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Determining the Sustainable Development Strategies and Adoption Paths for Public Bike-Sharing Service Systems (PBSSSs) under Various Users' Considerations

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Abstract: Public bike-sharing service systems (PBSSSs) offer an alternative to satisfy users' needs for short-trip connections. The PBSSSs provide options for short-trip connections and diversify the service experience for different users. PBSSSs also play a critical role in enabling urban citizens to reduce the needs to drive their cars and using public transport instead. This study explores the service performance of the public bike-sharing service systems for three styles of users. It proposes the integrated evaluation model of the public bike-sharing service system (PBSSS). The DEMATEL (Decision Making Trial and Evaluation Laboratory) was used to solve the network relation structure between aspects. The ANP (analytic network process) was applied to evaluate the relationship between aspects and component weights. VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) was used to analyze the public bike-sharing system's service performance for different users regarding its strengths and weaknesses. After comparing the strengths and weaknesses of the various users' preferences for the urban public bike service systems, the study proposes a service development strategy for different styles of users based on the NRM (network relation map). The results can aid PBSSS providers and urban managers, strengthen the PBSSSs' competitiveness, and make the PBSSSs become the best urban short-trip connection transportation tool.

Keywords: public bike-sharing service systems (PBSSSs); various user considerations; adoption paths; DEMATEL; ANP; VIKOR

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1. Introduction

The public bike-sharing service system (PBSSS) offers a solution to solve the needs of the last mile. More and more countries have been using public bike-sharing service systems (PBSSSs) in recent years. Their function is to reduce energy consumption and pollution and to meet the demand for modern and actively promoted green pollution-free options, while also providing additional benefits. These benefits include maintaining physical and mental health, social activities, and lower costs. Due to the development of urban public transport, such as MRT services, urban residents can take the MRT to many places and reduce the environmental load caused by their driving car. Bicycle-sharing service systems are sustainable transportation systems and have become increasingly popular. Researchers adopted the four-phase loyalty theory to evaluate the users' green loyalty to bicycle-sharing services using the Taipei City bike-sharing system. The research results show that users' green trust and perceived value positively affect green usage intention and loyalty behaviors. Furthermore, green perceived value indirectly affects green loyalty through green usage intention and trust. Researchers considered that the relative authorities can enhance the bicycle-sharing service system's user perceptions and increase green transportation trust and loyalty [1]. Because of the successful development of public transport, the gap between urban and rural areas is gradually narrowing. However, the existing transportation network cannot penetrate every place, and it cannot meet the needs of the last mile. The public bike-sharing service system (PBSSS) has played a critical role in enabling urban citizens to avoid driving their cars and take public transport instead. Therefore, the development of public bike rental services that meet most citizens' needs has tested service providers' service innovation capabilities. Discount service pricing informs facility planning, and users favor excellent service quality. Service providers of PBSSSs can also cooperate with local governments to enhance urban recreational and tourism convenience and develop local emerging tourist opportunities.

The public bike-sharing service can serve as mass commuting and leisure transportation options. In 2009, the Taipei City government proposed You-Bike, a rental system of shared bikes to satisfy daily commuters and those seeking leisure activities. Due to the difference in users' starting locations and bike return sites, bike rental stations often lack bikes and bike racks. Researchers explored the hotspots of the lack of bikes and bike racks through spatiotemporal analysis. Furthermore, the study also determined the selection of rental stations using retail location theory. The research found that the bike shortage is more severe than the bike rack shortage in You-Bike, and these hotspots are clustered significantly. The researchers considered that spatiotemporal analysis can analyze the rental stations' spatial patterns and determine suitable station locations for a more effective public bike-sharing rental service. The study also provided valuable suggestions to improve the public bike-sharing service system [2]. Bike-sharing services without docking stations have become increasingly popular and gradually changed the bike-sharing market. A study tried to understand the use of dockless bike-sharing services by Singapore's largest bike-sharing operators. The researcher collected 14 million GPS records of dockless bikes in 9 days. The study analyzed bike usage spatiotemporal patterns through spatial autoregressive models. The study also evaluated the effect of the surrounding built environment, bike fleet size, bike infrastructure, public transportation access, and weather impact on dockless bikes. The research results revealed that bike fleet size influences usage, but the effect diminishes as the bike fleet size increases. The study also found that more supportive cycling facilities, easy access to public transportation, high land-use mixtures, and free-ride promotions positively impact the dockless bike system. Comparatively, high temperatures and rainfall have a negative effect. The study also provided a bike-sharing service for transportation practitioners, policymakers, and urban planners, pushing urban sustainability through bike-sharing services [3]. Bike-sharing services have become more prevalent in urban environments, as bike-sharing services provide an environmentally friendly transportation alternative for urban development. However, bike-sharing services still need some improvement and optimization problems, such as bike maintenance, shared facilities, bike rebalancing, and system establishment of asymmetrical patterns. The study used data mining to analyze the unbalanced bike problem through actual datasets. The researchers also used different techniques to build the station's evaluation model according to the station's characteristics and users' perspectives. These evaluation models can propose accurate and effective predictions for bike-sharing service systems [4].

Smart mobility integrates the modern information communication technology (ICT) infrastructure and provides people with a high-quality life. Smart mobility includes many intelligent solutions such as bike-sharing, car-sharing, vehicle navigation systems, e-ticket, e-parking, and demand-responsive transport through intelligent information systems. Therefore, intelligent mobility service systems can improve sustainable urban development. A 2017 survey of smart mobility compared Croatia and Italy users' opinions on intelligent mobility solutions. The survey explored the users' current use, familiarity, and future expectations for intelligent mobility solutions. The research found that Italian users have greater acceptance of innovative mobility solutions, and Croatian users still have some limitations with adopting new technologies. Therefore, innovative mobility solutions should use public debate and promotion to get more people to understand the benefits [5]. Dockless bike sharing has become more and more popular in the world. However, disorderly parking can increase users' convenience but negatively impact urban development.

Therefore, the researchers provided a hybrid approach to evaluate the relationship between the socioenvironmental and individual factors and orderly parking behavior on the basis of 1722 geographic locations and diverse professional participants in China. The study considered that descriptive social norms can be critical in dockless bike-sharing regulations and public policy. The researchers pointed out that these descriptive social norms are crucial to shaping users' attitudes. Furthermore, the tightness and looseness of culture has a moderated effect on the descriptive social norms. At the individual level, subjective norms' antecedents (ascription of responsibility, moral awareness, and awareness of consequences) were analyzed through the norm activation model. Furthermore, the researchers also proposed some usable suggestions and insights for urban bike-sharing services [6].

Commuter cyclists work in the metropolitan area and adopt public transportation tools for their daily work commute. Thus, public bike-sharing service systems can provide alternatives to solve the last mile problem of public transportation tools for commuter cyclists. Because of different purposes, short-trip connection cyclists use bike sharing to save walking time and conveniently move to nearby destinations quickly. Regarding tourism and leisure, travel and leisure cyclists can visit and stay in tourist destinations, reduce walking time, and increase movement convenience. Public bike-sharing service systems can change the tourists' travel experience and expand their travel range. This study analyzes the facilities and services performance of the public bike-sharing service systems (PBSSSs) for three styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) in Taiwan. This study can aid the service providers of PBSSSs in understanding the competitive advantages and disadvantages of PBSSSs for three styles of users and further formulate diverse development strategies based on their competitive advantages. The study also proposes the development strategies and adoption plans for three styles of users, and it may increase the usage rate of public bikes for different users and establish the primary and ancillary facilities and services. In this way, the public bike-sharing service systems (PBSSSs) can satisfy the service needs of different styles of users and become energy-saving and sustainable short-trip connection transportation tools.

This study establishes a PBSSS evaluation system according to four aspects (main service, MS; main facilities, MF; ancillary services, AS; affiliated equipment, AE). The study adopts the DEMATEL (Decision Making Trial and Evaluation Laboratory) to construct a network relation map (NRM) and determine the aspects' weight using the ANP (analytic network process). Furthermore, the study also adopts the VIKOR (Vlsekriterijumska Optimizacija I Kompromisno Resenje) approach to evaluate the competitive factors of public bike service systems for different styles of users [7–14]. Besides, this study explores the driving forces for public bike-sharing service systems (PBSSSs) according to four evaluation aspects. The researchers break down the development restrictions and challenges of PBSSSs for different styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists). The research results can aid PBSSS providers, and relevant authorities can determine future development directions and increase the public's willingness to use bike-sharing service systems (PBSSSs).

The remainder of this study is organized as follows: Section 2 discusses the critical driving forces of the public bike-sharing service system (PBSSS). The proposed public bike-sharing service system (PBSSS) model is presented using the hybrid MCDM approach. This study adopts the integrated approach to determine the driving forces for public bike-sharing service systems (PBSSSs) in Section 3. In Section 4, an empirical study compares the competitive advantage and disadvantages of public bike-sharing service systems (PBSSSs) for different styles of users. The study also explores the driving forces of PBSSSs and determines development strategies and adoption paths. Lastly, the conclusions and recommendations propose valuable suggestions to aid the PBSSS providers in assessing their development directions and improvement strategies in Section 5.

2. Exploring Users' Service Needs for the PBSSSs

This study establishes four evaluation aspects (main service, main facilities, ancillary services, and affiliated equipment) and 16 criteria to evaluate public bike-sharing service systems (PBSSSs). Concerning the aspect of MS (main service), four criteria are identified: bike rental services (MS1), abnormal condition handling (MS2), ticket-integrated service (MS3), and an integrated consulting service (MS4). In the MF (main facilities) aspect, the four criteria identified are bike parking equipment (MF1), authentication service facilities (MF2), antitheft and security devices (MF3), and self-service facilities (MF4). In the AS (ancillary services) aspect, the four criteria identified are road rescue service (AS1), bike cycling service (AS2), mobile application service (AS3), and dispatch and maintenance service (AS4). With the AE (affiliated equipment) aspect, the four criteria identified are bike parking equipment (AE1), lane guidance facilities (AE2), bike cycling lanes (AE3), and bike marking system (AE4), as illustrated in Table 1.

2.1. Main Service (MS)

The consumed style of goods and services has shifted in the sharing economy era. Customers' preferences have prompted the change from exclusive ownership to the economic benefits of collective usage. Some studies have explored the customers' motives for sharing goods and services and the service styles of sharing. However, they explored the customers' perceptions, motives, and experiences for sharing services. The researchers identified three main characteristics of sharing services: (1) financial benefits as the primary motivator of participation, (2) emerging weak social values, and (3) strangers' networks as crucial preconditions. A study pointed out that the development of sharing services needs to balance the preservation of anonymity and community development in the intangible sharing service [15]. The sharing economy has become increasingly popular in recent years; thus, many enterprises have proposed the sharing service to adapt to green economic development. Mo-bike is a large global company of shared bike services and plays a critical role in Beijing. Researchers have explored the relationship between the shared bike environment and shared bike usage through qualitative and quantitative analysis using obtained data, actual situations, and online reports. Researchers have established the society contribution evaluation model of carbon dioxide reduction emission through these variables (usage rate, registered rate, and riding distance) and evaluated each variable's influence effect using Minitab and the response surface method. The research has found that the influence factor of CO_2 reduction emission follows the order of riding distance > registered user proportion > shared bike usage rate. A study found that the shared bike plays a positive and comprehensive role in a sustainable economy, and the research results also provided some valuable suggestions for shared bike development [16].

