit can result in discomfort during riding, reducing the enthusiasm for cycling and leading to overuse injuries, joint, tendon, and ligament damage. In severe cases, this can cause loss of control and accidents during riding [11,12]. Utilizing a suitable saddle can effectively reduce injuries to the buttocks and perineum during cycling. Prolonged cycling subjects the inner pudendal artery to sustained pressure, potentially causing numbness in the buttocks and infertility [13].

Research has indicated that experiments using self-made simple saddle pressure test pieces found that commercially available saddles with a short protruding nose exert the least pressure on the front end, protecting the perineum. However, the pressure is concentrated on the rear saddle, potentially injuring the ischium [14]. Research in Taiwan on the comfort related to cycling posture includes studies on handlebar height, shape, and angle, as well as saddle height and shape, and their effects on user subjective perception. Some studies employed Likert and Borg scales to inquire about the subjective comfort levels of various body parts and overall riding comfort. They examined the correlation between saddle height and other factors, estimating regression curves to determine the optimal saddle position and posture for cycling comfort. The results indicated that, as the vertical saddle height decreases, overall comfort increases, but excessively low saddle heights still result in discomfort. Similarly, as the horizontal displacement of the saddle decreases, overall comfort improves, but when positioned too close to the crank axis, subjective discomfort significantly increases [15].

Additionally, some studies used the Borg CR-10 scale to evaluate the exertion levels in six body parts, including the wrists, upper back, lower back, buttocks, knees, and ankles. The results indicated that low handlebar and high saddle configurations resulted in higher handlebar forces, increased subjective exertion in the hands, back, and feet, and greater physiological load. When the riding posture was characterized by high handlebars and low saddle height, there was more wrist flexion, greater displacement of the buttocks' pressure center, less torso forward inclination, and higher exertion levels in the buttocks [16].

2.3. Triz Method

TRIZ (Theory of Inventive Problem Solving) is a methodology designed for systematic and innovative problem-solving, particularly in engineering and technology development. Originating from the analysis of millions of patents, TRIZ identifies patterns of invention and innovation, making it one of the most comprehensive and structured approaches to problem-solving in design and engineering [17–27]. The term "Inventive Problem Solving Theory" implies that an inventive problem includes at least one conflict or contradiction, and its solution is unknown [28–30]. TRIZ is used to develop conceptual design solutions, aiming to determine the practicality of concepts for real-world implementation [31].

Central to TRIZ is the use of tools like the 39 engineering parameters (Table 1) [32], the contradiction matrix, and the 40 inventive principles (Table 2) [33], which guide users in systematically addressing conflicts between different system elements. The contradiction matrix helps identify key areas of conflict, while the inventive principles offer strategic approaches to resolving these contradictions, enabling breakthroughs in design without compromising overall functionality. The contradiction matrix helps identify conflicts between engineering parameters, which typically arise when enhancing one aspect of a system leads to the degradation of another. By using the matrix to map these conflicts, the methodology recommends the most suitable inventive principles from the 40 inventive principles to resolve the contradiction. These principles offer structured, creative solutions, transforming design conflicts into opportunities for innovation [34].

Table 1. Summary of the 39 engineering parameters.

1. Weight of the moving object	11. Stress or pressure	21. Power	31. Object-generated harmful factors
2. Weight of the stationary object	12. Shape	22. Loss of energy	32. Ease of manufacture
3. Length of the moving object	13. Stability of the object's composition	23. Loss of substance	33. Ease of operation
4. Length of the stationary object	14. Strength	24. Loss of information	34. Ease of repair
5. Area of the moving object	15. Duration of action by the moving object	25. Loss of time	35. Adaptability or versatility
6. Area of the stationary object	16. Duration of action by the stationary object	26. Quantity of the substance/matter	36. Device complexity
7. Volume of the moving object	17. Temperature	27. Reliability	37. Difficulty of detecting and measuring
8. Volume of the stationary object	18. Intensity of illumination	28. Measurement accuracy	38. Extent of automation
9. Speed	19. Use of energy by the moving object	29. Manufacturing precision	39. Productivity
10. Force	20. Use of energy by the stationary object	30. External harm affecting the object	

Table 2. Summary of the 40 invention principles.

1. Segmentation	11. Early cushioning	21. Skipping	31. Porous material
2. Tanking out	12. Equipotentiality	22. Convert harm into benefit	32. Changing the color
3. Local quality	13. Working in reverse	23. Feedback	33. Homogeneity
4. Asymmetry	14. Spheroidality–curvature	24. Intermediary	34. Discarding and recovery
5. Merging	15. Dynamicity	25. Self-service	35. Transformation of properties
6. Universality	16. Partial or excessive actions	26. Copying	36. Phase transition
7. Nested doll	17. Transition into a new dimension	27. Cheap, short-lived objects	37. Thermal expansion
8. Anti-weight	18. Mechanical vibration	28. Replacement of mechanical systems	38. Accelerated oxidation
9. Prior anti-action	19. Periodic action	29. Pneumatics and hydraulics	39. Inert environment
10. Preliminary action	20. Continuity of useful action	30. Flexible shells or thin films	40. Composite materials

TRIZ provides a rich toolkit of theories and methods that systematically drive innovation and problem-solving. Among the nine major theories of TRIZ, aside from the previously discussed contradiction matrix, the S-curve and eight laws of technological system evolution help predict the developmental stages of technologies, enabling designers to anticipate future innovations. The concept of the ultimate ideal solution encourages problem solvers to aim for solutions that achieve maximum results with minimal resources. The physical contradictions are addressed through the four separation principles, which provide strategies for separating conflicting requirements by time, space, or condition. The substance-field model analysis simplifies systems into a visual format to better understand and modify interactions between components, while standard solutions for inventive problems offer pre-established approaches based on past successful innovations. The algorithm for solving inventive problems (ARIZ) is a structured procedure for resolving highly complex issues, guiding users step-by-step toward inventive solutions. Lastly, the knowledge base of scientific effects and phenomena provides a repository of scientific principles and effects that can be applied to solve design challenges more effectively. Together, these tools foster systematic innovation by offering diverse methods to tackle complex problems efficiently [35–38].

