

Article

Research on the Influence of Wheelsets on the Visual Imagery of City Bicycles

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Abstract: City bicycles have become popular worldwide because they play an essential role in releasing urban traffic congestion and are environmentally friendly. Since wheelsets are the most prominent shape element in a bicycle, this research explores the influence of various wheel types on the visual image of a city bicycle. First, 10 wheelsets with a high market share in China were selected as the research samples. Meanwhile, vocabularies suitable for describing wheelsets were chosen from many vocabularies. Then, all vocabularies were summarized into six adjectives using factor analysis, and consumers were invited to evaluate all samples using the grouped adjectives. Finally, triangular fuzzy numbers were used to obtain the evaluation scores of 10 wheelsets on six adjectives, and the 10 wheelsets were divided into four groups based on the evaluation scores. The results show that the visual imagery evaluation of the 10 wheelsets had a significant difference in the “trimmed and stable”, “superior and presentable”, and “holistic and balanced” groups, but a slight difference in “novel and individualized”, “rhythmic and metrical”, and “mechanical and ordered.” The research results could serve as a reference for city bicycle operators and help improve product development efficiency, thereby promoting the sustainable development of city bicycles.

Keywords: city bicycle; wheelsets; visual evaluation; factor analysis; fuzzy logic



Citation: Wu, F.; Lu, P.; Lin, Y.-C.

Research on the Influence of Wheelsets on the Visual Imagery of City Bicycles. *Sustainability* **2022**, *14*, 2762. <https://doi.org/10.3390/su14052762>

Academic Editors: Yoshiki Shimomura and Shigeru Hosono

Received: 24 January 2022

Accepted: 25 February 2022

Published: 26 February 2022

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1. Introduction

The rapid development of industrialization has led to the excessive consumption of various natural resources. In recent years, as the concept of environmental protection has become deeply rooted in people's hearts, more and more ordinary consumers have been paying attention to environmental protection and energy conservation. City bicycles are green, energy-saving, and environmentally friendly healthy products among many urban vehicles. Besides, city bicycles have many advantages, such as small size and moderate speed, so they will not cause traffic jams or severe traffic accidents. Therefore, many city dwellers around the world tend to use city bicycles. Murphy and Usher [1] surveyed Irish citizens, and the results showed that city bicycles are more likely to be accepted by middle- and high-income groups. Suan et al. [2] surveyed 806 Hangzhou residents, and 30% of them said they would use city bicycles as their means of travel. The government and enterprises are committed to promoting city bicycles in the Chinese market environment. Chinese scholar Zhu [3] provided a set of statistics on Mobike, including that (1) there are more than 100 million registered users (2) and about 5 million city bikes put on the market, (3) covering more than 100 cities in China. In addition, according to public data, the number of city bicycles in four first-tier cities in China (i.e., Beijing, Shanghai, Guangzhou, and Shenzhen) has reached 200,000, 360,000, 200,000, and 320,000, respectively. The penetration rate has reached 1.5%, 0.9%, 1.4%, and 2.8%, respectively [4].

As we all know, China is one of the most popular countries for city bicycles. Vital development to the bicycle design domain also has the potential to positively impact soci-

ety [5]. Specifically, the Chinese market accommodates dozens of brands of city bicycles, and each brand of city bicycle has a unique appearance. To increase market share, various brands are focused on improving city bicycles' functional attributes and appearance. Several researchers have focused on improving the functional properties of bicycles. Rodrigues et al. [6] developed an elliptical handlebar for bicycles and invited 26 subjects for verification. Vansteenkiste et al. [7] explored the effect of the user's height on the comfort and satisfaction of the bicycle, and the results were helpful to improve the user experience. Hsiao et al. [8] proposed a method to measure the comfort of bicycles, and the research results could help consumers of different heights to choose a suitable bicycle. Besides, several researchers have studied the effects of the pedals [9], frame [10], and cranks [11] on the functional attributes of bicycles through experimental tests.

However, ordinary consumers pay more attention to the appearance of bicycles than the functional attributes of bicycles. Therefore, in the product development phase, designers should focus on the appearance of the city bicycle. Pan [12] believes that the market could receive city bicycles well by following the design principles of shape innovation. To design a bicycle appearance that meets consumer preferences, Hsiao and Ko [13] disassembled the overall form of the bicycle into five main components, namely, wheels, handlebars, frame, seat cushion, and crank center. Then, an evaluation model about bicycle appearance was proposed by integrating fuzzy comprehensive evaluation and the analytic hierarchy process. Regenwetter et al. [5] proposed a variety of bicycle data-driven design applications and used unsupervised learning methods to design bicycles and synthesize new bicycles. In addition, Lin et al. [14] focused on city bicycles in Hangzhou and obtained visual imagery of different frame shapes through the semantic difference method and factor analysis. Generally, consumers get the imagery conveyed by a product through sight. Arnheim [15], a contemporary American aesthetic intuition psychologist, believes that vision is a very active feeling. Zhang [16], a professor of Chinese psychology, pointed out that the most potent sense is sight, followed by hearing, and believed that world culture and progress rely more on sight. Regarding imagery interpretation, Peng [17] believes that imagery is a mental image or representation, with the information conveyed by a specific object or event, and that this information has distinct perceptual characteristics. Pala et al. [18] pointed out that only the perceiver's imagination of the object's shape and the similar content depicted by the perceiver can derive the imagery. Therefore, obtaining the imagery conveyed by the bicycle's form through scientific and practical research methods is crucial to the sustainable development of urban bicycles.

As mentioned above, there are dozens of brands of city bicycles in the Chinese market, and each brand of city bicycle has different wheelsets. In the past, the selection of wheelsets was mainly based on the subjective judgment of designers or design engineers. When designers use wheelsets of different shapes to design urban bicycles, ordinary consumers have different psychological feelings, which affect their desire to experience. Although Hsiao and Ko [13] believe that the priority of the five main shape elements that constitute a bicycle are handlebar, seat cushion, frame, crank center, and wheelset, the wheelsets are the largest component of all shape elements. In addition, compared with the research samples of Hsiao and Ko [13], the city bicycles in the Chinese market environment are more representative. Therefore, this study explores the impact of wheelsets with a high market share on the visual image of city bicycles through effective research methods.