Shared bikes are a new style of commuting short distances to solve urban traffic congestion. Many cities have adopted shared bikes to solve traffic congestion problems; however, various factors can cause a region's imbalance of bikes and bike racks. Therefore, accurate prediction of the supply and demand of bikes and bike racks has already become a critical challenge for shared bicycle service providers. A study proposed a novel hybrid approach for bike-sharing traffic analysis zone division and interest grading area. The researchers adopted visual analysis to explore the distribution characteristics of bike-sharing trips using Shanghai's spatiotemporal characteristic data and compared the prediction effect of different evaluation models. The multiblock hybrid (MBH) was determined as the highest accuracy evaluation model based on the multisource datasets. Furthermore, the study used prediction results for practical application and provided valuable suggestions for rebalancing and scheduling shared bike service systems [17]. More and more cities have adopted bike-sharing services to enhance the efficiency of short trips. Some studies have used global regression models to evaluate the effect of bike-sharing usage and environmental factors. Yet, there is limited research exploring the relationship between bike-sharing usage and the built environment in terms of the spatial variation. Hence, researchers have integrated the geographically weighted regression (GWR) approach and the global regression approach to analyze the local and international impact of bike sharing and built environments on non-workdays and workdays. A study examined the 1 year data of bike-sharing trips, points of interest (POI), metro ridership data, cellular signaling, and cycling infrastructure data in Suzhou, China. The research results showed that bike stations near educational and financial places, shopping malls, restaurants, and public transit have high trip numbers on non-workdays and workdays. Bike stations near workplaces have many bike trips on workdays but not non-workdays. The researchers found a relationship between bike-sharing usage and the built environment in different regions of Suzhou. Furthermore, the researchers compared the GWR (geographically weighted regression) and global regression model and obtained a partially consistent result. The healthy goodness of GWR was better than that of the worldwide regression model. The study provided strategic guidance to strengthen the service quality of bike-sharing systems and determine land use and bike station selection to improve bike-sharing service usage [18] as illustrated in Table 1.

2.2. Main Facilities (MF)

A study developed the public sector marketing model to evaluate the environmental and social values of the available strategies. The researchers adopted the path modeling of PLS (partial least squares) and analyzed 603 survey questionnaires based on the public bike-sharing service system. The study found that users simultaneously perceive outcomes of environmental and social value. Users also perceive a higher social value than the green public service's perceived environmental and ecological value. Therefore, public bike-sharing service users still evaluate self-centered values before environmental values. However, this approach can help citizens join in the actual usage of green public services and strengthen their intentions of green consumption [19]. The sharing economy has become more and more popular worldwide. However, repetitive and excessive investment often causes superfluous and idle resources. Therefore, a study explored the system redundancy problem of sharing service systems. The study established an evaluation model to analyze the redundancy problem of the bike-sharing industry through two big bike-sharing companies (OfO and Mobike). The research results revealed that the critical factors of redundancy include externality, operation cost, multi-homing, market structure, and competitive strategy. This study can aid relative authorities and service providers of bike sharing in understanding the reasons for redundancy and more effectively managing and regulating the bike-sharing service [20].

High automobile dependence often leads to traffic congestion and challenges sustainable urban development. Thus, bike sharing has become a new environmentally friendly transport style that can improve urban traffic congestion. A study explored the perspectives of bike-sharing users in Shanghai, China. The researchers used semi-structured interviews to analyze the driving (impeding and motivating) factors of bike-sharing development in Shanghai. The research results indicated that cost saving, time saving, and convenience were the primary usage motivations. Poorly maintained bikes, abuse by users, unsuitable business models, economic issues, and operational issues were the major usage obstacles. Furthermore, the study also considered that the service style of public and private partnership was the best operating model for bike-sharing services. Again, the government should provide bike-friendly infrastructure, financial incentives, regular operational management, and supportive policies for supporting the service providers of bike sharing [21]. This problem has already become the biggest challenge in the development of bike-sharing services. Bike sharing has already become an environmentally friendly transportation style and has reduced carbon-emission. Therefore, the temporally and spatially asymmetric supply and demand patterns often lead to an imbalance in bike sharing in some regions. Researchers have tried to solve the imbalanced problem of bike-sharing distribution from the perspective of an entire city through authentic cycling trip data. A study proposed an integrated programming model to solve the imbalanced bike distribution by considering multiple vehicles rebalanced with time-varying rental costs. Besides, the researchers also offered a programming model of chance constraints to optimize the bike-sharing service network. The study provided a modified approach to improve the imbalanced distribution of bike sharing and offered a high-quality bike-sharing service [22] as illustrated in Table 1.

2.3. Ancillary Service (AS)

Developing countries face air pollution and transportation congestion; hence, many developing countries are seeking to reduce car numbers by expanding bike-sharing services. Therefore, a study explored the choice factors of bike-sharing services using survey data from Taiyuan City. The researchers adopted the nested logit and mixed nested logit models to analyze both revealed preference and stated preference data for the bike-sharing service. The research results revealed that air pollution has a significant negative influence on bike-sharing service choices. Therefore, improving air quality may be effective by reducing car usage. However, bike-sharing services still need to strengthen the promotion of the service itself, such as travel cost saving and access time saving [23]. Transportation tools affect the ecological environment over time. Therefore, researchers have explored the relationship among the subjective norms of environment, one's perceived value environment, and environmental trust for bike-sharing service use intentions. Researchers have analyzed both nonusers' and users' motivations for green transportation systems. A study adopted SEM (structural equation modeling) to evaluate the use intentions of bike-sharing service and found that environmental subjective norms have a significantly higher effect than the perceived value of the environment for users and nonusers. Therefore, others' ecological influences are more important than personal perceptions of the domain. Accordingly, the trustworthiness of the environment plays an essential role for nonusers, while the authorities' environmental policies enhance people's sense of ecological responsibility and increase the usage intention of green transportation systems [24].

An SFSB (station-free shared bike) can provide new styles of free travel and let users park their shared bikes everywhere. Therefore, users can park their shared bikes near work and travel destinations. SFSB data can aid decision makers in understanding the ideal distribution of land use. A study provided the topic evaluation model of a text mining algorithm to analyze the travel behavior of SFSB users and discovered mainly urban functional regions through two-stage SFSB data. The distribution of mobility patterns represents the function, while the distribution of a function represents the region. A study integrated point-of-interest data to annotate clustered regions, discover the regions' main functions, and analyze the results through satellite map data based on 2 weeks of Beijing SFSB data. The research results could explain users' travel purposes and improve the region's operational planning of land use [25]. Another study explored the impact of shared bikes and ride-hailing for public transportation using the panel data of China's 273 cities. The researchers also analyzed the relationship between ride-hailing legitimation and public transport services. The research found that ride-hailing can increase rail transit ridership and reduce bus ridership. Besides, ride-hailing legitimation can positively influence the impact of rail transit and negatively affect the impact of bus transit. The study also proposed valuable suggestions for ride-hailing platforms to promote ride-hailing legitimation [26] as illustrated in Table 1.

2.4. Affiliated Equipment (AE)

Bike-sharing services have become increasingly critical in China, attracting many users and tourists. A study explored the traveling experience of tourists using bike sharing and analyzed the factors influencing perceived benefit. The researchers also examined the relationship between perceived experiences (entertainment, escape, educational experience, and aesthetics) and perceived satisfaction using 296 tourist samples in Chengdu, China. The research results revealed that the four experience dimensions significantly affect perceived benefit. Therefore, aesthetic experience and entertainment affect tourists' perceived satisfaction, but the escape experience and educational experience do not influence tourist satisfaction. The study also proposed some valuable suggestions for further research [27].

With increasing bike-sharing service programs, there is much need for a cross-sectional analysis of the current conditions. Some studies have discussed each station's bike distribution, whereas others have analyzed bike-sharing service trip behavior. One study adopted a quasi-experimental technique and explored data on bike-sharing services from 2010 to 2015 in Minneapolis-St. Paul, Minnesota. The research results indicated that the distance to stations significantly and negatively influences the accessibility frequency, while bike accessibility positively influences the customers' usage willingness. Therefore, the study also found that a higher population density and a higher percentage of retail land use increase the willingness to use bike-sharing services [28].

A survey of bike sharing was used to explore the bike infrastructure and bike-sharing service in urban transportation. The researchers integrated descriptive analysis, the binary choice model, and the multivariate ordinal model to evaluate the behavioral differences that cyclists and newcomers experienced before and after the dedicated infrastructure expansion, as well as evaluated use behaviors and frequency for non-work and work bike trips. The study also explored how bike sharing promotes bike usage. The research results indicated that expansion of the bike infrastructure attracts low-income individuals and women to use bicycles. The cycling frequency and travel time were evaluated through the purposes of the non-work and work. Bikes become an alternative to public transit and cars in congested urban areas. The study also found that the bike-sharing service is critical in traveling and working [29]. Due to sustainable urban development, sustainable bike-sharing service systems have become critical for urban mobility transportation. Users' mobility information can provide valuable insight into urban life, such as urban travel's temporal and spatial dynamics, bike interaction relationships with other transport tools, and social and territorial distribution inequalities of geographical space. A study explored the philosophical management issues of bike-sharing services and analyzed the optimization problems of bike-sharing services. Hence, the researchers integrated IoT technologies and machine learning, proposing a hybrid approach to evaluate user satisfaction. Moreover, the study presented an automatic management system to evaluate the different time use numbers of sharing bikes and tested the proposed model's effectiveness for bike-sharing services in London [30] as illustrated in Table 1.

Table 1. Description of value drivers forces for public bike-sharing service systems (PBSSSs).

Aspects/Criteria	**Evaluation Criteria Description**
Main services (MS)	
Bike rental services (MS1)	Bike-sharing service operators offer comprehensive and adequate sharing bike rental services to satisfy users' short-trip service needs.
Abnormal condition handling (MS2)	Bike-sharing service operators can aid users in handling abnormal rental and use conditions for sharing bike services.
Ticket-integrated service(MS3)	Bike-sharing operators can offer rental packages or ticket-integrated services to satisfy users' needs.
Integrated consulting service (MS4)	Bike-sharing service operators can establish an integrated consulting service center to offer various rentals and use consulting services.
Main facilities (MF)	
Bike parking equipment (MF1)	Complete and adequate bike parking equipment can satisfy users' need for temporary parking.
Authentication service facilities (MF2)	Automated authentication service facilities can provide convenience for users to finish the personal identification process independently.
Antitheft and security devices (MF3)	Antitheft and security devices can improve users' convenience and safety for sharing bike services.
Self-service facilities (MF4)	Self-service facilities can increase users' bike rental and independent return convenience.