The development and promotion of a TRIZ technical system ontology, to some extent, involve indexing knowledge within the existing resource scope [39]. This ontology not only organizes relevant information but also facilitates the effective application of TRIZ principles in various contexts. Furthermore, the TRIZ evolutionary approach provides opportunities for further system development by resolving contradictions through the use of TRIZ tools [40]. Six cognitive gaps in the TRIZ process for service system design have been identified, including opportunity identification, contradiction resolution, and efficient resource utilization. Addressing these gaps enhances the practical application of TRIZ, promoting more innovative and user-centered service solutions [41]. Familiarity with and mastery of various TRIZ problem-solving tools is essential, as it allows designers to navigate these cognitive gaps effectively. The systematic application of TRIZ theory in product innovation design equips practitioners with a structured method for selecting the appropriate tools to tackle specific challenges [42].

2.4. Human Factors Engineering

Human factors engineering is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance. In other words, human factors engineering aims to discover knowledge about human behavior, capabilities, limitations, and other characteristics and apply it to the design of tools, machines, systems, tasks, work, and environments. This application is intended to enhance human productivity, safety, comfort, and effectiveness in their use [43].

Human factors engineering seeks to identify principles that ensure the smooth and successful operation of human/machine interfaces [44,45]. Therefore, designers must consider human behavior, capabilities, and limitations when designing, manufacturing, and using various tools, machinery, systems, and work environments. This consideration ensures optimal human–machine interface design, improving productivity (by reducing equipment downtime and the difficulty of personnel training and learning, and increasing user acceptance and operability), safety (by reducing human error, accidents, and enhancing system safety), and comfort (by reducing operator fatigue and excessive workload). In simple terms, human factors engineering aims to improve the comfort, well-being, safety, and efficiency of operators, ensuring that the environment and systems/equipment are compatible with the sensory, cognitive, and physical characteristics of the operators, maintainers, controllers, or support personnel [46].

2.5. Universal Design

Universal design refers to products, environments, and communications that can be used by everyone without the need for modifications. The primary difference between universal design and mainstream design lies in the consideration of the diverse needs of disadvantaged individuals, aiming to create products or spaces that "more people can use". This concept is a successor to what was previously known as "barrier-free spaces" or "barrier-free design" [47,48]. However, the significance and value of "universal design" go beyond merely "specializing" the needs of a minority or disadvantaged group. It further transforms these needs into "general" needs, with the intention of penetrating the mainstream market [49].

The seven principles of universal design include equitable use by anyone, flexibility in use with various methods, simple and intuitive use, perceptible information through multiple sensory organs, tolerance for error ensuring no accidents and easy recovery even if used incorrectly, minimal physical effort, and appropriate size and space for easy use [50–52]. This paper evaluates and improves different design projects by selecting appropriate principles from these seven, making the products more perfect and universally applicable.

2.6. IPA-KANO Model

The IPA-Kano model as a novel methodology for categorizing and diagnosing service quality attributes, and formulating specific strategies for each category. The IPA-Kano model overcomes the Kano model's limitation of neglecting attribute performance and importance, while also addressing the IPA model's shortfall of considering only one-dimensional qualities. This proposed model empowers managers to precisely understand user perceptions of quality attributes and to develop corresponding strategies effectively [53]. Research has explored the application of the Kano model and IPA to improve the service quality of mobile healthcare. This approach involved classifying two-dimensional quality characteristics, calculating customer satisfaction and dissatisfaction levels, and identifying key service quality attributes for priority improvement, with a focus on critical factors such as safety and privacy protection [54]. Other research has evaluated student satisfaction with online learning during the COVID-19 pandemic using the IPA-Kano model. The findings aim to guide lecturers in enhancing the quality of online education, ensuring better service for students and determining their satisfaction with current online learning services [55].

3. Methodology

The aim of this study is to develop an innovative design for a bicycle saddle that features transformable functionality while maintaining user comfort. To achieve this objective, the research incorporates an analysis of existing products, TRIZ methodology, human factors engineering approaches, and universal design principles.

In order to clearly articulate the research process, the study begins with a review of the current state of related research through an analysis of existing products and patents. The TRIZ methodology is employed to systematically identify design deficiencies and propose improvement strategies. Human factors engineering and universal design principles are then applied to create a more user-friendly and inclusive product. By integrating these approaches, the innovative design developed in this study aims to offer a more comprehensive solution that meets the needs of a wider range of users.

3.1. Design of a Bicycle Saddle with Horizontal Expansion and Folding Functions

For the innovative design of a bicycle saddle with horizontal expansion and folding functions, the TRIZ methodology is employed to improve the design of the bicycle saddle. Subsequently, human factors engineering methods are used to analyze the operation methods. Finally, universal design principles are applied to make the bicycle saddle more convenient and suitable for a wide range of users. The design details are explained as follows.

3.1.1. Implementation of TRIZ Method for Bicycle Saddle with Horizontal Expansion and Folding Functions

In this study, we utilized the TRIZ contradiction matrix to identify the engineering parameters among the 39 parameters that need improvement. The parameters identified for improvement are No. 6 (Area of a Stationary Object): the size of any two-dimensional plane related to the surface or surface area of an object; No. 12 (Shape): the internal and external shapes and contours of the system and its components as required by their functions; No. 27 (Reliability): the ability of a system to perform its intended function in a predictable manner and condition; No. 33 (Ease of Operation): the degree of difficulty for a user to learn, operate, and control the methods of operation of the system or object.

The parameters to be avoided from deterioration are No. 14 (Strength): the degree to which an object can withstand changes when a force is applied to it; No. 32 (Manufacturing

Difficulty): the problems related to the manufacturing and production of the object and system; and No. 36 (Device Complexity): the number and variety of elements and interrelations among elements within and outside the system. The contradiction matrix is shown in Table 3.