The sustainable development of human society consists of ecological sustainability, economic sustainability, and social sustainability. If the visual imagery of city bicycles meets the aesthetics of urban residents, it could attract more residents to use city bicycles, thereby promoting the sustainable development of city bicycles. Besides, if the visual imagery of the city bicycle meets the style positioning of a city, it could make the city environment more harmonious, thereby promoting the sustainable development of the city economy and ecological environment. To promote the sustainable development of city bicycles, this study aims to explore the influence of various wheelsets on the visual imagery of city bicycles through an objective research method. Specifically, this study integrates

factor analysis and fuzzy theory to define the visual imagery of various wheelsets, thereby promoting the sustainable development of city bicycles. An outline of this paper is listed as follows. Section 2 describes in detail the materials and methods used in this study. Section 3 describes the results and discussion. Finally, the last sections conclude the article and offer a few perspectives.

2. Materials and Methods

2.1. Research Framework

This study explored the visual imagery of various wheelsets through questionnaires, factor analysis, and fuzzy logic. The specific research process is shown in Figure 1, and the detailed implementation steps are as follows.

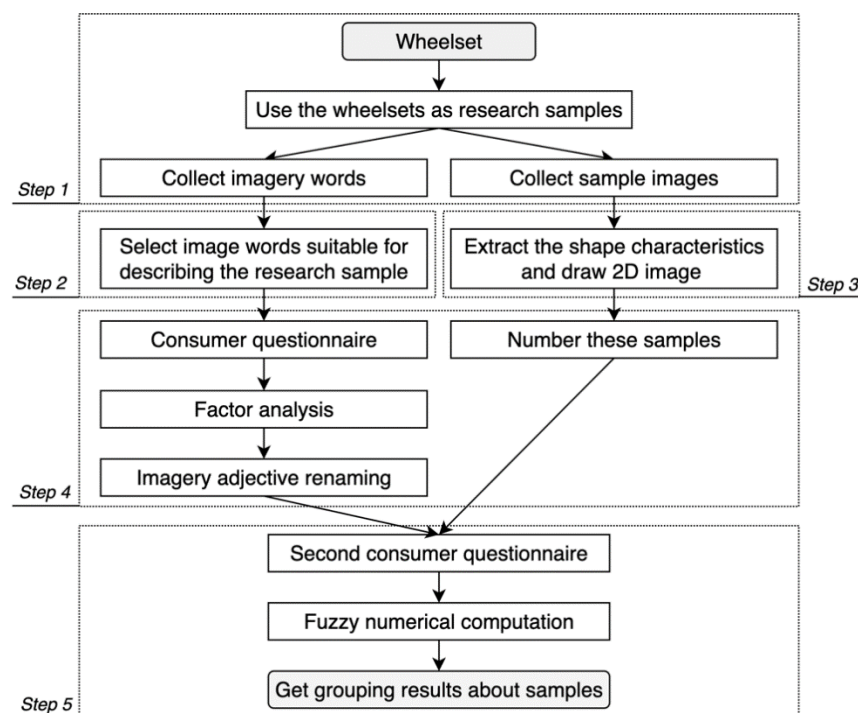


Figure 1. Research flowchart.

Step 1: Adjectives were collected that fit the visual imagery of the wheelsets. China is one of the most popular countries for city bicycles and bike-sharing. Thus, major mainstream media often report news about city bicycles, and many scholars focused on city bicycles. Therefore, this research mainly collected adjectives in two ways. The first way was to refer to published papers, and the second way was to query bicycle information websites and social networking sites' official accounts (e.g., Weibo and WeChat). Finally, a total of 110 adjectives were selected to describe the visual imagery of the wheelsets.

Step 2: Various types of wheelsets were collected as research samples. Ten wheelsets were selected as research samples, considering the user registration and usage of city bicycles with high market share (e.g., Mobike, Ofo, Hellobike, Bluegogo).

Step 3: Two-dimensional grayscale images of the study samples were plotted. This study investigated the influence of wheelsets on the visual imagery of city bicycles. To avoid the impact of color, texture, and texture on the visual image, this study used the plane software Photoshop to draw two-dimensional grayscale images of the research samples. In addition, to highlight the wheelsets, the principle of simple shape was adopted for the selection of other shape elements (i.e., frame, handlebar, seat cushion, and crank center), as shown in Figure 2.