Table 1. *Cont.*

Aspects/Criteria	Evaluation Criteria Description
Ancillary services (AS)	
Road rescue service (AS1)	Bike-sharing service operators can provide bike transportation services and recycling of faulty bikes service.
Bike cycling service (AS2)	Bike-sharing service operators can launch rides bikes integrated with railway/MRT service.
Mobile application service (AS3)	Bike-sharing operators can develop a mobile application platform to offer bike rental and information posting services.
Dispatch and maintenance service (AS4)	Bike-sharing service operators can provide simple repair and bike dispatch arranging services at service sites.
Affiliated equipment (AE)	
Bike parking equipment (AE1)	Bike-sharing service operators can establish bike parking racks and locks to satisfy the users' parking needs.
Lane guidance facilities (AE2)	Lane guidance facilities can aid cyclists in identifying the cycling lane and reducing traffic accidents.
Bike cycling lanes (AE3)	Bike lanes can reduce vehicle flow conflict with other transport tools and improve cyclists' safety.
Bike marking system (AE4)	A complete bike marking system can assist cyclists in evaluating traffic conditions and reducing traffic accidents.

3. Service Performance Evaluation and Improvement Strategies for PBSSSs

3.1. DEMATEL

Some recent studies adopted the DEMATEL approach to solve complex decision problems, such as the evaluation model of user interface [31], an evaluation system of failure sorting [32], an evaluation system of e-learning programs [33], an evaluation system of airline safety management [34], value-created methods of science (technology) parks [35], the critical factors of the organization's SaaS adoption [36], and the development strategies of matrix organization [37], in addition to the improvement strategies of cruise product sales based on the MCDM approach [38], design delay evaluation using the ISA-IRM approach [39], evaluation and selection of a telecommunication outsourcing provider using the hybrid MCDM approach [40], risk factor evaluation of China's cloud computing auditing based on the hybrid MADM approach [41], the assessment of supplier selection using CSR (corporate social responsibility) practices [42], the service position of package tour services using the hybrid MCDM approach [43], sustainable development strategies of industrial tourism using the IOA-NRM technique [44], determining the digital transformation strategies of Med-Tech enterprises using the AIA-NRM technique [45], an evaluation model of lockdown relaxation protocols for the COVID-19 pandemic using the fuzzy DEMATEL approach [46], exploring the technology application of Industry 4.0 in SMEs based on the hybrid MCDM technique [47], evaluation of the urban sustainable development strategies and the common suited paths through various stakeholders' perspectives [48], the driving forces of the music festival tourism based on the modified SIA-NRM approach [49], and the regional development strategies and local revitalization based on the various urban stakeholders' perspectives using the ISA-NRM approach [50]. The DEMATEL approach includes five steps: (1) calculating the original average matrix, (2) calculating the direct influence matrix, (3) calculating the indirect influence matrix, (4) evaluating the full influence matrix, and (5) determining the network relation map (NRM).

(1) Calculating the original average matrix

Respondents were asked to indicate the influence of each aspect on others through scales ranging from 0 to 4, where "0" means no influence on others, and "4" means "extremely strong influence on others"; "1", "2", and "3" denote "low influence", "medium influence", and "high influence" on others, respectively. The influence score of "main service (MS)" on "main facilities (MF)" was 2.838, indicating "high influence." On the other hand, the influence score of "affiliated equipment (AE)" on "main service (MS)" was 2.577, indicating "low influence," as illustrated in Table 2.

Table 2. The original influence matrix.

Aspects	MS	MF	AS	AE	Total
Main services (MS)	0.000	2.838	2.641	2.725	8.204
Main facilities (MF)	2.880	0.000	2.641	2.648	8.169
Ancillary services (AS)	2.746	2.563	0.000	2.585	7.894
Affiliated equipment (AE)	2.577	2.585	2.577	0.000	7.739
Total	8.204	7.986	7.859	7.958	-

(2) Calculating the direct influence matrix

This study obtained the "original influence matrix A" through Equations (1) and (2) and obtained the "direct influence matrix (X)", as illustrated in Table 3. The direct influence matrix was determined by dividing the max sum rows and columns in the original average matrix, as shown in Table 3.

$$X = sA, \quad s > 0, \tag{1}$$

where

$$s = \min_{i,j}[1/\max_{1\leq i\leq n}\sum_{j=1}^{n} a_{ij}, 1/\max_{1\leq j\leq n}\sum_{i=1}^{n} a_{ij},] \quad i,j = 1,2,\ldots,n \text{ and } \lim_{m\to\infty} X^m = [0]_{n\times n'}, \tag{2}$$

where $X = [x_{ij}]_{n\times n'}$ when $0 < \sum_{j=1}^{n} x_{ij} \leq 1$ or $0 < \sum_{i=1}^{n} x_{ij} \leq 1$, and $\sum_{j=1}^{n} x_{ij}$ or $\sum_{i=1}^{n} x_{ij}$ equal 1, but not all cases. Thus, we can guarantee $\lim_{m\to\infty} X^m = [0]_{n\times n}$.

Table 3. The direct influence matrix.

Aspects	MS	MF	AS	AE	Total
Main services (MS)	0.000	0.346	0.322	0.332	1.000
Main facilities (MF)	0.351	0.000	0.322	0.323	0.996
Ancillary services (AS)	0.335	0.312	0.000	0.315	0.962
Affiliated equipment (AE)	0.314	0.315	0.314	0.000	0.943
Total	1.000	0.973	0.958	0.970	-

The diagonal items of X are all 0, and the row sum is 1 at most, as illustrated in Table 3. Furthermore, the study obtained the row and column sums by adding the rows and columns in Table 4. In Table 4, the row and column sum for "main service (MS)" was 2.000, highlighting a critical influence. On the other hand, the sum of the rows and columns for "affiliated equipment (AE)" was 1.913, representing the least influential aspect.

Table 4. The comparison table of the direct influence matrix.

Aspects	Sum of Row	Sum of Column	Sum of Row and Column	Importance of Influence
Main services (MS)	1.000	1.000	2.000	1
Main facilities (MF)	0.996	0.973	1.969	2
Ancillary services (AS)	0.962	0.958	1.920	3
Affiliated equipment (AE)	0.943	0.970	1.913	4

(3) Calculating the indirect influence matrix

The indirect influence matrix was obtained through Equation (3), as shown in Table 5.

$$IX = \sum_{i=2}^{\infty} X^i = X^2 (I - X)^{-1}. \quad (3)$$

Table 5. The indirect influence matrix (*IX*).

Aspects	MS	MF	AS	AE	Total
Main services (MS)	10.116	9.826	9.716	9.806	39.464
Main facilities (MF)	9.997	9.887	9.689	9.783	39.357
Ancillary services (AS)	9.741	9.555	9.512	9.528	38.336
Affiliated equipment (AE)	9.600	9.407	9.292	9.458	37.756
Total	39.454	38.674	38.210	38.575	-

(4) Evaluating the full influence matrix

The T (full influence matrix) was obtained through Equations (4) or (5). The T (full influence matrix) consisted of multiple elements, as indicated in Equation (6) and illustrated in Table 6. In Equations (7) and (8), d_i is the sum vector of the row value, and r_i is the sum vector of the column value; then, let $i = j$, and $\{d_i + r_i\}$ is the sum vector of the row value plus sum vector of the column value, representing the full influence of the matrix T. As $\{d_i + r_i\}$ (sum of the row value plus sum of the column value) increases, the relationship of the aspect/criterion becomes stronger. $\{d_i - r_i\}$ (sum of the row value minus the sum of the column value) indicates the net influence relationship status. If $d_i - r_i > 0$, it means that the degree of influence on other aspects is more substantial than the degree of being influenced; otherwise, $d_i - r_i < 0$.

$$T = X + IX = \sum_{i=1}^{\infty} X^i. \quad (4)$$

$$T = \sum_{i=1}^{\infty} X^i = X(I - X)^{-1}. \quad (5)$$

$$T = [t_{ij}], \quad i, j \in \{1, 2, \ldots, n\}. \quad (6)$$

$$d = d_{n\times 1} = [\sum_{j=1}^{n} t_{ij}]_{n\times 1} = (d_1, \ldots, d_{i,\ldots,} d_n). \quad (7)$$

$$r = r_{n\times 1} = [\sum_{i=1}^{n} t_{ij}]'_{1\times n} = (r_1, \ldots, r_{i,\ldots,} r_n). \quad (8)$$

Table 6. The full influence matrix (T).

Aspects	MS	MF	AS	AE	Total
Main services (MS)	10.116	10.172	10.038	10.138	40.464
Main facilities (MF)	10.348	9.887	10.011	10.106	40.353
Ancillary services (AS)	10.076	9.867	9.512	9.843	39.298
Affiliated equipment (AE)	9.914	9.722	9.606	9.458	38.699
Total	40.454	39.647	39.168	39.545	-

The MS (main services) aspect was the aspect with the most significant influence ($d_1 + r_1$ = 80.918), whereas the AE (affiliated equipment) aspect was that with the least significant influence ($d_4 + r_4$ = 78.244), as illustrated in Table 7. The aspects of MF (main facilities) ($d_2 - r_2$ = 0.706), AS (ancillary services) ($d_3 - r_3$ = 0.130), and MS (main services)

($d_1 - r_1$ = 0.010) had a positive influence. In contrast, the aspect of AE (affiliated equipment) ($d_4 - r_4$ = −0.845) had a negative influence, as illustrated in Table 7.

Table 7. The degree of full influence.

Aspects	$\{d_i\}$	$\{r_i\}$	$\{d_i + r_i\}$	$\{d_i - r_i\}$
Main services (MS)	40.464	40.454	80.918	0.010
Main facilities (MF)	40.353	39.647	80.000	0.706
Ancillary services (AS)	39.298	39.168	78.465	0.130
Affiliated equipment (AE)	38.699	39.545	78.244	−0.845

(5) Determining the network relation map (NRM)

According to the aspects/criteria defined in Table 1, some experts were invited to discuss the relationships and influence levels of criteria under the same aspects, and then score them using the DEMATEL approach. Aspects/criteria were divided into different types so that the experts could answer the questionnaire according to area/field. The net full influence matrix, T_{net}, was determined through Equation (9).

$$T_{net} = [t_{ij} - t_{ji}], \quad i, j \in \{1, 2, \ldots, n\}. \tag{9}$$

The diagonal items of the matrix were all 0. In other words, the matrix contained a strictly upper triangular matrix and a strictly lower triangular matrix. Moreover, although the values of the upper triangular matrix and the lower triangular matrix were the same, their symbols were opposites. This property helped in that we only needed to choose one of the strictly triangular matrices. The MS (main service) aspect had the greatest full influence, whereas the AS (ancillary services) aspect has the smallest full influence. The MF (main facilities) aspect was the primary aspect with net influence. In contrast, the AE (affiliated equipment) aspect had a significant net influence. Decision makers can improve the AE (affiliated equipment) aspect through the aspects of MF (main facilities), AS (ancillary services), and MS (main service), as well as enhance the MS aspect through the MF and AS aspects. Additionally, the AS aspect can be strengthened through the MF aspect, as illustrated in Table 8 and Figure 1.