Table 3. Technical contradiction matrix for horizontal expansion and folding functions.

Avoid Deterioration Parameters Want to Improve Parameters	14. Strength	32. Manufacturing Difficulty	36. Device Complexity
6. Area of a Stationary Object	40	16, 40	01, 18 36
12. Shape	10, 14 30, 40	01, 17 28, 32	01, 16 28, 29
27. Reliability	11, 28		01, 13 35
33. Ease of Operation	03, 28 32, 40	02, 05 12	12, 17 26, 32

By summarizing the corresponding inventive principles derived from the technical contradiction matrix, we identified the principles that appear with the highest frequency in descending order as follows: No. 1 (Segmentation), No. 28 (Mechanical Substitution), No. 40 (Composite Materials), No. 32 (Color Change), No. 12 (Equipotentiality), No. 16 (Partial or Excessive Actions), No. 17 (Another Dimension), and others. To address the deformation issue of the bicycle seat cushion, our analysis revealed that No. 1 (Segmentation), No. 28 (Mechanical Substitution), and No. 40 (Composite Materials) are most applicable for the innovative design of a bicycle seat cushion with horizontal expansion and contraction functions.

Based on these three corresponding inventive principles, our design incorporates the following solutions: No. 1 (Segmentation): the bicycle seat cushion is divided into three separate components. No. 28 (Mechanical Substitution): the left and right sections of the cushion can be expanded laterally by an internal spring-actuated mechanism, allowing them to separate from the fixed middle seat cushion, thus increasing the overall surface area of the bicycle seat. No. 40 (Composite Materials): the use of silicone or foam mixed materials enhances the comfort of the cushion. Additionally, high-strength materials such as carbon fiber are used in parts of the seat structure that bear significant stress, thereby increasing the strength of the deformation mechanism of the bicycle seat cushion.

3.1.2. Implementation of Human Factors Engineering for Bicycle Saddle with Horizontal Expansion and Folding Functions

The current design of bicycle saddles often provides insufficient support for the rider's gluteal muscles, leading to localized muscle pressure accumulation and discomfort, which, over time, can cause physical harm to the user. To address this issue, this study applies human factors engineering, incorporating biomechanics and human–machine system analysis, to the current bicycle saddle design. The objective is to resolve the problems of inadequate gluteal muscle support and localized muscle pressure accumulation. Through this analysis, two design approaches have been developed:

1. Inadequate Gluteal Muscle Support: increase the contact area between the saddle and the buttocks to enhance support, allowing more gluteal muscles to bear the downward pressure of the body.
2. Localized Muscle Pressure Accumulation: by increasing the contact area between the saddle and the buttocks, the body pressure on the gluteal muscles is distributed more evenly, reducing the pressure.

3.1.3. Implementation of Universal Design for Bicycle Saddle with Horizontal Expansion and Folding Functions

In the innovative design of a bicycle saddle with horizontal expansion and folding functions, the saddle is designed with multiple components, utilizing internal springs to push the side saddle segments outward, achieving the expansion function. This design is based on the 39 engineering parameters and 40 inventive principles of the TRIZ methodology. The final design improvements are guided by the principles of universal design, focusing on equitable use, simplicity and intuitive operation, and low physical effort. The expansion range of the bicycle saddle can be adjusted to accommodate various user needs, ensuring that the innovative design with horizontal expansion and folding functions adheres to the principle of equitable use.

3.2. Innovative Design of Bicycle Backrest with Vertical Lifting Function

For the innovative design of a bicycle backrest with vertical lifting functionality, we utilized the TRIZ methodology to improve the bicycle seat design. Subsequently, we analyzed the operation methods using human factors engineering. Finally, we applied universal design principles to ensure the bicycle seat is more convenient and suitable for the general public.

3.2.1. Implementation of TRIZ Method for Bicycle Backrest with Vertical Lifting Function

This study identified the parameters to be improved from the 39 engineering parameters in the TRIZ contradiction matrix. The parameters selected for improvement are No. 8 (Volume of a Stationary Object): the size of the three-dimensional volume related to the object; No. 10 (Force); No. 27 (Reliability); and No. 35 (Adaptability or Versatility). The parameters to be avoided from deterioration are No. 2 (Weight of a Stationary Object), No. 32 (Manufacturing Difficulty), and No. 36 (Device Complexity). The contradiction matrix is shown in Table 4.

Table 4. Technical contradiction matrix for vertical lifting function.

Avoid Deterioration Parameters Want to Improve Parameters	**2. Weight of a Stationary Object**	**32. Manufacturing Difficulty**	**36. Device Complexity**
8. Volume of a Stationary Object	35, 10 19, 14	35	01, 31
10. Force	18, 13 01, 28	15, 37 18, 01	36, 35 10, 18
27. Reliability	03, 10 08, 28		01, 13 35
35. Adaptability or Versatility	19, 15 29, 16	01, 13 31	15, 29 37, 28

By summarizing the inventive principles corresponding to the technical contradiction matrix, the principles with the highest frequency of occurrence are, in descending order: No. 1 (Segmentation), No. 13 (The Other Way Round), No. 18 (Mechanical Vibration), No. 28 (Mechanical Substitution), No. 35 (Parameter Changes), No. 10 (Preliminary Action), No. 31 (Porous Materials), and No. 37 (Thermal Expansion). The remaining principles appear only once. To address the deformation issue of the bicycle saddle backrest, our analysis revealed that No. 1 (Segmentation), No. 15 (Dynamism), and No. 28 (Mechanical Substitution) are the most applicable for the innovative design of a bicycle backrest with vertical lifting functionality.

Based on these three corresponding inventive principles, our design incorporates the following solutions: No. 1 (Segmentation): the saddle is divided into a seat and a backrest. No. 15 (Dynamism): the connection mechanism between the seat and backrest utilizes the principle of dynamism, allowing it to be pulled out or retracted under the seat. No. 28 (Mechanical Substitution): the connection mechanism between the seat and backrest is replaced with an adjustable height structure, achieving the innovative design of a bicycle backrest with vertical lifting functionality.

