Improving the service quality of public bike-sharing systems under information uncertainty

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Abstract. Cycling as a mode of transportation brings certain benefits to the user, such as improving health and saving money. Thus, public bike-sharing systems have been adopted as a modal choice in several cities around the world. However, there are problems when designing a bike-sharing system, one of which is how to improve service quality and attract more users. This study proposes a hybrid model, combining the Decision-Making Trial and Evaluation Laboratory (DEMATAL) method with the Analytical Network Process (ANP) approach (called DANP), which addresses the dependent relationships between various criteria of service quality in bike-sharing systems to better reflect the real-world situation. After building a complex evaluation system, a modified VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) method is applied to explore the weighted-gap in the aspiration levels. Furthermore, human preferences cannot be estimated with an exact numerical value, which can make it difficult to judge the performance or make comparisons. One remedy to improve upon this uncertainty for decision makes is to apply Grey Theory. The proposed method is demonstrated using data from Taipei's Youbike system. The resulting analysis and the managerial applications for improving the service quality of a bike-sharing system are also discussed with regards to the current policies of Taipei City.

Keywords: Service quality; Public bike system; Grey-DANP; Grey-VIKOR; Multiple criteria decision-making (MCDM)

1. Introduction

One of the biggest concerns of the urban transportation planner is to provide the most adequate response to the traveller's needs, to accurately estimate transportation demand and its variations. A public bike system has the potential to increase options when complementing other transportation modes, or when parking problems exist at the origin or destination of the traveller's trip. Sin the mid-2000s bike-sharing programs have gradually developed to serve as an alternative urban transit system, and this new form of mobility has spread across the globe (Parkes et al., 2013).

Although bike-sharing programs have existed for almost half a century, the most recent decade has seen a sharp increase in both their prevalence and popularity worldwide (Institute for Transportation & Development Policy, 2013). There are currently more than 700 cities operating bike-sharing programs. The service quality of a transportation system is a key factor that affects the willingness of citizens to choose to use the public transportation system rather than drive their private vehicles (Liou et al., 2014). Thus, how to improve service quality and thus attract more passengers to use public transportation systems is an important concern for city governments around the world.

The problems encountered with public bike-sharing programs have been investigated in several studies and great contributions have been made. For example, work has been done on the factors influencing bike use and route choice (Wardman et al., 2007; Pucher and Buehler, 2008; Su et al., 2010; Fisherman, 2014), the different bike-sharing systems and their efficiencies (Nakamura and Abe, 2014; O'Brien et al., 2014; Zhao et al., 2014) and the optimization of pick-up and drop-off points (Dell'Olio et al., 2011; Lin and Yang, 2011). The role of infrastructure in the demand for cycling has been approached in depth with a variety of methodologies (Akar and Clifton, 2009; Dill and Carr, 2003; Chu and Guo, 2015). To the best of our knowledge the only study discussing the service quality of the bike sharing system would be that by Bordagaray et al. (2012) who applied Probit models to investigate user perceptions about public bike services.

Most prior studies have assumed that the variables/criteria are independent. In the real world, though, the criteria are seldom independent. There is always some degree of interactive relationship, sometimes with dependence and feedback effects, especially for the very intricate mix of the intangibles comprising service quality (Liou et al., 2014). This study utilizes a hybrid MCDM model that combines the DEMATEL technique with the concepts of the ANP method to resolve the dependence and feedback problems, and thus, more accurately reflect real-world situations. Further, more a modified VIKOR method along with values expressed in intervals (called Grey-VIKOR) are employed to investigate the weighted-gaps to aspiration levels for improving the service quality of bike-sharing programs.

We use data from the Taipei bike-sharing program to demonstrate the usefulness of this model in practice. Managerial implications are derived and discussed in relation to the current policies of Taipei City government. In practice, the managerial implications can serve as a reference for the Taipei City government, urban planners, and bike system designers seeking to improve their services and the physical environment.

2. A Brief Review of the Existing Literature

The public bike-sharing system allows bikes to be picked up and dropped-off at different points (stations or docks) around the city, allowing for coordination with other transport modes (Fradea and Ribeiroa, 2014). These services capture users from other transport services such as buses, public transit, pedestrians, private vehicles, and taxis. Furthermore, some have suggested that bike-sharing acts as a competitor and complement to the existing modal options because it can be used as alternative to cars and trips can be combined with other modes of transport (Shaheen et al., 2011).

In terms of operating models, DeMaio (2009) noted that the current bike-sharing providers cover a large spectrum, including local governments, transportation agencies, non-profit organizations (NPOs), advertising companies, and private companies. Nakamura and Abe (2014) discussed different types of public bike-sharing operating models and provided the means to evaluate the efficiency of these models.