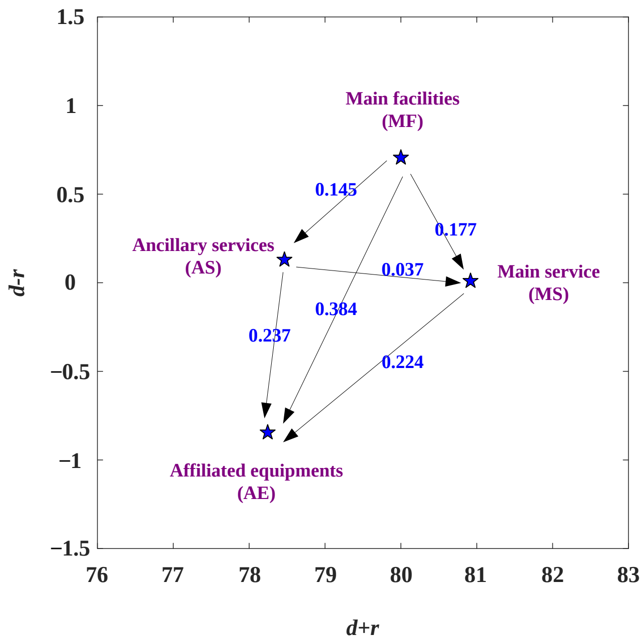

Figure 1. The development strategy map for public bike-sharing service systems.

Table 8. The net influence matrix of bike-sharing service systems.

Aspects	MS	MF	AS	AE
Main services (MS)	-			
Main facilities (MF)	0.177	-		
Ancillary services (AS)	0.037	−0.145	-	
Affiliated equipment (AE)	−0.224	−0.384	−0.237	-

3.2. PCA (Principal Component Analysis)

The AHP/ANP approach can evaluate the aspects/criteria that are mutually independent/dependent. However, the inventor of the ANP approach, Professor Saaty, did not explicitly define it [51]. The PCA approach can be applied to satisfy the hypothesis of independence/dependence of criteria according to aspects for the AHP/ANP approach and simplify the criteria through the PCA approach. This study adopted the PCA approach to analyze the original data of the importance degree. The study conducted PCA for the original data of importance degree (minimum value = 0; maximum value = 10) collected via the questionnaire survey.

3.3. ANP (Analytic Network Process)

The AHP (analytic hierarchy process) approach allows evaluating multicriteria decision problems, and it establishes an evaluation system on the basis of the vertical independence hierarchy. However, real-world decision problems are often complicated and interrelated; hence, the idealized AHP approach cannot solve the real-world decision problem. Thus, researchers have modified the independence assumption of the AHP approach and proposed an ANP approach for solving the real-world decision problems as a function of the dependence and interrelationships in a hierarchical relationship structure [51–53]. The ANP approach can analyze the natural world's interrelationships and interdependence decision problems [54–56]. Decision problems are closer to actual adoption. The following steps are taken to evaluate decision problems using the ANP approach: (1) clarify the decision problem and construct the network relationship structure; (2) design the questionnaire and survey the influence effect; (3) use pairwise comparisons to determine the relative importance of the criteria/aspects; (4) calculate the transposed and normalized full influence matrix, (5) calculate the weighted super-matrix, and (6) determine the component weights. There are several steps to determine the factor weights, as described below.

(1) Clarify the decision problem and construct the network relationship structure

The complex decision problem can be simplified by determining the relation structure of the evaluation system. Decision makers should consider all possible alternatives and establish the structure relationship of the evaluation system through expert review and brainstorming. However, an evaluation system often includes many aspects/criteria, and these aspects/criteria influence each other. Thus, decision makers must determine the network relation structure (including dependence and feedback) through the NRM (network relation map) approach. This study adopted the DEMATEL approach to determine the network relation structure and utilized the ANP approach to establish the relation weights of aspects/components.

(2) Design the questionnaire and survey the influence effect

According to the evaluation framework, experts can judge the relative importance of aspects/criteria. Hence, this study used a questionnaire to achieve this goal.

(3) Determine the relative importance of the aspect/criteria using a pairwise comparison

The ANP obtains the weights as follows: (1) evaluate the relative importance of aspects/components through pairwise comparisons and obtain an $n \times n$ pairwise comparison matrix, where n is the number of components; (2) calculate the logical judgment consistency using both the consistency index (*C.I.*) and the consistency ratio (*C.R.*). In general, *C.I.* and *C.R.* should be less than 0.1.

(4) Calculate the transposed and normalized full influence matrix

The full influence matrix (T) can be derived from Equations (4) or (5). Moreover, d_i can be calculated using Equation (10) as a function of the column sum of the full influence matrix (T). Then, the normalized full influence matrix (T_N) can be obtained using Equation (11), and the transposed and normalized full influence matrix (T_N^t) can be derived from Equation (12). T_N^t is the transposed and normalized full influence matrix, as illustrated in Table 9.

$$T = \begin{bmatrix} t_{11} & \cdots & t_{1j} & \cdots & t_{1n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{i1} & \cdots & t_{ij} & \cdots & t_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{n1} & \cdots & t_{nj} & \cdots & t_{nn} \end{bmatrix} \begin{matrix} \rightarrow d_1 = \sum_{j=1}^{n} t_{1j} \\ \rightarrow d_i = \sum_{j=1}^{n} t_{ij} \\ \rightarrow d_n = \sum_{j=1}^{n} t_{nj} \end{matrix}, \quad (10)$$

where $d_i = \sum_{j=1}^{n} t_{ij}, i = 1, 2, \ldots, n$.

$$T_N = \begin{bmatrix} t_{11}/d_1 & \cdots & t_{1j}/d_1 & \cdots & t_{1n}/d_1 \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{i1}/d_i & \cdots & t_{ij}/d_i & \cdots & t_{in}/d_i \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{n1}/d_n & \cdots & t_{nj}/d_n & \cdots & t_{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_{11}^N & \cdots & t_{1j}^N & \cdots & t_{1n}^N \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{i1}^N & \cdots & t_{ij}^N & \cdots & t_{in}^N \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{n1}^N & \cdots & t_{nj}^N & \cdots & t_{nn}^N \end{bmatrix}. \quad (11)$$

$$T_N^t = (T_N)' = \begin{bmatrix} t_{11}^N & \cdots & t_{i1}^N & \cdots & t_{n1}^N \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{1j}^N & \cdots & t_{ji}^N & \cdots & t_{nj}^N \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ t_{1n}^N & \cdots & t_{in}^N & \cdots & t_{nn}^N \end{bmatrix}. \quad (12)$$

Table 9. The relative weights of aspects.

Aspects	MS	MF	AS	AE
Main services (MS)	0.250	0.256	0.256	0.256
Main facilities (MF)	0.251	0.245	0.251	0.251
Ancillary services (AS)	0.248	0.248	0.242	0.248
Affiliated equipment (AE)	0.251	0.250	0.250	0.244
Total	1.000	1.000	1.000	1.000

(5) Calculate the weighted super-matrix

The W_p (unweighted super-matrix) is illustrated in Equation (13), where W_p is composed of W_{ij} (many submatrices). The study analyzed the relationship between dependency and feedback using an NRM (network relation map). The ANP approach explores the weight of the submatrix using the pairwise comparison matrix, as illustrated in Equation (14). If only a single aspect of the component exists, the submatrix is the unit matrix ($\boldsymbol{I}$). When the aspect includes more than one component, the sum of the component weight is equal to 1. As shown in Table 10, the W_L (weighted super-matrix) can be calculated by multiplying T_N^t (transposed and normalized full influence matrix) and W_p (unweighted super-matrix), or it can be obtained using Equation (15). Therefore, when there is more than one component in each aspect, W_L (weighted super-matrix) should be modified through Equations (15) and (16), as illustrated in Table 11.

$$W_P = \begin{bmatrix} W_{11} & \cdots & W_{1j} & \cdots & W_{1m} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ W_{i1} & \cdots & W_{ij} & \cdots & W_{im} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ W_{m1} & \cdots & W_{mj} & \cdots & W_{mm} \end{bmatrix}. \quad (13)$$

$$W_{ij} = \begin{bmatrix} w_{P_{11}} & \cdots & w_{P_{1j}} & \cdots & w_{P_{1m}} \\ \vdots & & \vdots & & \vdots \\ w_{P_{i1}} & \cdots & w_{P_{ij}} & \cdots & w_{P_{im}} \\ \vdots & & \vdots & & \vdots \\ w_{P_{m1}} & \cdots & w_{P_{mj}} & \cdots & w_{P_{mm}} \end{bmatrix} = 1 \quad i = 1,2,\ldots.m \quad j = 1,2,\ldots\ldots m, \quad (14)$$

where $\sum_{i=1}^{m} w_{P_{i1}} = \sum_{i=1}^{m} w_{P_{ij}} = \sum_{i=1}^{m} w_{P_{im}} = 1$.

$$W_L = T_N^t \times W_P = \begin{bmatrix} t_{11}^N \times W_{11} & \cdots & t_{i1}^N \times W_{1j} & \cdots & t_{n1}^N \times W_{1m} \\ \vdots & & \vdots & & \vdots \\ t_{1j}^N \times W_{i1} & \cdots & t_{ji}^N \times W_{ij} & \cdots & t_{nj}^N \times W_{im} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^N \times W_{m1} & \cdots & t_{in}^N \times W_{mj} & \cdots & t_{nn}^N \times W_{mm} \end{bmatrix}. \quad (15)$$

$$t_{ji}^N \times W_{ij} = \begin{bmatrix} t_{11}^N \times w_{P_{11}} & \cdots & t_{i1}^N \times w_{P_{1j}} & \cdots & t_{n1}^N \times w_{P_{1m}} \\ \vdots & & \vdots & & \vdots \\ t_{1j}^N \times w_{P_{i1}} & \cdots & t_{ji}^N \times w_{P_{ij}} & \cdots & t_{nj}^N \times w_{P_{im}} \\ \vdots & & \vdots & & \vdots \\ t_{1n}^N \times w_{P_{m1}} & \cdots & t_{in}^N \times w_{P_{mj}} & \cdots & t_{nn}^N \times w_{P_{mm}} \end{bmatrix}. \quad (16)$$

Table 10. Unweighted super-matrix.

Aspects	MS	MF	AS	AE
Main services (MS)	1.000	1.000	1.000	1.000
Main facilities (MF)	1.000	1.000	1.000	1.000
Ancillary services (AS)	1.000	1.000	1.000	1.000
Affiliated equipment (AE)	1.000	1.000	1.000	1.000
Total	4.000	4.000	4.000	4.000

Table 11. Weighted super-matrix.

Aspects	MS	MF	AS	AE
Main services (MS)	0.250	0.256	0.256	0.256
Main facilities (MF)	0.251	0.245	0.251	0.251
Ancillary services (AS)	0.248	0.248	0.242	0.248
Affiliated equipment (AE)	0.251	0.250	0.250	0.244
Total	1.000	1.000	1.000	1.000

The super-matrix can be expressed as $(W_L \times W_L)^{2p+1}$, where p is determined by assumption. The ANP approach can determine the weight of components, and the derived reduced criteria are based on the independent component obtained. The criteria weights can be established through the ANP approach. In the limitation process, multiples of the super-matrix M for 45 squares and the component weights can be obtained, as illustrated in Table 12.