3.2.2. Implementation of Human Factors Engineering for Bicycle Backrest with Vertical Lifting Function

The current design of bicycle saddles often provides insufficient support for the rider's gluteal muscles, leading to localized muscle pressure accumulation and discomfort. To address this issue, this study applies human factors engineering, incorporating biomechanics and human-machine system analysis, to the current bicycle saddle design. The proposed solution involves incorporating a backrest into the saddle design, allowing the pressure from the user's body on the gluteal muscles to be distributed to the lower back. This redistribution alleviates localized muscle pressure and helps prevent gluteal muscle pain.

3.2.3. Implementation of Universal Design for Bicycle Backrest with Vertical Lifting Function

In the innovative design of a bicycle backrest with vertical lifting functionality, a backrest is added to the saddle, with rails and connectors at the junction between the backrest and the seat to facilitate the backrest's expansion and retraction. This design is based on the 39 engineering parameters and 40 inventive principles of the TRIZ methodology. The final design improvements are guided by the principles of universal design, focusing on equitable use and simplicity and intuitive operation.

1. Equitable Use Principle:

The height of the bicycle saddle's backrest can be adjusted to meet the needs of various users, ensuring that the innovative design with vertical lifting functionality adheres to the principle of equitable use.

2. Simplicity and Intuitive Use Principle:

Following the simplicity and intuitive use principles of universal design, the backrest expansion and retraction mechanism of the bicycle saddle uses rails for movement and fixation. The user only needs to release the fasteners to adjust the backrest, making the innovative design of the bicycle backrest with vertical lifting functionality easy to operate.

3.3. Innovative Design of Bicycle Saddle with Quick Operation Function

For the innovative design of a bicycle saddle with quick operation functionality, we utilized the TRIZ methodology to improve the saddle design. Subsequently, we analyzed the operation methods using human factors engineering. Finally, we applied universal design principles to ensure the bicycle saddle is more convenient and suitable for the general public.

3.3.1. Implementation of TRIZ Method for Bicycle Saddle with Quick Operation Function

This study identified the parameters to be improved from the 39 engineering parameters in the TRIZ contradiction matrix. The parameters selected for improvement are No. 27 (Reliability), No. 33 (Ease of Operation), and No. 35 (Adaptability or Versatility). The parameters to be avoided from deterioration are No. 12 (Shape), No. 14 (Strength), and No. 36 (Device Complexity). The contradiction matrix is shown in Table 5.

By summarizing the inventive principles corresponding to the technical contradiction matrix, the principles with the highest frequency of occurrence are, in descending order: No. 28 (Mechanical Substitution), No. 1 (Segmentation), No. 15 (Dynamism), No. 32 (Color Change), No. 35 (Parameter Changes), No. 11 (Cushion in Advance), No. 29 (Fluid), and No. 37 (Thermal Expansion). The remaining principles appear only once. To address the issue of the quick operation functionality of the bicycle saddle, our analysis revealed that No. 1 (Segmentation), No. 28 (Mechanical Substitution), and No. 32 (Color Change) are the most applicable for solving the deformation mechanism of the bicycle saddle.

Table 5. Technical contradiction matrix for quick operation function.

Avoid Deterioration Parameters **Want to Improve Parameters**	**12. Shape**	**14. Strength**	**36. Device Complexity**
27. Reliability	35, 01 16, 11	11, 28	01, 31 35
33. Ease of Operation	15, 34 29, 28	32, 40 03, 28	32, 26 12, 17
35. Adaptability or Versatility	15, 37 01, 08	35, 03 31	15, 29 37, 28

Based on these three corresponding inventive principles, our design incorporates the following solutions for the innovative design of a bicycle saddle with quick operation functionality: No. 1 (Segmentation): The saddle expansion mechanism is segmented into components, springs, and a mechanism for controlling spring length. No. 28 (Mechanical Substitution): The mechanism for controlling the spring length is replaced with quick-release screws and a rail design, allowing for the continuous adjustment of the spring's extension length. No. 32 (Color Change): Length sections are marked with scales or color indicators, enabling users to easily understand and select the required scale range, achieving an innovative design with adjustable saddle size.

3.3.2. Implementation of Human Factors Engineering for Bicycle Saddle with Quick Operation Function

The current design of bicycle saddles fails to meet the comfort needs of all users. To address this issue, this study applies biomechanics and human–machine system analysis from human factors engineering to the current bicycle saddle design. The proposed solution involves designing a bicycle saddle with a quick operation function, allowing the product to be adjusted according to individual user preferences, thereby meeting the comfort needs of all users.

3.3.3. Implementation of Universal Design for Bicycle Saddle with Quick Operation Function

In the innovative design of a bicycle saddle with a quick operation function, the saddle is designed with additional expansion components and limiters, which are fixed on a graduated rail to achieve quick operation functionality. This design is based on the 39 engineering parameters and 40 inventive principles of the TRIZ methodology. The final design improvements are guided by the principles of universal design, focusing on equitable use, simplicity and intuitive operation, and perceptible information.

1. Equitable Use Principle:

The range of expansion and the height of the backrest can be adjusted to meet the needs of various users, ensuring that the innovative design of the bicycle saddle with a quick operation function adheres to the principle of equitable use.

2. Simplicity and Intuitive Use Principle:

Following the simplicity and intuitive use principles of universal design, the expansion and retraction mechanism of the bicycle saddle and backrest is controlled by a knob. Users can easily adjust it by turning clockwise or counterclockwise, making the innovative design of the bicycle saddle with a quick operation function user-friendly.

3. Perceptible Information Principle:

Utilizing the perceptible information principle of universal design, color indicators are used to mark the expansion width or height range, allowing users to quickly understand the current adjustment level of the mechanism.