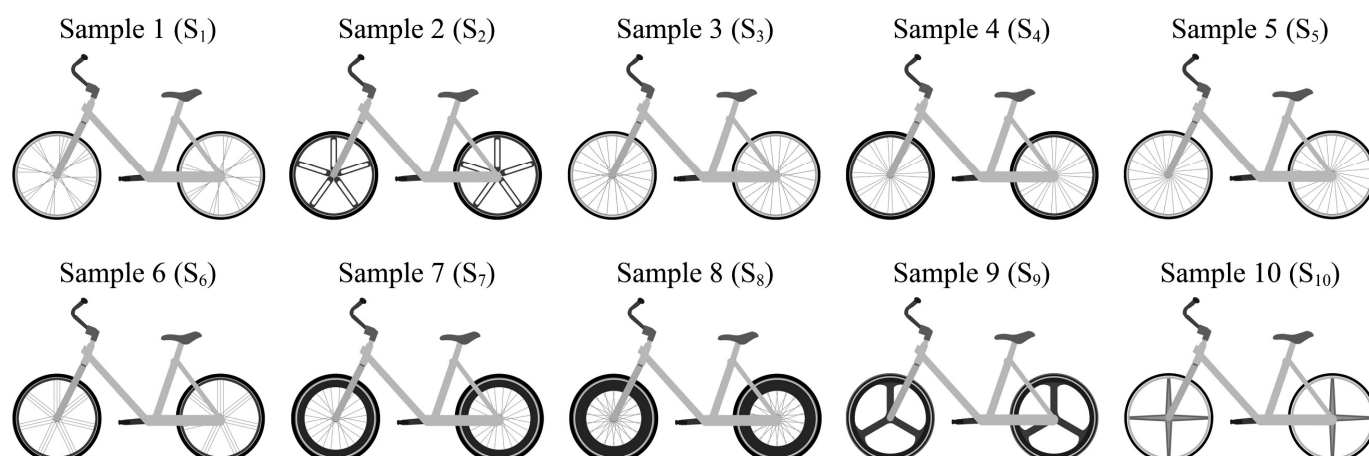


Figure 2. Two-dimensional grayscale images of 10 research samples.

Step 4: Adjectives were further screened by using questionnaires and factor analysis. First, 10 designers and teachers of product design majors were invited as subjects. They were asked to select 40 to 50 adjectives suitable for describing the visual imagery of wheelsets from 110 adjectives according to their subjective feelings. Then, the top 40 adjectives were sorted out. In addition, to further clarify the similarity and affiliation between adjectives, this study first set up a semantic difference questionnaire to classify 40 adjectives. Specifically, the questionnaire adopted the five-point Likert scale method, and the five levels were “very unsuitable”, “unsuitable”, “ordinary”, “suitable”, and “very suitable”. Then, the questionnaire data were analyzed by using factor analysis. Finally, a total of 104 valid questionnaires were collected, including 47 males and 57 females, and then each group of adjectives was renamed according to the analysis results.

Step 5: The visual imagery of wheelsets was obtained by using questionnaires and triangular fuzzy numbers. Potential consumers of city bikes were first invited to use the renamed adjectives to conduct a questionnaire survey on the 10 samples (see Figure 2). To ensure the validity of the questionnaire results, this study invited all subjects to use the same iPad to observe the research samples. As shown in Figure 3, when observing the samples, the subjects looked at each research sample in turn by sliding their fingers left and right and filling out the questionnaire simultaneously. Then, the questionnaire results were calculated using triangular fuzzy numbers to obtain the total utility value of each sample concerning all adjectives. Finally, a radar chart was drawn using the total utility value.



Figure 3. Schematic diagram of the second questionnaire.

2.2. Factor Analysis

Factor analysis, also known as empirical analysis, is a qualitative analysis method. Kline [19] clarified that factor analysis is a method that uses an index system to analyze or measure the degree of influence of multiple factors on the overall objective phenomenon. Brown et al. [20] believes that factor analysis is a statistical method that can clarify how many factors are needed to explain the relationship of a set of variables. The factor analysis method is essential and practical in modern statistics. The specific operation steps are as

follows: (1) Clarify the index to be analyzed, (2) determine the factors that affect the index and the relationship between each factor and the index, and (3) determine the influence degree of each factor through calculation. In specific applications, Lin et al. [14] obtained a set of adjectives suitable to describe bicycle frames through factor analysis. In addition, Chen et al. [21] used factor analysis to study visual imagery of wooden floors. Therefore, factor analysis is an objective and effective research method, and this method can also be used to study city bicycle wheelsets.

2.3. Fuzzy Logic

The phenomena encountered in scientific research can be roughly divided into deterministic, random, and fuzzy. To solve the deterministic phenomenon, the commonly used methods are geometry, algebra, mathematical analysis, and differential equations; probability theory and mathematical statistics can explain random phenomena; and fuzzy theory is an effective tool to study fuzzy phenomena [22]. Zadeh [23,24] defined fuzzy theory as a research method to deal with fuzzy phenomena and fuzzy problems. Fuzzy theory is often used to deal with decision-making problems [25–27].

Fuzzy numbers in fuzzy theory are often used for semantic measurement. Common fuzzy numbers mainly include triangular fuzzy numbers, trapezoidal fuzzy numbers, and normal fuzzy numbers. Among them, the triangular fuzzy number is the most commonly used, and its characteristic is that the distribution of the membership function is a triangle [28]. Specifically, suppose $\tilde{t}$ is a triangular fuzzy number in the membership function $\mu_i(x)$, expressed as $\tilde{t} = (t_1, t_2, t_3)$. When t_1, t_2, t_3 are real numbers and $t_1 \leq t_2 \leq t_3$, the membership function can be expressed as shown in Figure 4.

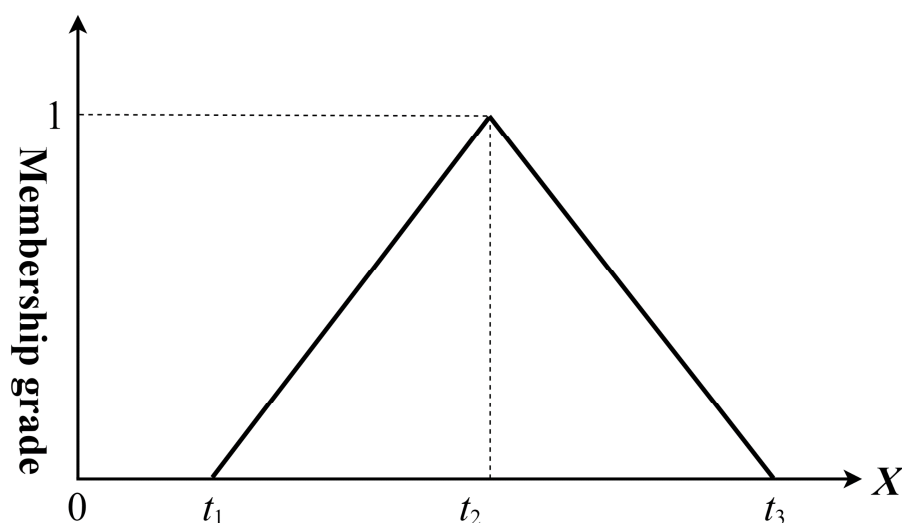
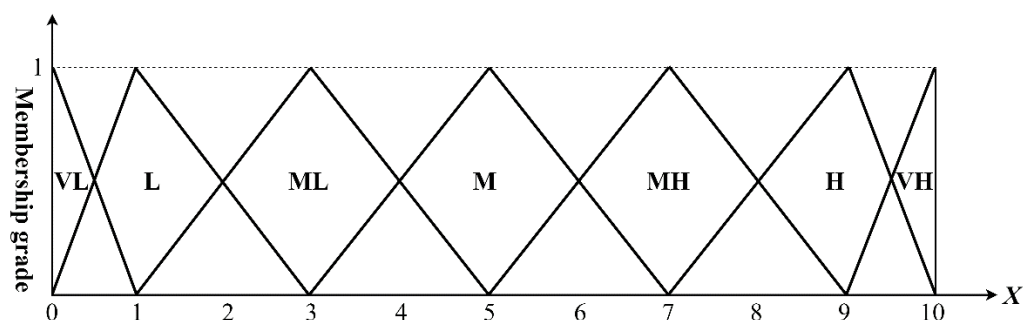