Table 12. Limited super-matrix.

Aspects	MS	MF	AS	AE
Main services (MS)	0.255	0.255	0.255	0.255
Main facilities (MF)	0.250	0.250	0.250	0.250
Ancillary services (AS)	0.247	0.247	0.247	0.247
Affiliated equipment (AE)	0.249	0.249	0.249	0.249
Total	1.000	1.000	1.000	1.000

(6) Determine the component weights

As illustrated in Table 13, the values in parentheses denote the weights of the aspects/components. The highest component weight, according to the PCA approach, was obtained for the aspect MS (main service) (0.255), followed by the aspects of MF (main facilities) (0.250), AE (affiliated equipment) (0.249), and AS (ancillary services) (0.247). Therefore, MS (main services)/MSP1 (exception handling and service) was the most critical aspect/component. AS (ancillary services)/ASP1 (dispatch and rescue service) was the least important aspect/component, followed by the MF (main facilities)/MFP1 (certification and security facility) and AE (affiliated equipment)/AEP1(guidance and marking facilities) for bike-sharing service systems.

Table 13. The weights of the aspects and components.

Aspects	Components	Weight
Main services (MS)	Exception handling and service (MSP1)	0.255
Main facilities (MF)	Certification and security facility (MFP1)	0.250
Ancillary services (AS)	Dispatch and rescue service (ASP1)	0.247
Affiliated equipment (AE)	Guidance and marking facilities (AEP1)	0.249
	Total	1.000

3.4. The Modified VIKOR

This VIKOR (Vlse kriterijumska Optimizacija I Kompromisno Resenje)approach can evaluate the rank of alternatives and select the best-suited options. It can also solve discrete decision problems with non-commensurable and conflicting conditions [57–63]. The gap between the consumers' most satisfactory and most unsatisfactory assessment was also analyzed regarding the services/utilities of the existing service systems of social game platform services. The VIKOR approach proposes a maximum group utility of the "majority" and a minimum individual regret of the "opponent". The compromise solutions can be used as the basis for negotiation, involving user preferences according to aspects/components weights, as shown in Figure 2.

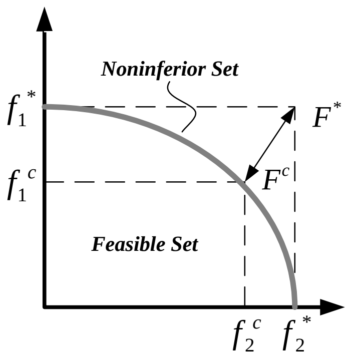

Figure 2. Ideal and compromise solutions. Here, F^* is the ideal solution. f_1^* represents the desired/aspired level of Factor 1. f_2^* represents the desired/aspired level of Factor 2. The compromise solution, F^c is a feasible solution that is "closest" to the ideal F^*. A compromise means an agreement established by mutual concessions.

The VIKOR approach can described as follows:

(1) Define the best value and the worst value of an aspect/component

$$f_i^+ = \left\{ \left(\max_k f_{ik} \middle| k \in I_1 \right), \left(\min_k f_{ik} \middle| k \in I_2 \right); \text{or setting the aspired level for } i \text{ aspect} \right\}, \forall k, \quad (17)$$

$$f_i^- = \left\{ \left(\min_k f_{ik} \middle| k \in I_1 \right), \left(\max_k f_{ik} \middle| k \in I_2 \right); \text{or setting the worst level for } i \text{ aspect} \right\}, \forall k, \quad (18)$$

where: k is the kth alternative; i is the criterion; f_{ik} is the performance value of the ith component/criterion of kth alternative; I_1 is the cluster of utility-oriented component/criteria; I_2 is the cluster of the cost-oriented component/criteria; f_i^* is the positive-ideal solution (or setting the aspired level); and f_i^- is the negative-ideal solution/setting the worst level.

(2) Calculate the values S_k and Q_k, $k = 1, 2, \ldots, m$, using the relationships described below.

Let r_{ik} be $r_{ik} = (|f_i^* - f_{ik}|)/(|f_i^* - f_i^-|)$. This paper followed a class of distance functions:

$$d_k^p = \left\{ \sum_{i=1}^{n} \left[w_i (|f_i^* - f_{ik}|)/(|f_i^* - f_i^-|) \right]^P \right\}^{1/p} = \left\{ \sum_{i=1}^{n} \left[w_i r_{ik} \right]^P \right\}^{1/p}, P \geq 1, \quad (19)$$

$$S_k = d_k^{p=1} = \sum_{i=1}^{n} w_i r_{ik}, \quad (20)$$

$$Q_k = d_k^{p=\infty} = \max_k \{ r_{ik} | i = 1, 2, \ldots, n \}, \quad (21)$$

where S_k shows the average gap for achieving the aspired/desired level, Q_k illustrates the maximal degree of regret for prior improvement of the gap criterion, and w_i is the weight of aspect/component i and $i = 1, 2, \ldots, n$, expressing the relative importance value of the criteria gained via the application of the ANP approach.

(3) Calculate the index values R_k, $k = 1, 2, \ldots, m$, using the following relationship:

$$R_k = v(S_k - S^*)/(S^- - S^*) + (1 - v)(Q_k - Q^*)/(Q^- - Q^*), \quad (22)$$
$$S^* = \min_k S_k,\ S^- = \max_k S_k,$$
$$Q^* = \min_k Q_k,\ Q^- = \max_k Q_k,$$

where $S^* = \min_k S_k$ (when illustrating the minimal average gap as best, set $S^* = 0$), $S^- = \max_k S_k$ (we can set $S^- = 1$), $Q^* = \min_k Q_k$ (when representing the minimum degree of regret as best, set $Q^* = 0$), and $Q^- = \max_k Q_k$ (we can set $Q^- = 1$). Equation (22) can be rewritten as

$$R_k = vS_k + (1 - v)Q_k. \quad (23)$$

(4) Rank the alternatives

The variable v affects the ranking order of the aspects/components/criteria, which is typically determined by decision makers/field experts. When $0 \leq v \leq 1$ when $v > 0.5$, this indicates that S is emphasized more than Q in Equation (23), whereas, when $v < 0.5$, this indicates that Q is emphasized more than S in Equation (23). More specifically, when $v = 1$, it represents a decision-making process that can use the strategy of maximum group utility, whereas, when $v = 0$, it represents a decision-making process that can use the strategy of minimum individual regret, which is obtained using the maximum individual regrets/gaps of lower level dimensions of each aspect/component. This study adopted R_k to determine the CSI (cyclists' satisfaction index). R_k can also be considered as the index of the maximum group utility and the minimum individual regret of the "opponent", where a smaller R_k is better, and $0 \leq R_k \leq 1$.

4. Empirical Study of Service Performance for Public Bike-Sharing Service Systems (PBSSSs)

The study proposes four aspects and 16 criteria. It analyzes three styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) for public bike-sharing service systems (PBSSSs). The questionnaires surveyed the service performance of aspects/criteria through the PBSSS field experts and service users. A total of 160 surveys were collected, and 142 were considered valid samples. The valid samples included 17 work commuter cyclists, 71 short-trip connection cyclists, and 54 travel and leisure cyclists for the public bike-sharing service systems (PBSSSs).

4.1. The Competitive Analysis of Public Bike-Sharing Service Systems (PBSSSs)

This study compared the competitive advantage of the CSI (cyclists' satisfaction index) for the three styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) for public bike-sharing service systems (PBSSSs). The study conducted the competitive analysis for the original data of satisfaction degree (minimum value = 0; maximum value = 10) collected by the questionnaire survey. In the horizontal analysis, Style 3 (travel and leisure cyclists) considered the PBSSSs competitive in the aspects of MS (main service), MF (main facilities), AS (ancillary services), and AE (affiliated equipment). Style 1 (work commuter cyclists) considered the PBSSSs uncompetitive in the MS, MF, AS, and AE aspects. In the vertical analysis, Style 1, Style 2 (short-trip connection cyclists), and Style 3 (travel and leisure cyclists) considered the PBSSSs competitive in the MS aspect, but uncompetitive in the AS aspect, as shown in Table 14. The four aspects of competitive analysis for PBSSSs are shown in the Supplementary Materials.

Table 14. The competitive analysis of PBSSSs for three styles of cyclists.

Users Aspects	Work Commuter Cyclists (Style 1)	Short-Trip Connection Cyclists (Style 2)	Travel and Leisure Cyclists (Style 3)
Horizontal analysis (0~10)			
Main services (MS)	4.794 (3)	6.176 (2)	6.417 (1)
Main facilities (MF)	4.735 (3)	6.063 (2)	6.319 (1)
Ancillary services (AS)	4.221 (3)	5.782 (2)	6.245 (1)
Affiliated equipment (AE)	4.706 (3)	5.863 (2)	6.333 (1)
Vertical analysis (0~10)			
Main services (MS)	4.794 (1)	6.176 (1)	6.417 (1)
Main facilities (MF)	4.735 (2)	6.063 (2)	6.319 (3)
Ancillary services (AS)	4.221 (4)	5.782 (4)	6.245 (4)
Affiliated equipment (AE)	4.706 (3)	5.863 (3)	6.333 (2)

4.2. Principal Component Analysis (PCA)

The study adopted the PCA approach to analyze the primary components. If the eigenvalue is larger than one ($\lambda_j > 1$), the analysis can preserve the potential component j; otherwise, it is removed. The MS aspect had an eigenvalue of 3.382 and could explain 84.560% of the variance. The Cronbach's α of MSP1 (exception handling and integrated service) was 0.939, indicating high reliability (Cronbach's $\alpha > 0.7$), as illustrated in Table 15. When principal components need further explanation, the cumulative factor loading threshold can be applied. Only one principal component each was extracted for the MS (main service), MF (main facilities), AS (ancillary services), and AE (affiliated equipment) aspects. Thus, the study subsequently examined the MSP1 (exception handling and integrated service), MFP1 (certification and security facility), ASP1 (dispatch and rescue service), and AEP1 (guidance and marking facilities) components, as shown in Table 15.

Table 15. The PCA analysis for the PBSSSs.

Aspects	Components	Criteria	Components	Community
Main services (MS)	Exception handling and integrated service (MSP1)	Abnormal condition handling (MS2)	0.947	0.897
		Integrated consulting service (MS4)	0.916	0.840
		Ticket integrated service (MS3)	0.914	0.835
		Bike rental services (MS1)	0.901	0.811
		Eigenvalue λ	3.382	
		% of Variance	84.560	
		Cumulative (%)	84.560	
		Cronbach's α	0.939	
Main facilities (MF)	Certification and security facility (MFP1)	Authentication service facilities (MF2)	0.959	0.919
		Antitheft and security device (MF3)	0.946	0.895
		Self-service facilities (MF4)	0.925	0.856
		Bike parking equipment (MF1)	0.919	0.845
		Eigenvalue λ	3.514	
		% of Variance	87.857	
		Cumulative (%)	87.857	
		Cronbach's α	0.954	
Ancillary services (AS)	Dispatch and rescue service (ASP1)	Dispatch and maintenance service (AS4)	0.958	0.919
		Bike cycling service (AS2)	0.939	0.882
		Road rescue service (AS1)	0.934	0.873
		Mobile application service (AS3)	0.915	0.836
		Eigenvalue λ	3.510	
		% of Variance	87.755	
		Cumulative (%)	87.755	
		Cronbach's α	0.953	
Affiliated equipment (AE)	Guidance and marking facilities (AEP1)	Lane guidance facilities (AE2)	0.969	0.939
		Bike marking system (AE4)	0.958	0.917
		Bike cycling lanes (AE3)	0.957	0.916
		Bike parking equipment (AE1)	0.880	0.774
		Eigenvalue λ	3.545	
		% of Variance	88.623	
		Cumulative (%)	88.623	
		Cronbach's α	0.957	

Note: Cronbach's $\alpha \leq 0.35$ is low reliability, $0.35 < \alpha < 0.70$ is intermediate reliability, and $\alpha \geq 0.7$ is high reliability.