3.4. Questionnaire Design

This study's questionnaire design is based on the SERVQUAL model proposed by Parasuraman et al. (1985) [56]. The questionnaire was refined through interviews and consultations with five experts from academia, manufacturing, and retail sectors. This approach aims to evaluate the product's tangibility, reliability, responsiveness, assurance, and empathy. Subsequently, the study employs the IPA-KANO model for further analysis and validation.

4. Product Design

This study aims to address the shortcomings of existing bicycle saddles. To solve the identified problems, based on the aforementioned research objectives, we employed patent analysis, the TRIZ contradiction matrix, the 40 inventive principles, human factors engineering, universal design, and structural design and manufacturing. This approach led to the innovative design of a bicycle saddle and backrest with adjustable expansion and folding mechanisms. The product design outcomes include a general description of the entire structure of the bicycle saddle, followed by the design details of the saddle with horizontal expansion and folding functions, which comprise the saddle body and the horizontal expansion and folding mechanism. Additionally, the design of the bicycle backrest with a vertical lifting function includes the saddle backrest and the vertical lifting mechanism. Furthermore, the product design of the bicycle saddle with a quick operation function encompasses detailed descriptions of the quick operation mechanisms for each component. Upon finalizing the prototype structure, the components and overall product structure were rendered using Inventor software. Furthermore, the design has been validated through analyses using the IPA and Kano models, confirming that it meets user requirements and expectations.

4.1. Structure of the Bicycle Saddle

The overall structure of the bicycle saddle in this product is divided into two parts: the saddle and the backrest. These components are explained as follows:

1. Saddle: The saddle includes a horizontal expansion and folding mechanism, consisting of three main components and their associated mechanisms. This design not only considers providing substantial support to the user's gluteal muscles, but also ensures the ease of operation for the horizontal expansion and folding mechanism.
2. Backrest: The backrest is positioned at the rear of the saddle. In addition to providing lumbar support to the user, the design also incorporates a vertical lifting and storage function.

4.2. Bicycle Saddle with Horizontal Expansion and Folding Functions

During bicycle riding, current bicycle saddles often fail to provide adequate support for the user's gluteal muscles, leading to discomfort and pain during prolonged use. This study addresses this issue by designing a bicycle saddle with horizontal expansion and folding functionality, ensuring a larger support area to enhance the support for the user's gluteal muscles.

The innovative design process of this study identified several key inventive principles from the TRIZ contradiction matrix related to the horizontal expansion and folding function of the bicycle saddle (Table 3). The relevant principles include:

1. Segmentation (Principle No. 1): The bicycle saddle is divided into three parts: a left horizontal component, a right horizontal component, and a central component, as shown in Figure 1.
2. Substitution of Mechanical Means (Principle No. 28): The design incorporates a press switch and latch mechanism to replace traditional connecting parts, as shown in Figure 2.

3. Composite Materials (Principle No. 40): Different materials with varying degrees of softness are used to construct the saddle, while more robust materials are used for the saddle frame.

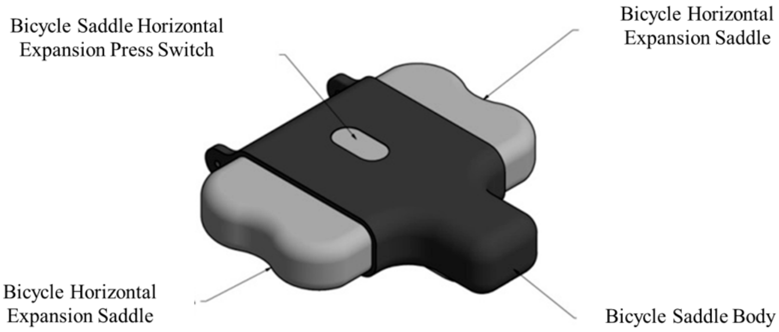

Figure 1. Bicycle saddle with horizontal expansion and structural folding function.

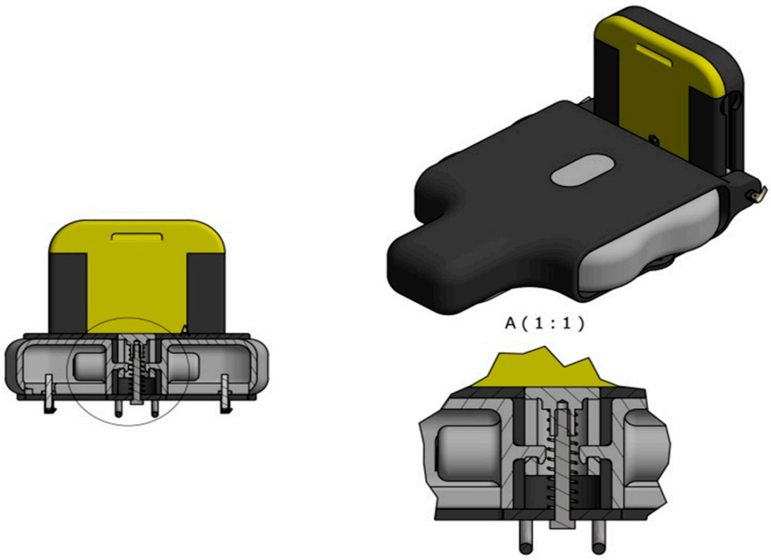

Figure 2. Press switch combined with horizontal expansion saddle buckle schematic.

By incorporating biomechanics analysis within human factors engineering, the increased saddle area helps distribute body pressure more evenly across the muscles, providing enhanced support. Specifically, increasing the saddle area reduces fatigue caused by the gluteus maximus muscle supporting the body in a suspended position during long rides, as shown in Figure 3. The design follows universal design principles, such as equitable use, simplicity, intuitive operation, and minimal physical effort, making the horizontal expansion and folding mechanism easy to operate for users of varying abilities. The ergonomic design of the saddle also takes into account anthropometric data, specifically hip circumference measurements from Asian populations, where adult males typically have a hip circumference ranging from 85 to 95 cm, and females from 80 to 90 cm. Based on these data, the saddle width was designed to fall within 40 to 45 cm, accommodating a wide range of users. Additionally, a saddle thickness of 5 to 10 cm was incorporated to provide sufficient support and comfort, reducing pressure on the hips and spine during extended use. This approach ensures that the design not only enhances usability but also optimizes comfort for prolonged sitting, aligning with the goals of ergonomic and inclusive design.