Figure 4. The membership function of a triangular fuzzy number.

Hsiao and Tsai [29] proposed an evaluation of the imagery of product shapes using triangular fuzzy numbers and machine learning. Chen et al. [21] used triangular fuzzy numbers to perceptually evaluate wooden floors with multiple textures to obtain several groups of wooden floors with similar visual images. Wang et al. [30] proposed a fault tree analysis method based on TOPSIS and triangular fuzzy numbers, which can evaluate the failure rate of events. In this study, a perceptual evaluation questionnaire was set up using linguistic variables to obtain consumers' evaluation of the wheelsets. The semantic variables included "very low", "low", "medium low", "medium", "medium high", "high", and "very high", and the triangular fuzzy numbers corresponding to each semantic variable are shown in Table 1. Subsequently, triangular fuzzy numbers can represent the membership of a research sample on any adjective, as shown in Figure 5.

Table 1. Linguistic variables for importance and ratings.

Linguistic Variables	Triangular Fuzzy Numbers
Very low (VL)	(0, 0, 1)
Low (L)	(0, 1, 3)
Medium low (ML)	(1, 3, 5)
Medium (M)	(3, 5, 7)
Medium high (MH)	(5, 7, 9)
High (H)	(7, 9, 10)
Very high (VH)	(9, 10, 10)

**Figure 5.** Membership functions of triangular fuzzy numbers.

2.4. Total Utility Value in Triangular Fuzzy Numbers

To compare triangular fuzzy numbers in membership functions more intuitively, each fuzzy number must be interpreted as a crisp value by defuzzification. Generally, there are three defuzzification methods: the centroid method, the maximum membership method, and the maximum set and minimum set method [31]. This study used the maximum set and minimum set method to convert triangular fuzzy numbers into total utility values, and the specific calculation methods are described below.

It is assumed that there are n fuzzy numbers in the membership function of triangular fuzzy numbers, namely, $\tilde{t}_i = (t_{i1}, t_{i2}, t_{i3})$, $i = 1, 2, \dots, n$. The minimum membership function $\mu_G(x)$ and the maximum membership function $\mu_M(x)$ can be expressed as G and M , respectively, and $G = (X_{min}, X_{min}, X_{max})$, $M = (X_{min}, X_{max}, X_{max})$. Thus, the total utility value $U_T(\tilde{t}_i)$ of triangular fuzzy numbers can be expressed as:

$$U_T(\tilde{t}_i) = \left[\frac{(t_{i3} - X_{min}) / ((X_{max} - X_{min}) + (t_{i3} - t_{i2})) + 1}{-(X_{max} - t_{i1}) / ((X_{max} - X_{min}) + (t_{i2} - t_{i1}))} \right] / 2, i = 1, 2, \dots, n \quad (1)$$

Based on the above analysis, to further understand consumers' perception of the visual imagery of the 10 wheelsets, this study set up an evaluation questionnaire about the 10 wheelsets using linguistic variables and renamed adjectives. Then, according to Equation (1), the total utility value of the 10 wheelsets on each image adjective was calculated. Finally, a radar chart was drawn based on the total utility values.

3. Results and Discussion

3.1. The Result of Factor Analysis

In this study, 10 designers and teachers were invited to screen the top 40 adjectives suitable to describe wheelsets from 110 adjectives and then the 40 adjectives were used to conduct a questionnaire survey. Finally, factor analysis was performed on the questionnaire results using SPSS, and the analysis results are as follows.

The first-factor analysis was performed using 40 discriminative adjectives. After principal component analysis, the second-factor analysis was performed using 16 adjectives with factor loadings greater than 0.6 in absolute value, as shown in Table 2. The factor analysis results show that the KMO value was 0.735 and the Bartlett spherical test value

reached 633.345 (df 136), which means that the analysis result was significant and there was a common factor between the correlation matrix of the population.

Table 2. The 16 adjectives whose absolute factor loading values were ranked in the front.

Adjectives	Initial	Extraction	Adjectives	Initial	Extraction
Trimmed	1.000	0.769	Presentable	1.000	0.800
Regular	1.000	0.728	Rhythmic	1.000	0.834
Stable	1.000	0.723	Metrical	1.000	0.821
Interesting	1.000	0.785	Novel	1.000	0.747
Mechanical	1.000	0.729	Balanced	1.000	0.799
Ordered	1.000	0.849	Holistic	1.000	0.605
Individualized	1.000	0.774	Secure	1.000	0.771
Superior	1.000	0.740	Symmetrical	1.000	0.689

Furthermore, as shown in Table 3, the accumulative percentage was 76.008%, and there were six factors with eigenvalues greater than 1. The accumulative percentage is used to account for the contribution of a factor. Generally, the accumulative percentage should be higher than 70%. A factor is considered valid when its initial eigenvalue is greater than 1. Conversely, when the initial eigenvalue of a factor is less than 1, it indicates that the information for this factor should not be preserved. Besides, as shown in Table 4, the transformed matrix shows that the six component factors were apparent in the second-factor analysis, and no redundant factor components were covered. Therefore, the 16 adjectives and six components obtained by the second-factor analysis could be used for the follow-up study.