4.3. The Service Satisfaction of PBSSSs Using the VIKOR Approach

In this section, the degree of the cyclists' satisfaction index (CSI) (0–10) for the public bike-sharing service systems (PBSSSs) was analyzed for three styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) using the VIKOR approach.

(1) Evaluate the aspired level f_i^* and the worst value f_i^-

The scores of each style of cyclist for public bike-sharing service systems (PBSSSs), ranging from 0 to 10, are illustrated in Table 16. In Equations (17) and (18), *i* is the criterion, *k* is the alternative, f_{ik} is the public bike-sharing service system (PBSSS) service performance of the alternative evaluated by criterion i, and i is the aggregation of aspects/criteria in the CSI (cyclists' satisfaction index). f_i^* is the positive ideal solution, while f_i^- is the negative ideal solution. This research set f_i^* as 10 and f_i^- as 0 to evaluate the difference in CSI (cyclists' satisfaction index) for each alternative.

Table 16. The scores of f_{ik}.

Aspects	Weight	Work Commuter Cyclists	Short-Trip Connection Cyclists	Travel and Leisure Cyclists	f_i^*	f_i^-
Styles		Style 1	Style 2	Style 3		
Main services (MS)	0.255	4.794	6.176	6.417	10	0
Main facilities (MF)	0.250	4.735	6.063	6.319	10	0
Ancillary services (AS)	0.247	4.221	5.782	6.245	10	0
Affiliated equipment (AE)	0.249	4.706	5.863	6.333	10	0

(2) Calculate the S_k and Q_k, $k = 1, 2, \ldots, m$

As illustrated in Tables 13 and 17, w_i is the relative weight of the aspects/components produced using the ANP approach. In Table 17, focusing on the aspect of CSI evaluation aspects/criteria, travel and leisure cyclists (Style 3) had the lowest S_k evaluation (S_k = 0.367), while work commuter cyclists (Style 1) had the highest S_k evaluation (S_k = 0.538). Travel and leisure cyclists (Style 3) had the lowest Q_k evaluation (Q_k = 0.375), while work commuter cyclists (Style 1) had the highest Q_k evaluation (Q_k = 0.578).

Table 17. The weighted value of the components of f_{ik}.

Aspects	Weight	Work Commuter Cyclists	Short-Trip Connection Cyclists	Travel and Leisure Cyclists
		Style 1	**Style 2**	**Style 3**
Main services (MS)	0.255	0.521	0.382	0.358
Main facilities (MF)	0.250	0.526	0.394	0.368
Ancillary services (AS)	0.247	0.578	0.422	0.375
Affiliated equipment (AE)	0.249	0.529	0.414	0.367
S_k		0.538	0.403	0.367
Q_k		0.578	0.422	0.375

(3) Calculate the value of R_k

When v exceeds 0.5, a decision maker can establish overall agreement, and vice versa. According to to Equations (12)–(14), $\underset{k}{Min} S_k$ denotes the maximum group utility (“majority” rule), and $\underset{k}{Max} Q_k$ denotes the minimum individual regret of “the opponent”. R_k is the indicator of the gap in alternative k (the smaller, the better). The R_k of three styles of users (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) decreased as v increased from 0 to 1, as shown in Table 18.

Table 18. R_k for different v according to three styles of cyclists.

v	Work Commuter Cyclists	Short-Trip Connection Cyclists	Travel and Leisure Cyclists
	Style 1	**Style 2**	**Style 3**
0.00	0.578	0.422	0.375
0.10	0.574	0.420	0.375
0.20	0.570	0.418	0.374
0.30	0.566	0.416	0.373
0.40	0.562	0.414	0.372
0.50	0.558	0.412	0.371
0.60	0.554	0.410	0.370
0.70	0.550	0.408	0.370
0.80	0.546	0.407	0.369
0.90	0.542	0.405	0.368
1.00	0.538	0.403	0.367

(4) Rank the alternatives

Under v = 0.0, R_k = 0.375 and CSI = 0.625 for travel and leisure cyclists (Style 3), while R_k = 0.578 and CSI = 0.422 for work commuter cyclists (Style 1). Travel and leisure cyclists (Style 3) had the highest CSI (cyclists' satisfaction index) evaluation for public bike-sharing service systems (PBSSSs), whereas work commuter cyclists (Style 1) had the lowest CSI evaluation for PBSSSs. The CSI ranking for the three styles of cyclists was $Style_3 \supset Style_2 \supset Style_1$, as illustrated in Table 19. As shown in Table 19, travel and leisure cyclists (Style 3) had the highest CSI evaluation (0.625). In contrast, the work commuter cyclists (Style 1) demonstrated the lowest CSI evaluation (0.422), followed by short-trip connection cyclists (Style 2). Under v = 0.5, travel and leisure cyclists (Style 3) had the highest CSI evaluation (CSI = 0.629), whereas work commuter cyclists (Style 1) had the lowest CSI evaluation (CSI = 0.442) for public bike-sharing service systems (PBSSSs). The CSI ranking for the three styles of cyclists was $Style_3 \supset Style_2 \supset Style_1$, as shown in Table 19. Under v = 1.0, travel and leisure cyclists (Style 3) had the highest CSI evaluation (CSI = 0.633), while work commuter cyclists (Style 1) had the lowest CSI evaluation (CSI = 0.462) for public bike-sharing service systems (PBSSSs). The CSI ranking for the three styles of cyclists was $Style_3 \supset Style_2 \supset Style_1$, as illustrated in Table 19.

Table 19. The robustness analysis of CSI ranks for PBSSSs.

v	Styles	Work Commuter Cyclists	Short-Trip Connection Cyclists	Travel and Leisure Cyclists
		Style 1	**Style 2**	**Style 3**
v = 0.0	V(R_k)	0.578	0.422	0.375
	CSI (1 − R_k)	0.422	0.578	0.625
	Rank	3	2	1
v = 0.5	V(R_k)	0.558	0.412	0.371
	CSI (1 − R_k)	0.442	0.588	0.629
	Rank	3	2	1
v = 1.0	V(R_k)	0.538	0.403	0.367
	CSI (1 − R_k)	0.462	0.597	0.633
	Rank	3	2	1

4.4. Adoption Path Analysis

This study suggests development paths according to the ranking of service satisfaction for work commuter cyclists. Disadvantage aspects can be improved through advantage aspects such that aspects of higher satisfaction can improve aspects of lower satisfaction. For work commuter cyclists (Style 1), the CSI ranking was $MS \supset MF \supset AE \supset AS$ and the four available paths were MF → AE, MF → AS → AE, MF → MS → AE, and MF → AS → MS → AE, as illustrated in Figure 3 and Table 20. The MF (main facilities) aspect could enhance the AE (affiliated equipment) aspect through the first adoption path (MF (2) → AE (3){Y}). The MF aspect could improve the AS (ancillary services) aspect through the second adoption path (MF (2) → AS (4) → AE (3) {Y}). The MS (main services) aspect could enhance the AE aspect through the third adoption path (MF (2) → MS (1) → AE (3) {Y}). The MF aspect could improve the AS aspect, and the MS aspect could enhance the AE aspect through the fourth adoption path (MF (2) → AS (4) → MS (1) → AE (3) {Y}), as shown in Figure 3 and Table 20.

This study suggests development paths according to the ranking of satisfaction for short-trip connection cyclists. For short-trip connection cyclists (Style 2), the CSI ranking was MS ⊃ MF ⊃ AE ⊃ AS, and the four adoption paths were MF → AE, MF → AS → AE, MF → MS → AE, and MF → AS → MS → AE, as illustrated in Figure 4 and Table 21. The MF (main facilities) aspect could enhance the AE (affiliated equipment) aspect through the first adoption path (MF (2) → AE (3) {Y}). The MF aspect could improve the AS (ancillary services) aspect through the second adoption path (MF (2) → AS (4) → AE (3) {Y}). The MS (main service) aspect could enhance the AE aspect through the third adoption path (MF (2) → MS (1) → AE (3) {Y}). The MF aspect could improve the AS aspect, and the MS aspect could improve the AE aspect through the fourth adoption path (MF (2) → AS (4) → MS (1) → AE (3) {Y}), as illustrated in Figure 4 and Table 21.

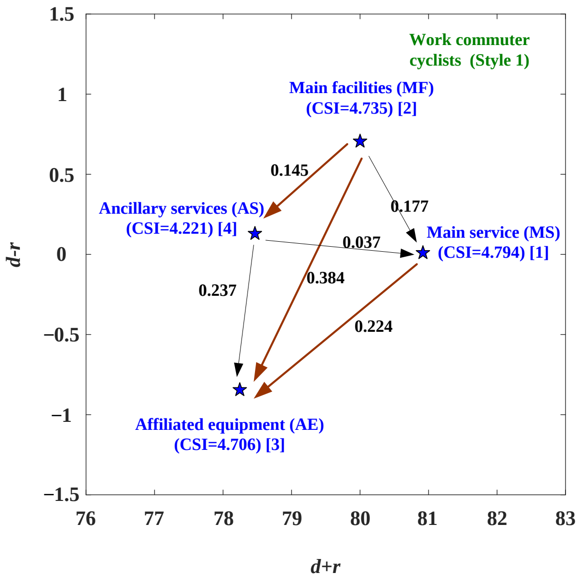

Figure 3. The adoption paths of work commuter cyclists (Style 1).

Table 20. The adoption paths of users of work commuter cyclists (Style 1).

Work Commuter Cyclists (Style 1)
Main services (MS) (1) > Main facilities (MF) (2) > Affiliated equipment (AE) (3) > Ancillary services (AS) (4)
Available paths
1. MF (2) → AE (3) {Y} 2. MF (2) → AS (4) → AE (3) {Y} 3. MF (2) → MS (1) → AE (3) {Y} 4. MF (2) → AS (4) → MS (1) → AE (3){Y}
Adoption paths
1. Main facilities (MF) → Affiliated equipment (AE) 2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE)

Table 21. The adoption paths of short-trip connection cyclists (Style 2).