The final product design divides the bicycle saddle into three parts: left, right, and center. These parts combine to achieve the horizontal expansion and folding function. Springs and latches are integrated into the horizontal expansion mechanism within the left and right movable parts and the central fixed part. The saddle can be expanded by pressing a button and folded back by simply pushing it manually.

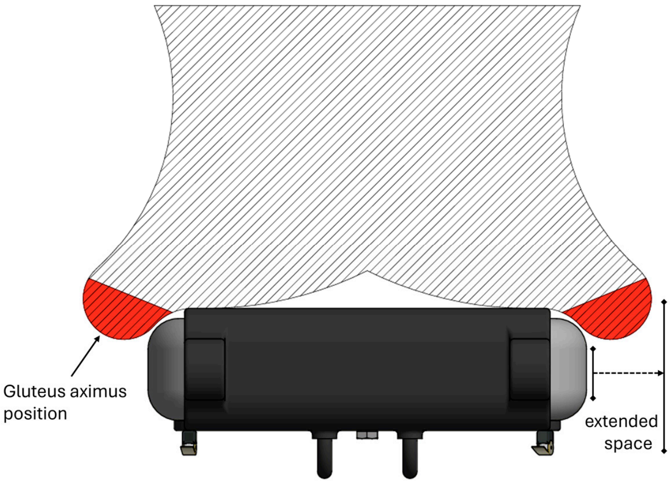

Figure 3. Saddle design with extended space to support gluteus maximus position.

4.3. Bicycle Backrest with Vertical Lifting Function

During cycling, the current bicycle saddles often lack sufficient support for the user's buttock muscles, which can lead to discomfort or soreness in the buttock muscles over prolonged periods of riding. This study aims to address this issue by designing a bicycle backrest with vertical lifting functionality. Such a backrest should allow for vertical adjustment of the bicycle saddle to distribute the user's body pressure to the waist area, thereby reducing pressure on the buttock muscles.

Through the innovative design process of this study, the technical contradiction matrix corresponding to the design of the bicycle backrest with vertical lifting functionality was analyzed, resulting in several inventive principles. Firstly, Principle No. 1 (Segregation) suggests dividing the saddle into seat and backrest components, as depicted in Figure 4. Secondly, Principle No. 15 (Variability) involves employing variable mechanisms in the connection between the seat and backrest components, enabling them to be pulled out or stored beneath the seat, as illustrated in Figure 5. Lastly, Principle No. 28 (Substitution of Mechanisms) advocates replacing the connection mechanism between the seat and backrest with a freely adjustable height structure, achieving the functionality of backrest expansion and folding.

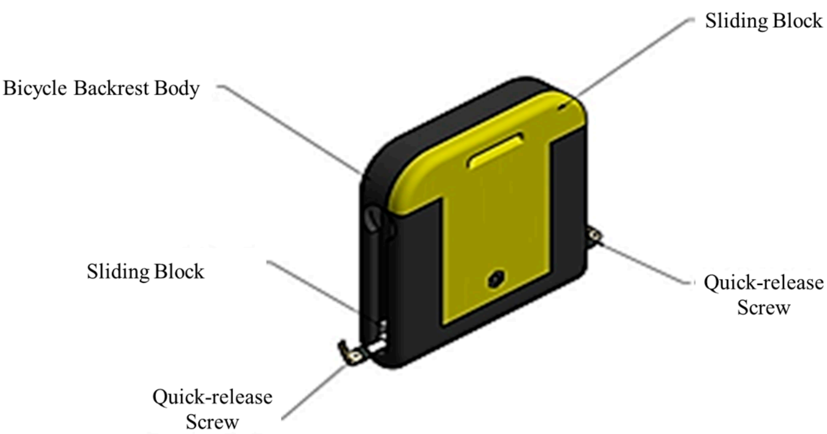

Figure 4. Backrest Structure.

Additionally, employing biomechanical analysis from human factors engineering, the increased surface area of the saddle and backrest can help distribute body pressure and provide more support to the buttock muscles. Finally, adherence to the principles of universal design, including fairness, simplicity, and intuitive use, ensures that the bicycle backrest with vertical lifting functionality is suitable for all users.

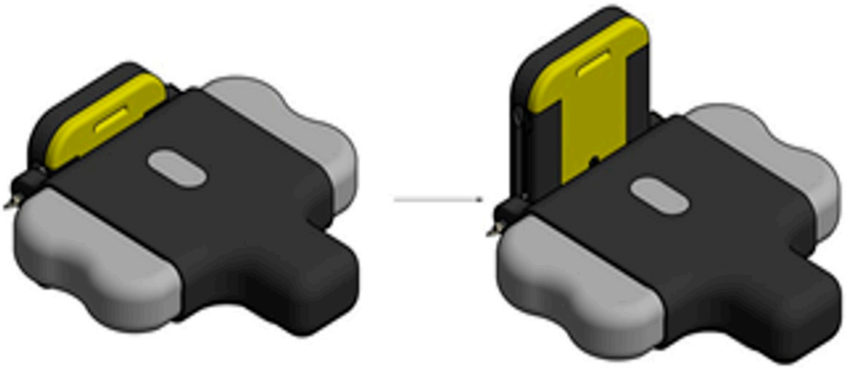

Figure 5. Backrest operation schematic.

4.4. Bicycle Saddle with Quick Operation Function

The current bicycle saddles fail to meet the needs of all users. If the saddle is too small, it can lead to insufficient support for the user's buttock muscles, resulting in discomfort or soreness. A bicycle saddle with quick operation functionality, as addressed in this study, requires a mechanism that allows for rapid adjustments to accommodate the preferences of any user.