Table 3. Total variance explained.

Component	Initial Eigenvalues			Square Loading Extraction			Transformed Square Loading		
	Total	Variance (%)	Accumulative (%)	Total	Variance (%)	Accumulative (%)	Total	Variance (%)	Accumulative (%)
1	4.831	30.195	30.195	4.831	30.195	30.195	2.264	14.152	14.152
2	2.062	12.886	43.081	2.062	12.886	43.081	2.198	13.735	27.887
3	1.509	9.431	52.512	1.509	9.431	52.512	2.175	13.593	41.480
4	1.329	8.304	60.816	1.329	8.304	60.816	1.985	12.406	53.886
5	1.307	8.166	68.981	1.307	8.166	68.981	1.984	12.398	66.284
6	1.124	7.026	76.008	1.124	7.026	76.008	1.556	9.724	76.008

Table 4. Transformed component matrixes.

Adjectives	Component					
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
Presentable	0.794	−0.022	0.088	0.013	0.388	0.100
Secure	0.789	0.290	0.171	−0.114	−0.011	0.151
Superior	0.675	0.194	0.345	0.317	0.005	−0.163
Balanced	−0.034	0.778	0.230	0.137	0.314	0.148
Symmetrical	0.131	0.769	−0.002	0.118	0.244	0.080
Holistic	0.231	0.726	0.075	0.095	−0.089	0.040
Interesting	0.076	0.069	0.818	0.184	0.240	−0.114
Individualized	0.133	0.030	0.789	−0.099	0.073	0.344
Novel	0.406	0.233	0.713	0.016	−0.068	0.117
Trimmed	−0.023	0.356	0.131	0.790	−0.013	−0.003
Regular	−0.135	0.065	−0.110	0.753	0.269	0.233
Stable	0.446	−0.022	0.110	0.700	0.047	0.136
Metrical	−0.002	0.123	0.139	0.227	0.855	0.060
Rhythmic	0.253	0.196	0.068	−0.011	0.852	0.031
Ordered	0.035	0.324	−0.054	0.098	0.236	0.822
Mechanical	0.110	−0.036	0.304	0.206	−0.106	0.755

3.2. Renaming Results of Factor Analysis

From the 40 adjectives, 16 adjectives belonging to 6 groups were screened out by factor analysis. Considering that the adjectives in each group were related, the adjectives in the six groups were renamed. As shown in Table 5, the renamed adjectives included “superior and presentable”, “holistic and balanced”, “novel and individualized”, “trimmed and stable”, “rhythmic and metrical”, and “mechanical and ordered”.

Table 5. Factor renaming list.

Factor	Adjective Groups	Factor Naming	Code
Factor 1	Presentable; secure; superior	Superior and Presentable	S&P
Factor 2	Balanced; symmetrical; holistic	Holistic and Balanced	H&B
Factor 3	Interesting; individualized; novel	Novel and Individualized	N&I
Factor 4	Trimmed; regular; stable	Trimmed and Stable	T&S
Factor 5	Metrical; rhythmic	Rhythmic and Metrical	R&M
Factor 6	Ordered; mechanical	Mechanical and Ordered	M&O

3.3. Evaluation of the Visual Imagery of Wheelsets

This study used linguistic variables (see Table 1) to conduct a questionnaire survey on 10 wheelsets (see Figure 2) based on the six renamed adjectives. A total of 90 valid questionnaires were collected, 50 for males and 40 for females. All subjects used city bicycles regularly in their daily lives. Subsequently, the questionnaire results were transformed into triangular fuzzy numbers. The fuzzy number used in this paper is the average of the fuzzy numbers generated by all the subjects, as shown in Table 6. In addition, to more intuitively observe the ranking of the 10 samples on the six adjectives, this study used triangular fuzzy numbers to draw six graphs, as shown in Figure 6.

Table 6. The sequences and means of the visual evaluations of the wheelsets.

Wheel Species	Superior and Presentable	Holistic and Balanced	Novel and Individualized	Trimmed and Stable	Rhythmic and Metrical	Mechanical and Ordered
S1	(4.0 5.9 7.6)	(3.9 5.9 7.7)	(3.9 5.8 7.5)	(3.4 5.3 7.1)	(4.5 6.4 8.1)	(4.4 6.3 8.0)
S2	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.9 6.8 8.4)	(4.8 6.7 8.3)	(4.7 6.6 8.3)
S3	(3.8 5.6 7.3)	(4.5 6.4 8.1)	(4.3 6.1 7.9)	(2.9 4.6 6.4)	(4.0 5.9 7.6)	(4.2 6.1 7.9)
S4	(4.4 6.4 8.2)	(4.9 6.8 8.5)	(4.6 6.6 8.3)	(3.8 5.7 7.5)	(4.5 6.4 8.2)	(4.2 6.2 8.0)
S5	(4.2 6.1 7.8)	(4.5 6.4 8.0)	(4.2 6.1 7.8)	(4.1 6.0 7.8)	(4.7 6.6 8.2)	(4.4 6.3 8.1)
S6	(4.5 6.4 8.1)	(4.7 6.6 8.3)	(4.3 6.3 8.0)	(4.8 6.7 8.3)	(4.6 6.5 8.2)	(4.2 6.1 7.9)
S7	(3.1 4.8 6.6)	(3.2 5.0 6.8)	(4.0 5.9 7.5)	(4.2 6.1 7.8)	(3.4 5.3 7.1)	(3.4 5.2 7.0)
S8	(3.1 4.9 6.6)	(3.5 5.2 6.9)	(3.9 5.7 7.4)	(4.1 5.9 7.5)	(3.4 5.3 7.0)	(3.7 5.5 7.2)
S9	(4.9 6.7 8.4)	(4.7 6.5 8.1)	(5.1 7.0 8.5)	(5.5 7.2 8.5)	(4.9 6.7 8.3)	(4.7 6.5 8.1)
S10	(4.0 5.7 7.4)	(3.6 5.4 7.1)	(3.4 5.1 7.0)	(4.8 6.6 8.0)	(3.9 5.7 7.5)	(3.6 5.4 7.2)