Short-Trip Connection Cyclists (Style 2)
Main services (MS) (1) > Main facilities (MF) (2) > Affiliated equipment (AE) (3) > Ancillary services (AS) (4)
Available paths
1. MF (2) → AE (3) {Y} 2. MF (2) → AS (4) → AE (3) {Y} 3. MF (2) → MS (1) → AE (3) {Y} 4. MF (2) → AS (4) → MS (1) → AE (3){Y}
Adoption paths
1. Main facilities (MF) → Affiliated equipment (AE) 2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE)

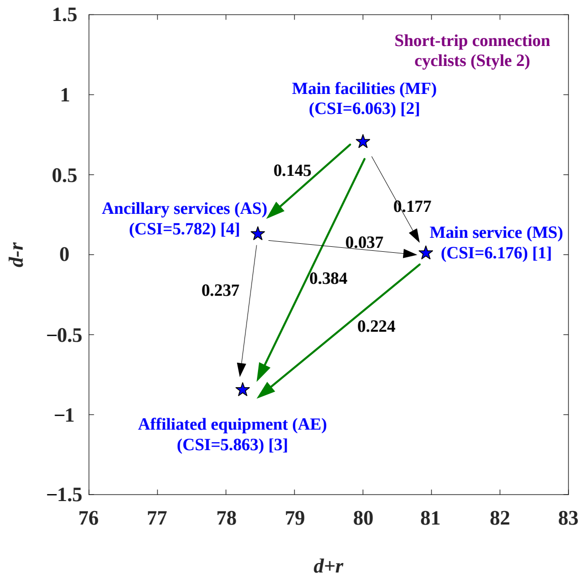

Figure 4. The development paths of short-trip connection cyclists (Style 2).

This study suggests adoption paths according to the aspect ranking of satisfaction for travel and leisure cyclists. For travel and leisure cyclists (Style 1), the CSI ranking was MS ⊃ AE ⊃ MF ⊃ AS, and the four adoption paths were MF → AE, MF → AS → AE, MF → MS → AE, and MF → AS → MS → AE, as shown in Figure 5 and Table 22. The MF (main facilities) aspect could not enhance the AE (affiliated equipment) aspect through the first adoption path (MF (3) → AE (2) {N}). The MF aspect could improve the AS (ancillary services) aspect through the second adoption path (MF (2) → AS (4) → AE (3){Y}). The MS aspect could enhance the AE aspect through the third adoption path (MF (2) → MS (1) → AE (3){Y}). The MF aspect could improve the AS aspect, and the MS aspect could improve the AE aspect through the fourth adoption path (MF (2) → AS (4) → MS (1) → AE (3){Y}), as shown in Figure 5 and Table 22.

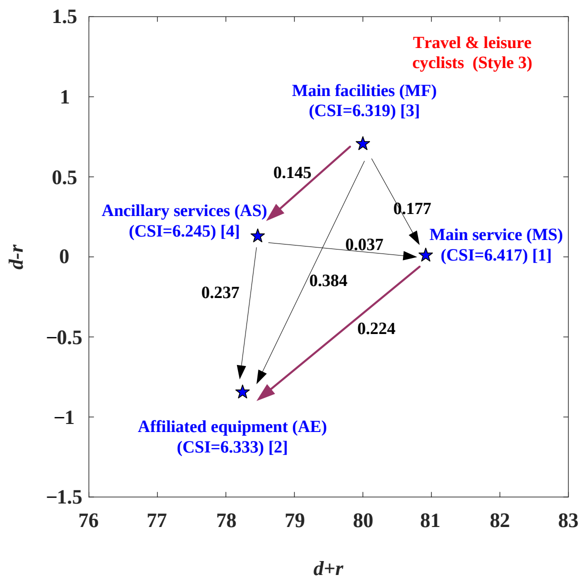

Figure 5. The adoption paths of travel and leisure cyclists (Style 3).

Table 22. The adoption paths of travel and leisure cyclists (Style 3).

Travel and Leisure Cyclists (Style 3)
Main services (MS) (1) > Affiliated equipment (AE) (2) > Main facilities (MF)(3) > Ancillary services (AS) (4)
Available paths
1. MF (3) → AE (2) {N} 2. MF (3) → AS (4) → AE (2) {Y} 3. MF (3) → MS (1)→AE (2) {Y} 4. MF (3) → AS (4)→MS (1) → AE (2){Y}
Adoption paths
2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE)

4.5. Discussion

Under v = 0.0, R_k = 0.578 and CSI (cyclists' satisfaction index) = 0.422 for work commuter cyclists (Style 1), whereas R_k = 0.422 and CSI = 0.578 for short-trip connection cyclists (Style 2), and R_k = 0.375 and CSI = 0.625 for travel and leisure cyclists (Style 3). Under v = 0.5, R_k = 0.558 and CSI = 0.442 for work commuter cyclists (Style 1), and R_k = 0.412 and CSI = 0.588 for short-trip connection cyclists (Style 2). R_k = 0.371 and CSI = 0.629 for travel and leisure cyclists (Style 3), as shown in Table 23. Under v = 1.0, R_k = 0.538 and CSI (cyclists' satisfaction index) = 0.462 for work commuter cyclists (Style 1), whereas R_k = 0.403 and CSI = 0.597 for short-trip connection cyclists (Style 2), and R_k = 0.367 and CSI = 0.633 for travel and leisure cyclists (Style 3), as shown in Table 19.

Table 23. The adoption paths for three styles of cyclists.

Work Commuter Cyclists (Style 1)
1. Main facilities (MF) → Affiliated equipment (AE) 2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE) Short-trip connection cyclists (Style 2)
1. Main facilities (MF) → Affiliated equipment (AE) 2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE) Travel & leisure cyclists (Style 3)
2. Main facilities (MF) → Ancillary services (AS) → Affiliated equipment (AE) 3. Main facilities (MF) → Main service (MS) → Affiliated equipment (AE) 4. Main facilities (MF) → Ancillary services (AS) → Main service (MS) → Affiliated equipment (AE)

This study evaluated the CSI ranking in a stable and steady state, as well as compared different v values. The best evaluation and the worst evaluation for the three cyclists were the same. The highest evaluation was that of travel and leisure cyclists (Style 3), whereas the worst was that of work commuter cyclists (Style 1). Thus, decision makers can adopt the ranking under v = 0.0 as the pessimistic state and the ranking under v = 1.0 as the optimal state. Therefore, this study determined the suitable CSI for the cyclists' evaluation (v = 0.5), as illustrated in Table 19. Bike-sharing service providers can use robustness analysis to understand the CSI rank in the three states and the cyclists' evaluation, as shown in Table 19. Bike-sharing service providers can also understand the advantageous and disadvantageous aspects/components and determine the adoption paths using Figures 3–5 and Tables 20–22 through the NRM approaches. The adoption paths of the three styles of cyclists are presented in Table 23. The four adoption paths of MF → AE, MF → AS → AE, MF → MS → AE, and MF → AS → MS → AE) can be applied for work commuter cyclists (Style 1), the four adoption paths of MF → AE, MF → AS → AE, MF → MS → AE, and MF → AS →

MS → AE can be applied for short-trip connection cyclists, and the three adoption paths of MF → AS → AE, MF → MS → AE, and MF → AS → MS → AE can be applied for travel and leisure cyclists (Style 3).

There were four adoption paths for work commuter cyclists (MF → AE; MF → AS → AE; MF → MS → AE; MF → AS → MS → AE). The MF (main facilities) aspect enhanced the AE (affiliated equipment) aspect through the first adoption path (MF (2) → AE (3){Y}), as illustrated in Tables 20 and 23. For work commuter cyclists (Style 1), PBSSSs should enhance the main facilities, such as self-service facilities, authentication service facilities, and bike parking equipment to save time and increase convenience. Furthermore, PBSSSs and relevant authorities can also build lane guidance facilities, bike marking systems, and bike cycling lanes to increase the safety and convenience for work commuter cyclists.

The MF (main facilities) aspect could enhance the AS (ancillary services) aspect through the second adoption path (MF (2) → AS (4) → AE (3) {Y}), as illustrated in Tables 20 and 23. Many different reasons (environmentally friendly, recreational sports, healthy life, and use convenience) encourage people to become work commuter cyclists. Therefore, the convenience and efficiency of PBSSSs are the main driving forces supporting cyclists' continual use. Accordingly, self-service and authentication service facilities have become more and more critical for the work commuter cyclists. Furthermore, the convenient and friendly design of mobile application services can also reduce the use barriers of PBSSS integrated service platforms. Dispatch and maintenance services and road rescue services can save time and solve inconveniences in unexpected traffic accidents. The MS (main service) aspect could enhance the AE aspect through the third adoption path (MF (2) → MS (1) → AE (3) {Y}), as illustrated in Tables 20 and 23. PBSSSs should establish friendly and convenient integrated service platforms to satisfy various service needs, such as bike rental services, ticket integrated services, and integrated consulting services. Moreover, lane guidance facilities, bike cycling lanes, and bike marking systems can improve cyclists' safety and reduce conflict with other transport modes.

The MF aspect could improve the AS aspect, and the MS aspect could enhance the AE aspect through the fourth adoption path (MF (2) → AS (4) → MS (1) → AE (3){Y}), as illustrated in Tables 20 and 23. Many work commuter cyclists often combine the MRT/regional railway system and PBSSS in daily commuting. Thus, PBSSSs should build enough bike parking equipment, which should be close to the MRT/railway service stations. Furthermore, the mobile application service should integrate various service functions, such as service route planning and service schedule, as well as offer integrated service packages to satisfy the cyclists' diverse service needs. Furthermore, PBSSSs should analyze the peak bike demand on working days and during rush hours, as well as strengthen the dispatch and maintenance service. PBSSSs should consider how to satisfy peak serviceability. Furthermore, some unexpected traffic accidents are often due to cyclists needing to replace other sharing bikes or other transport tools; hence, the road rescue service and dispatch and maintenance service become more critical for work commuter cyclists. With the MRT/regional railway system becoming more convenient and complex, work commuter cyclists will continually increase. Thus, the relevant authorities should consider building lane guidance facilities, bike marking systems, and bike cycling lanes to reduce conflict with other transport modes and improve safety for the work commuter cyclists.

There were four adoption paths for short-trip connection cyclists (PF → AF; PF → PS → AF; PF → AS → AF; PF → PS → AS → AF). The MF (main facilities) aspect could enhance the AE (affiliated equipment) aspect through the first adoption path (MF (2) → AE (3) {Y}), as illustrated in Table 23. For short-trip connection cyclists (Style 2), PBSSSs should enhance the main facilities, such as authentication service facilities and self-service facilities, which can increase convenience. Moreover, PBSSSs and relevant authorities can also offer bike cycling lanes and lane guidance facilities to reduce conflict with other transport modes and increase convenience and use safety. The MF aspect could enhance the AS (ancillary services) aspect through the second adoption path (MF (2) → AS (4) → AE (3) {Y}), as illustrated in Tables 21 and 23.