Through the innovative design process of this study, the technical contradiction matrix corresponding to the design of a bicycle saddle with quick operation functionality was analyzed, yielding several inventive principles. Firstly, Principle No. 1 (Segregation) suggests dividing the saddle expansion mechanism into components such as springs and controls for spring length. Secondly, Principle No. 28 (Substitution of Mechanisms) proposes replacing the mechanism controlling spring length with a design featuring quick-release tightening screws and sliding tracks, enabling continuous adjustment of the spring length. Thirdly, Principle No. 32 (Color Change) advocates using length indicators or color markings to help users easily understand the range of adjustments required.

Furthermore, employing human factors engineering and the human–machine systems approach, the design incorporates a horizontally expandable and collapsible mechanism for the bicycle saddle, integrating adjustable sliding tracks. Users can adjust the desired expansion length using calibrated indicators, followed by tightening the quick-release screws to secure the position. Finally, adherence to the principles of universal design, including fairness, simplicity, and clear information presentation, ensures that the bicycle saddle with quick operation functionality is suitable for all users, as illustrated in Figure 6.

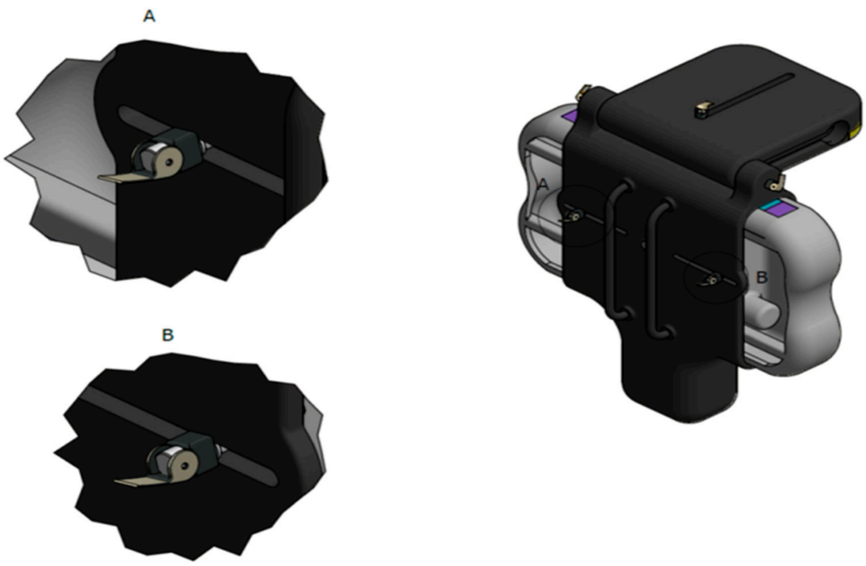

Figure 6. Bicycle saddle size with rapid operation function expansion scale schematic.

4.5. Combined Analysis of IPA and the Kano Model

The analysis of the survey results reveals that users rated the overall importance of the bicycle saddle developed in this study with an average score of 4.137 and the overall satisfaction with an average score of 3.963. The survey included 182 participants, with 97 males and 85 females, and participant characteristics such as age, education, average annual income, and occupation are summarized in Table 6. According to the IPA-Kano cross-analysis, the key elements of this analysis are summarized as follows (see Figures 7 and 8).

Table 6. Participant characteristics table.

Variables		Numbers	Percentage (%)
Gender			
	Male	97	53.30%
	Female	85	46.70%
Age			
	20–29	35	19.23%
	30–39	17	9.34%
	40–49	69	37.91%
	$\geq$50	61	33.52%
Occupation			
	Administrative	43	23.63%
	Managerial	9	4.95%
	Skilled Worker	13	7.14%
	Service Worker	52	28.57%
	Education	32	17.58%
	Student	26	14.29%
	Homemaker/Retired	7	3.85%
Education Level			
	Junior High School	2	1.10%
	Senior High School	2	1.10%
	University	149	81.87%
	Graduate School	29	15.93%
Annual Income			
	<500,000(TWD)	21	11.54%
	500,000–700,000(TWD)	54	29.67%
	700,000–800,000(TWD)	51	28.02%
	80,000–100,000(TWD)	31	17.03%
	>100,0000(TWD)	25	13.74%

1. Quadrant I (Keep Up the Good Work): Features in this quadrant, such as innovative horizontal expansion (1), high satisfaction with folding (2), practical quick-operation (4), and comfortable height adjustment for different riding environments (7), are rated both highly important and satisfactory. These are the strengths of the current design, and no immediate changes are required. They align with the "Attractive Quality" attributes in the Kano model, signifying that their presence significantly enhances user satisfaction.

2. Quadrant II (Concentrate Here): The height adjustment features, especially convenient height adjustment (3) and necessary height adjustment (11), appear in this quadrant. These attributes are rated as highly important but have lower satisfaction levels. According to the Kano model, these represent a mix of "Must-Be" and "Attractive" qualities, meaning that improvements in these areas are critical to meeting basic user expectations and enhancing satisfaction.

3. Quadrant III (Low Priority): Features like saddle color (13), saddle design aesthetics (15), and saddle brand (16), located in the bottom-left quadrant, are rated lower in both importance and satisfaction. These features are not urgent to improve, as they do not significantly influence user satisfaction. This aligns with the "Indifferent Quality" category in the Kano model, indicating that their improvement would not substantially affect user perceptions.

4. Quadrant IV (Possible Overkill): In the bottom-right quadrant, features like convenient folding for storage (6), necessary folding (10), and convenient quick-release operation (8) are highly satisfactory but of lower perceived importance. Overinvestment in these features might not yield proportional increases in overall satisfaction.