This study used the total utility value to explain the performance of the 10 samples in each visual imagery. Precisely, by substituting the data in Table 6 into Equation (1), we could calculate the total utility value of each sample on any visual imagery. As shown in Figure 7, taking sample 1 as an example, the process for calculating its absolute utility value on “superior and presentable” was as follows:

Given $\tilde{t}_i = (t_{i1}, t_{i2}, t_{i3}) = (4.0, 5.9, 7.6)$, $X_{max} = 8.4$, $X_{min} = 3.1$. These were substituted into Equation (1) to get:

$$U_T(\tilde{t}_i) = \left[\frac{(7.6 - 3.1)/((8.4 - 3.1) + (7.6 - 5.9)) + 1}{-(8.4 - 4)/((8.4 - 3.1) + (5.9 - 4))} \right] / 2 = 0.4240$$

Similarly, substituting the data in Table 6 into Equation (1) in turn led to the absolute utility value of the 10 wheelsets on each visual image, as shown in Table 7.

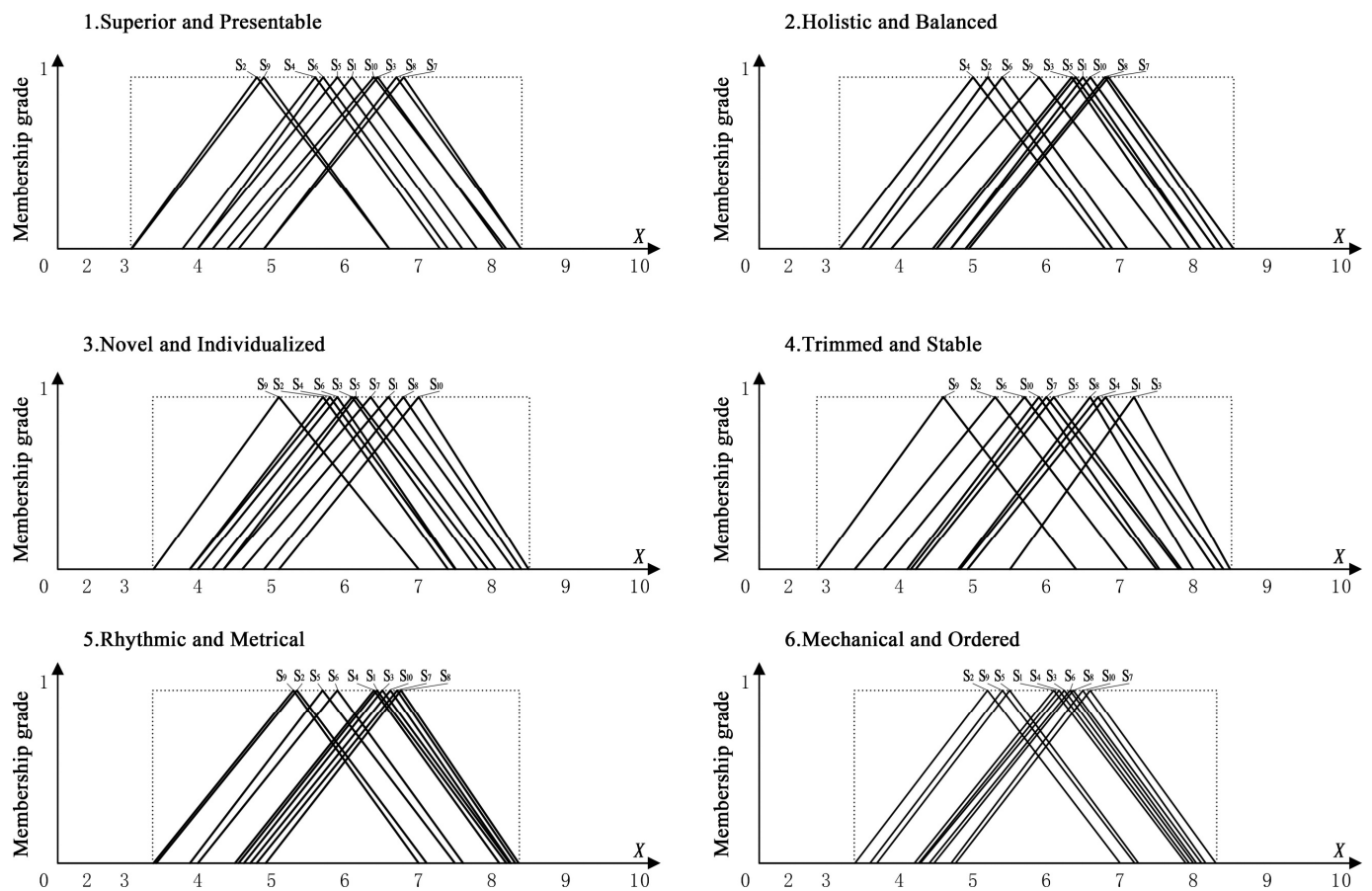


Figure 6. The triangular fuzzy numbers of the 10 types of wheelsets in each visual evaluation.