Short-trip connection cyclists may want to visit nearby destinations, such as restaurants, convenience stores, and bookstores. Hence, convenient rental services and an adequate number of rental service sites can reduce the waiting time and increase short-trip connection cyclists' use willingness through authentication service facilities and self-service. Furthermore, dispatch and maintenance services can aid short-trip connection cyclists in handling some unexpected traffic accidents and continue finishing their trips. The MS (main service) aspect could enhance the AE aspect through the third adoption path (MF (2) → MS (1) → AE (3) {Y}), as shown in Tables 21 and 23. PBSSSs should integrate some service providers and offer ticket integrated services, such as EasyCard/i PASS, as well as allow short-trip connection cyclists to use bike rental services through ticket integrated services. Additionally, PBSSSs also provide some service offers, such as no cost for the first 15/30 min, to attract more short-trip connection cyclists. Lane guidance facilities and bike cycling lanes can also reduce conflict during rush hour and increase safety.

The MF aspect could enhance the AS aspect, and the MS aspect could improve the AE aspect through the fourth adoption path (MF (2) → AS (4) → MS (1) → AE (3){Y}), as shown in Tables 21 and 23. Short-trip connection cyclists do not need to use bike-sharing services every day. Therefore, authentication and self-service facilities can also increase convenience and offer a better alternative in the hot summer/cold winter. However, PBSSSs can integrate MRT/railway operators to provide local bike cycling services, which can solve repeat rentals over short trips of greater distance. Furthermore, dispatch and maintenance services can address the lack of sites and increase the available bike-sharing service. Furthermore, PBSSSs should evaluate bike rental services for diverse short-trip connection cyclists, as well as provide ticket integrated services, such as short-term transport passes, long-term transport passes, specific zone transport passes, and diverse ticket integrated services. With PBSSS becoming more convenient, the number of cyclists has also increased. Lane guidance facilities and bike cycling lanes have also become more critical for cyclists, which can aid car drivers in paying attention to cyclists, as well as grant cyclists their own lanes. Bike cycling lanes and lane guidance facilities can also attract cyclists to adopt the sharing bikes for short-trip connections.

There were three adoption paths for travel and leisure cyclists (PF → PS → AF; PF → AS → AF; PF → PS → AS → AF). The MF (main facilities) aspect could enhance the AS (ancillary services) aspect through the second adoption path (MF (3) → AS (4) → AE (2) {Y}), as shown in Tables 22 and 23. Due to the interest in the environment and recreational sports, more and more people are joining the travel and leisure cyclist community. Short distance trips using shared bikes have become more and more popular on weekly holidays. Furthermore, travel and leisure cyclists pay attention to service quality. Thus, authentication service facilities and parking equipment are becoming more and more critical, which can improve service efficiency and save time. Bike cycling services also help travel and leisure cyclists to extend service at some tourism destinations lacking bike-sharing sites, as well as save costs at tourism destinations with lower demand. Furthermore, road rescue services can aid the travel and leisure cyclists to handle bike-sharing malfunctions and unexpected traffic accidents, enabling them to complete their trips. The MS (main service) aspect could enhance the AE aspect through the third adoption path (MF (3) → MS (1) → AE (2) {Y}), as illustrated in Tables 22 and 23. Furthermore, PBSSSs can provide various bike rental services and ticket integrated services, such as short-term transport passes, long-term transport passes, specific events transport passes, urban (full zone) transport passes, and diverse ticket integrated services. Additionally, more and more travel and leisure cyclists are visiting local towns/tourism destinations using bikes. They also organize cycling clubs to share their travel experiences at different vacation destinations. Thus, the relevant authorities can establish bike cycling lanes and lane guidance facilities to attract more travel and leisure cyclists to visit and share their travel experience.

The MF aspect could enhance the AS aspect, and the MS aspect could improve the AE aspect through the fourth adoption path (MF (3) → AS (4) → MS (1) → AE (2){Y}), as illustrated in Tables 22 and 23. More and more people are visiting tourist destinations during critical festivals and holidays; thus, bike sharing can provide visitors with another alternative to visit tourism destinations. Moreover, authentication service facilities can quickly lease and conveniently return sharing bikes. Bike parking equipment can aid travel and leisure cyclists in getting closer to tourism destinations and allow for short stays, where they can eat some local cuisine and buy native products. Additionally, road rescue services can aid travel and leisure cyclists in handling unexpected traffic accidents during their trip. Bike cycling services can help travel and leisure cyclists in extending some tourism destinations with no service sites. PBSSSs can provide various bike rental services packages and ticket integrated services, such as 1 day short-term transport passes. They may use different transport modes, such as MRT, local railway, urban bus, and bike sharing. Integrated ticket services can save time in leasing various transport services. Some local governments have established lane guidance facilities and bike cycling lanes to attract more tourists to town/tourism destinations through bike in-depth tourism. These travel and leisure cyclists can ride their shared bikes to visit their desired destinations and stay to take photos and share their travel experiences via social network services, such as Facebook and Instagram. In addition, local governments can also integrate PBSSSs near tourist attractions to offer different routes to satisfy tourists' needs.

5. Conclusions

Some researchers adopted the Hopfield neural network approach to evaluate structure relationships [64–68]. This study integrated four approaches (DEMATEL, PCA, ANP, and VIKOR). The DEMATEL approach can aid decision makers in establishing network relations, and the PCA approach can simplify the criteria and determine the independent component. The ANP approach was used to obtain the relationship weights for each aspect and the VIKOR approach was used to determine the CSI (cyclists' satisfaction index) evaluation and CSI rank. PBSSSs can understand the cyclists' CSI evaluation and choose their adoption path. Through service competition analysis for public bike-sharing service systems (PBSSSs), CSI evaluation (here $v = 0$, $v = 0.5$, and $v = 1.0$) can be considered as an index of the maximum group utility or the minimum individual regret of the "opponent". Travel and leisure cyclists (Style 3) had the highest CSI, while work commuter cyclists (Style 1) had the lowest CSI for the public bike-sharing service system (PBSSSs).

According to the NRM (network relation map) analysis, the MF (main facilities) aspect was dominant, whereas AE (affiliated equipment) was the least important aspect. The MF aspect could influence the aspects of AS (ancillary services), MS (main service), and AE (affiliated equipment). The AS aspect could influence the MS aspect and AE aspect, and the MS aspect could influence the AE aspect. The proposed model modified the ANP approach through the PCA approach and adopted a modified VIKOR approach to determine the desired solution. Therefore, the VIKOR approach still had some limitations for determining v. This study compared different v values and evaluated three specific states ($v = 0$, $v = 0.5$, and $v = 1.0$) for the CSI (cyclists' satisfaction index) robustness analysis. Other researchers can determine the best v values for their different states. Decision makers should evaluate the conditions for their decision. Then, they can consider the CSI evaluation under $v = 0.0$ in the pessimistic condition and adopt the CSI evaluation under $v = 1.0$ in the optimal condition. This study considered CSI evaluation and CSI ranking in the stable and steady state. Therefore, this study determined the proper CSI evaluation for different cyclists based on $v = 0.5$. The suitable determination of v remains a limitation for different conditions. Other researchers can consider how to determine the best v values for different conditions.

This study explored three styles of cyclists (work commuter cyclists, short-trip connection cyclists, and travel and leisure cyclists) for public bike-sharing service systems (PBSSSs). Four adoption paths (MF $\rightarrow$ AE, MF $\rightarrow$ AS $\rightarrow$ AE, MF $\rightarrow$ MS $\rightarrow$ AE, and MF $\rightarrow$ AS $\rightarrow$ MS $\rightarrow$ AE) could be adopted to enhance PBSSS quality for commuter cyclists. Four adoption paths (MF $\rightarrow$ AE, MF $\rightarrow$ AS $\rightarrow$ AE, MF $\rightarrow$ MS $\rightarrow$ AE, and MF $\rightarrow$ AS $\rightarrow$ MS $\rightarrow$ AE) could improve PBSSS quality for short-trip connection cyclists. Three adoption paths (MF $\rightarrow$ AE, MF $\rightarrow$ MS $\rightarrow$ AE, and MF $\rightarrow$ AS $\rightarrow$ MS $\rightarrow$ AE) could be adopted to enhance PBSSS quality for travel and leisure cyclists. Therefore, PBSSSs can improve the adoption paths based on the network relation map (NRM).

Because of traffic jams and parking problems, more office workers are choosing to combine MRT/railway and bike-sharing transport modes for their daily commute. For work commuter cyclists, enough sharing bikes in the rush hours of working days and 24 h convenient rental services are the most important factors. Therefore, public bike-sharing service system (PBSSS) providers should consider offering self-service facilities and authentication service facilities to support 24 h rental services. Then, PBSSSs should also establish more bike parking equipment near MRT/railway stations to satisfy work commuter cyclists from different places. PBSSS providers can offer diverse service information such as route planning, MRT/railway schedules, and merchant service information through mobile application services. Furthermore, dispatch and maintenance services and road rescue services can ensure the serviceability of stations at any time for work commuter cyclists and solve the need for bike replacement or other transport modes in some unexpected traffic accidents.

Short-trip connection cyclists do not need to use bike sharing every day; however, it can be another convenient alternative to save time. Therefore, PBSSS providers can integrate the MRT/railway to offer the first 15/30 min for free to attract short-trip connection cyclists. They can also provide various ticket integrated services, such as the 1–3 month long-term transport passes, 1–7 day short-term transportation passes, specific zone transport passes, and other different ticket integrated services. Furthermore, off-site rental service and bike parking equipment can provide more convenience and solve problems related to sharing, borrowing, and returning bikes. With bike-sharing services becoming more and more popular, cyclists also need lane guidance facilities and bike cycling lanes. Therefore, the local government and relative authorities should build lane guidance facilities and bike cycling lanes to aid car drivers and cyclists in paying attention to traffic safety, reduce conflict with other transport modes, and increase safety. Additionally, lane guidance facilities and bike cycling lanes can attract cyclists in short-trip connections.

With people paying more attention to sports, leisure, and healthy life, bike tours have become more and more popular. Some tourists like to visit tourism destinations using bikes and share their travel experiences on social media. Therefore, local authorities and governments should build lane guidance facilities and bike cycling lanes to attract more visitors to visit tourism destinations and bring local commerce activities and job opportunities. Moreover, self-service facilities and authentication service facilities can increase convenience to lease and return bikes. Then, bike parking equipment and antitheft and security devices can connect them more closely to tourism destinations, such that they can park their sharing bikes with confidence. These travel and leisure cyclists can appreciate the natural scenery and participate in local activities. Therefore, PBSSS providers can also plan more tourist routes to attract more travel and leisure cyclists to visit and stay at local town/tourism destinations, where they can enjoy local cuisine and purchase native products. Various bike rental services packages and ticket integrated services can save money and time in leasing various transport services. For example, 1 day short-term transport passes can satisfy the travel and leisure cyclists' diverse needs for using different transportation modes (local railway, MRT, urban buses, and bike sharing). PBSSSs can also integrate other lodging service providers and local merchants to propose various tour packages using bikes for satisfying different travel and leisure cyclists' needs.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/math11051196/s1, Table S1: The PBSSSs competitive analysis of MS (main service) aspect for three styles of cyclists; Table S2: The PBSSSs competitive analysis of MF (main facilities) aspect for three styles of cyclists; Table S3: The PBSSSs competitive analysis of AS (ancillary services) aspect for three styles of cyclists; Table S4: The PBSSSs competitive analysis of AE (affiliated equipment) aspect for three styles of cyclists.

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