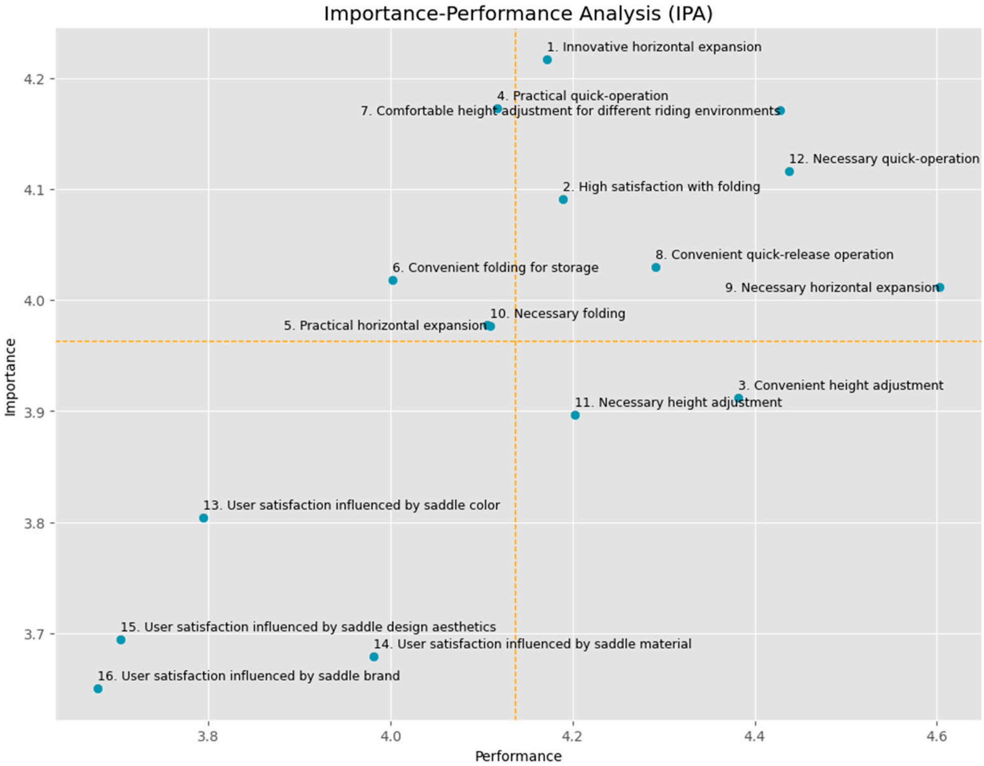

Figure 7. Importance–performance analysis scatter plot.

Quadrant II

Service quality items	Kano	Importance
4. Practical quick-operation	A	4.117
5. Practical horizontal expansion	O	4.106
6. Convenient folding for storage	O	4.002
10. Necessary folding function	M	4.109

Quadrant I

Service quality items	Kano	Importance
1. Innovative horizontal expansion	A	4.172
2. High satisfaction with folding	A	4.189
7. Comfortable height adjustment for different riding environments	O	4.428
8. Convenient quick-release operation	O	4.291
9. Necessary horizontal expansion	M	4.603
12. Necessary quick-operation	M	4.438

Quadrant III

Service quality items	Kano	Importance
13. User satisfaction influenced by saddle color	I	3.794
14. User satisfaction influenced by saddle material	I	3.981
15. User satisfaction influenced by saddle design aesthetics	I	3.703
16. User satisfaction influenced by saddle brand	I	3.678

Quadrant IV

Service quality items	Kano	Importance
3. Convenient height adjustment	A	4.382
11. Necessary height adjustment	M	4.202

Figure 8. Cross-tabulations of IPA and the Kano model.

The results of the IPA and Kano model analysis indicate that height adjustment functions are identified as key areas for improvement, whereas features such as folding and quick-release operation received higher levels of satisfaction from users. Although attributes related to materials and aesthetics were deemed lower in priority, these elements present potential opportunities for enhancement in subsequent iterations of the product. The IPA visualization further validates the necessity to focus on optimizing both the functional and aesthetic aspects of the bicycle saddle to align with user expectations and enhance overall product satisfaction.

5. Conclusions

This study aimed to utilize the TRIZ method for analyzing bicycle saddle functions and designing an innovative saddle. By integrating ergonomic principles, the design seeks to provide comfort during riding while incorporating deformable features that maintain aesthetic appeal and storage functions. Universal design principles ensure the saddle accommodates various bicycles and users in the market. The design highlights are as follows:

1. Horizontal Expansion and Folding Functions.

The innovative bicycle saddle design addresses the common issue of inadequate support for buttock muscles, which often leads to soreness during long rides. By increasing the saddle's surface area, this feature enhances support and reduces pressure, receiving high ratings in both importance and satisfaction. Classified as "Attractive Quality", it significantly improves user comfort and adaptability.

2. Vertical Lifting Function.

The bicycle backrest's vertical lifting functionality redistributes body pressure effectively, enhancing support for the waist while alleviating pressure on the buttock muscles. Identified as a key improvement, this feature meets basic user needs for comfort and support, classified as a "Must-Be Quality". Its refinement is expected to notably boost user satisfaction.

3. Quick Operation Function.

This design incorporates a mechanism for rapidly adjusting saddle size, catering to diverse user preferences and body types. By allowing customization based on individual needs, this feature addresses the limitations of current saddles, which may not adequately support all users. Rated highly for its performance and satisfaction, it aligns with user expectations for adaptability.

This study demonstrates the potential of applying innovative ergonomic saddle design to improve posture, comfort, and overall cycling experience. By integrating the TRIZ Innovation System Method and validating with the IPA-Kano Model, the saddle's optimized dimensions and geometry show promise in enhancing user comfort, particularly for prolonged use. The design also holds potential for applications in rehabilitation and competitive cycling, with positive effects on the lumbar spine and muscle engagement. Future work could focus on refining these ergonomic solutions for broader use, including integration into automated bicycles and enhancing the design's accessibility.

6. Patents

The research results were awarded a patent for invention by the Intellectual Property Office, Ministry of Economic Affairs, Republic of China (Patent No. I687334).

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