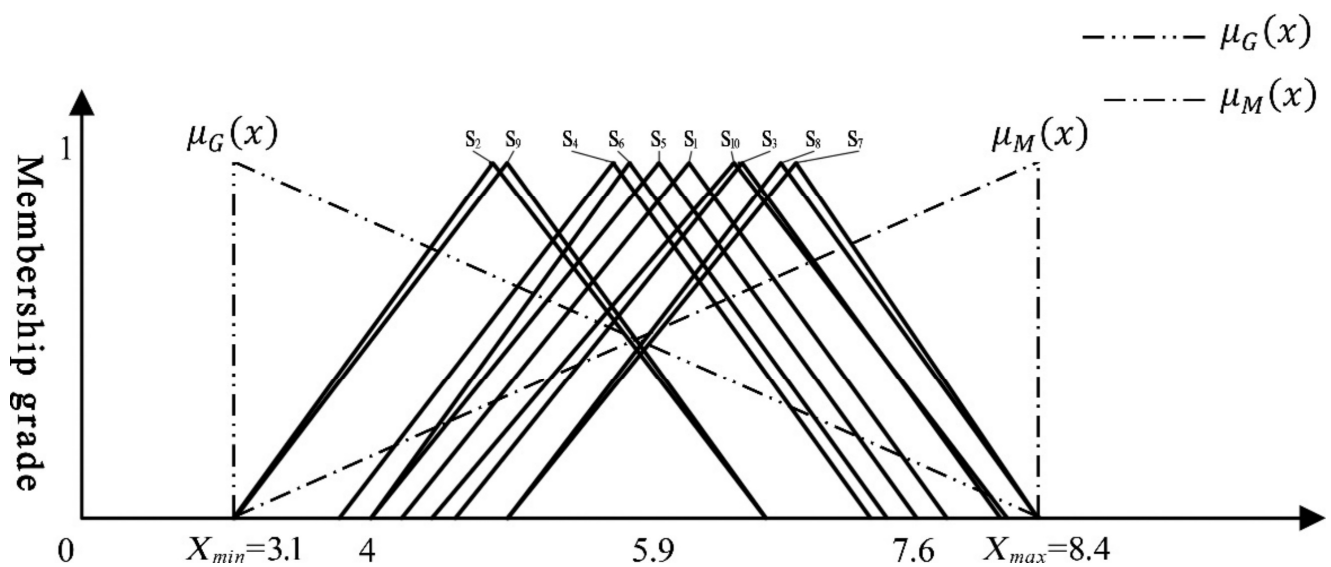


Figure 7. The triangular fuzzy numbers of the 10 species of wheel type in the visual evaluation of “superior and presentable”.

In summary, the ranking and total utility value of the 10 samples on six visual imageries were obtained through a questionnaire survey and triangular fuzzy number calculation. As shown in Figure 6, the 10 samples had significant differences in “trimmed and stable”, “superior and presentable”, and “holistic and balanced.” Conversely, there were fewer differences in “novel and individualized”, “mechanical and ordered”, and “rhythmic and metrical.” Thus, consumers had higher discrimination ability for “trimmed and stable”, “superior and presentable”, and “holistic and balanced.” Besides, as shown in Table 7, sample 2 and sample 9 were particularly outstanding, as sample 2 had the four highest total utility values of all visual imagery, and sample 9 had the two highest total utility values. Thus, samples 2 and 9 can be considered the most competitive wheelsets.

Table 7. The visual evaluation values of the 10 wheelsets.

Wheel Type	Superior and Presentable	Holistic and Balanced	Novel and Individualized	Trimmed and Stable	Rhythmic and Metrical	Mechanical and Ordered
S1	0.4240	0.5018	0.4729	0.4002	0.5766	0.5617
S2	0.6410 *	0.6268 *	0.6160	0.6419 *	0.6196	0.6065 *
S3	0.4761	0.5722	0.5217	0.3529	0.5020	0.5344
S4	0.5852	0.5591	0.5856	0.4975	0.5788	0.5462
S5	0.5440	0.5700	0.5164	0.5377	0.6045	0.5640
S6	0.5863	0.6004	0.5425	0.6163	0.5916	0.5344
S7	0.3679	0.3803	0.4845	0.5489	0.4158	0.4030
S8	0.3732	0.4071	0.4608	0.5221	0.4124	0.4446
S9	0.6321	0.5875	0.6435 *	0.6279	0.6232 *	0.5929
S10	0.5000	0.4335	0.3821	0.6143	0.4776	0.4328

* Highest scores of wheelsets in each evaluation factor.

To observe the performance of the 10 samples on the six visual imageries more intuitively, this study further used the total utility value to draw a radar chart. As shown in Figure 8, according to the distribution of the 10 samples in six dimensions, all samples could be grouped into four groups, namely, group 1: sample 2 and sample 9; group 2: sample 4, sample 5, and sample 6; group 3: sample 7, sample 8, and sample 10; and group 4: sample 2 and sample 9. Specifically, the samples in group 1 scored high on each visual imagery and were characterized by a small number of spokes, but very thick ones. The samples in group 2 also scored high, but not as high as the samples in group 1, which were characterized by a large number of spokes and a uniform distribution. The samples in group 3 performed conspicuously on “superior and presentable” and “holistic and balanced”, but less so on other visual imagery, characterized by thicker rims or thinner ends of the spokes. The samples in group 4 performed poorly on “superior and presentable” and “trimmed and stable”, but the performance in other visual imagery was conspicuous, characterized by many spokes and a staggered distribution.

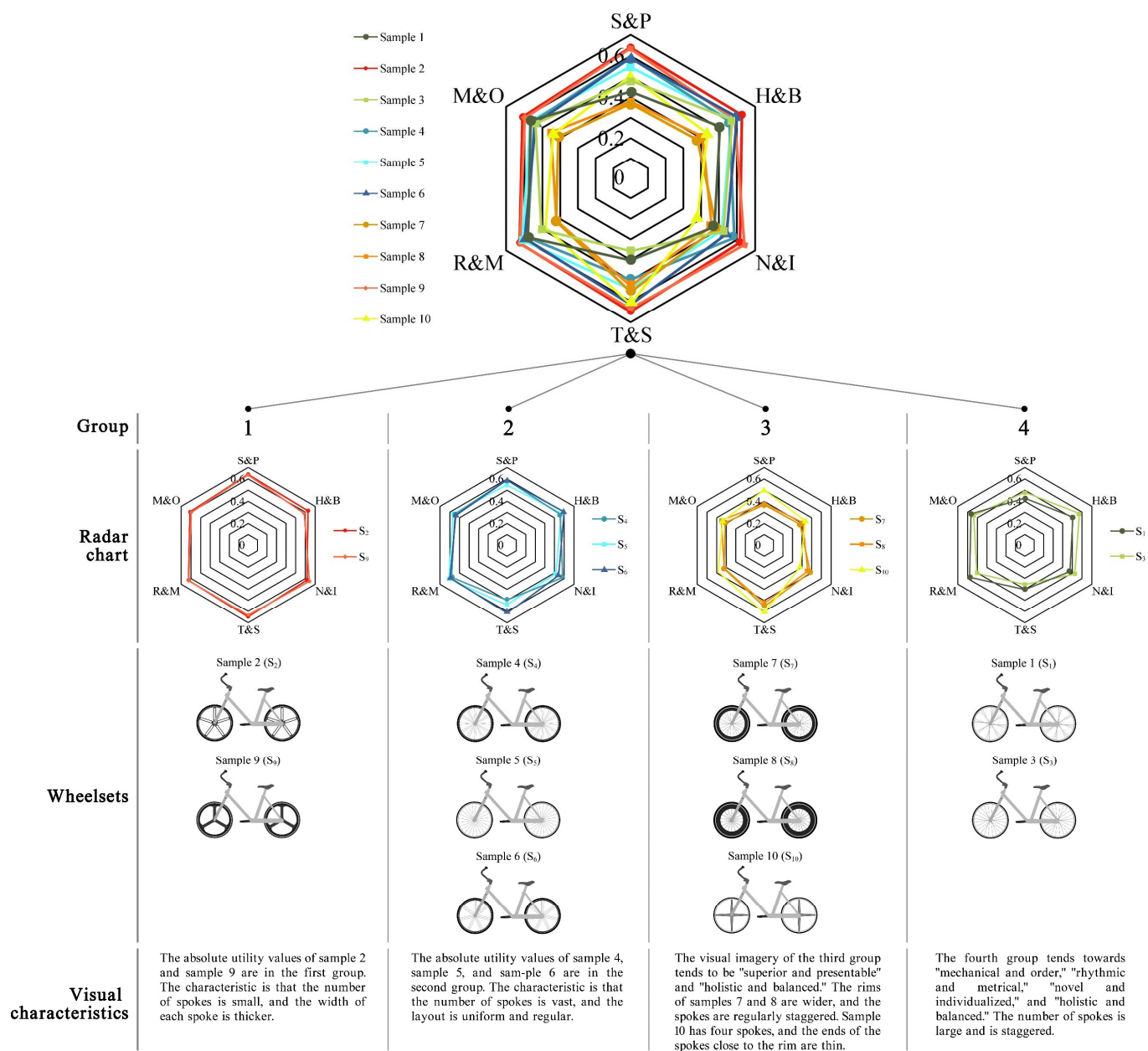


Figure 8. Radar chart and grouping of samples.

4. Conclusions

This study explored the effects of 10 wheelsets on the visual imagery of city bicycles through questionnaires, factor analysis, and triangular fuzzy numbers. To this end, 40 adjectives suitable to describe the visual imagery of the wheelsets were obtained by using an expert questionnaire and six valid adjectives were obtained through a consumer questionnaire and factor analysis. The total utility values of the 10 wheelsets concerning the six adjectives were obtained through a second consumer questionnaire and triangular fuzzy number calculation. Finally, according to the distribution of the total utility value on the radar chart, the wheelsets' effect on the city bicycle's visual imagery could be judged. This study took 10 wheelsets with high market share as research samples and divided them into four groups according to six adjectives. Overall, the 10 samples differed significantly in three visual imageries (i.e., "trimmed and stable", "superior and presentable", "holistic and balanced"), and the other three visual imageries (i.e., "novel and individualized", "mechanical and ordered", "rhythmic and metrical") were less different. Besides, there

were differences between the four groups, but the wheelsets within the four groups were similar and interchangeable. Therefore, in-group replacement is possible when designing city bicycles.

The results of this study can be applied to the design problem of city bicycles. Generally, bicycle designers design based on their subjective judgment and accumulated experience and therefore cannot ensure that the appearance of a bicycle will meet the preferences of urban residents. However, this study could reduce the differences in perception of wheelsets between designers and users. In addition, designers can choose suitable wheelsets according to the overall style of a city (e.g., industrial style, antique style, garden style, European style), thereby promoting the sustainable development of urban bicycles. The present study is subject to some limitations. First, different lifestyles would lead to differences in people's aesthetic standards, so the results of this research are only applicable to the Chinese market environment. Second, because of the competition between brands, the replacement of city bicycles is swift. Therefore, to improve the applicability of the research results, it is necessary to regularly update the wheelsets with a high market share in the same period as new research samples. Lastly, the study's selection of shape elements such as frame and handlebars was based on the principle of simplicity in shape. However, to evaluate city bicycles more comprehensively and accurately, further research could use the same method as this study to explore the effects of other shape elements on the visual imagery of city bicycles. Still, much research is needed to improve the evaluation of visual imagery for city bicycles.

Author Contributions: All the authors contributed to the paper. F.W. collected the data and wrote the manuscript. P.L. acted as a corresponding author, wrote the manuscript, and modified it. Y.-C.L. carried out supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to restrictions on right of privacy.

Conflicts of Interest: The authors declare no conflict of interest.

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