To date, the existing practical knowledge of bike-sharing is relatively thin but it is growing rapidly with bike-sharing's wide-spread expansion (Zhao et al., 2014). Parkes et al. (2013) explored the patterns of adoption of bike-sharing systems, providing an analysis of the diffusion of public bike-sharing systems in Europe and North America. They concluded that "Europe is still in a major adoption process with new systems emerging and growth in some existing systems", while "in North America, the adoption process is at an earlier stage and is gaining momentum". In another study, O'Brien et al. (2014) strove to obtain a global view of bike-sharing characteristics, analysing data from 38 systems located in Europe, the Middle East, Asia, Australasia and the Americas. After analysis of variation in occupancy rates over time and comparison across systems, they proposed a classification of bike-sharing systems, based on the geographical footprint and diurnal, day-of-week and spatial variations in occupancy rates, which laid the foundation for the analysis of larger scale bike-sharing systems.

Studies relating to the service quality of bike-sharing systems are few but can be found. In particular, a recent report by Bordagaray et al. (2012) indicated that there are many factors that influence the perception of the quality of a public bike service with the greatest impact on perceived quality being safety and information. The success of the bike-sharing program depends on how well the service aspirations are satisfied. However, the definition of just what ensures bike-sharing service quality is not yet a popular subject in the literature. As a continuation of and complement to these published materials, we make an effort to model and analyse the service quality of bike-sharing systems. The proposed methods and procedures are discussed in the next section.

3. Proposed Model

In a complex system, all system criteria are either directly or indirectly interrelated. For such intricate systems, it is very difficult for a decision-maker to obtain a specific objective/aspect and avoid interference from the rest of the system. The method proposed here remedies the shortcomings of prior models in three ways. First, the DEMATEL technique is used to confirm the effect on each dimension and criterion. Subsequently, the DANP approach, a combination of the DEMATEL and ANP methods, based on the concepts of Saaty (1996), is adopted to calculate the influential weights of the criteria.

Second, human perceptions and attitudes can be vague, uncertain and subjective. To cope with uncertainty in survey responses, a novel Grey-DANP method and Grey-VIKOR method are employed and values are expressed in intervals expressed in natural language. These methods are employed to investigate the performance values given for improving the service quality of a bike-sharing system.

Finally, the concept of "aspired quality" must be differentiated from that of the "perceived quality" which arises from what users have experienced and perceived using the public transport system. Thus, this study utilize the “aspired quality” to replace the concept of “relative good” used in the Grey-VIKOR model for weighted-gaps analysis. The detail procedures can be seen from Opricovic and Tzeng (2004) and Liou et al. (2014).

4. Empirical Example

Taipei is Taiwan’s largest city, as well as capital and business center, and it is situated on the north of the island. To reduce the negative impact caused by private cars and motorcycles, Taipei City developed the Youbike system in 2009. The system has since grown to encompass 491 kilometers (km) of bike tracks and 196 bike rental/docking stations dispersed around the city, with over 70,000 average daily usages in 2015. Although the initial success of the Youbike system is undeniable, car and motorcycle usage is still very high. Good service is essential to attract more users to the Youbike system and to reduce the usage of private cars and motorcycles in Taipei City.

4.1 Variable Selection and Data Collection

The public bike-sharing system is new and complex and any evaluation of service quality must take into account many factors. To reduce the complexity of the task, we first proposed 24 related factors after consulting SERVQUAL, as well as frequent users and the relevant literature. A preliminary survey was conducted with responses received from 52 Youbike users. Respondents were asked to rate the importance of these factors on the 5-ponit Likert scale. Based on the results, we reduced the 24 factors to the most crucial 14 factors with four dimensions. These 14 factors and their related items are shown in Table 1. The system was divided into four dimensions, namely bike (D_1), rental system (D_2), infrastructure (D3), and safety (D_4).

The formal questionnaire process was conducted at the bike rental/docking stations, thereby accessing a wide spectrum of users. Due to time and budgetary limits, we selected 10 major rental stations near the intersections of Metro lines for inclusion in our study. For our primary survey, we approached passengers using the Youbike system and asked them for three types of data: (1) pairwise comparisons of the degree of influence of service criteria from their own perceptions; (2) their level of satisfaction regarding each service criterion; and (3) personal profiles. We distributed 752 questionnaires and received 374 useful responses, after eliminating some questionnaires due to incomplete answers. Furthermore, since answering the first part of the questionnaire was a time-consuming process, we only invited 20 frequent users to answer this part. Of the respondents 45.4% were male and 54.6% female; in terms of age, the majority were 16-40 years old occupying 72% of the whole with others making up only 28%. Most of the respondents used the Youbike system 1-2 times per month at 46.5%, 3-4 times at 31.2% and 5 or above 22.3%.

Table 1 Evaluation criteria for Youbike service quality

Dimensions	Criteria	Factor loading
Bike (D_1)	Functions (C_{11})	The parts and accessories on the Youbikes are satisfactory to meet users’ needs, such as headset, derailleur, carrier, saddle, lock, etc.
	Appearance (C_{12})	The size, color and design of the Youbike are attractive.
	Riding comfortable (C_{13})	Passengers feel comfortable when they ride the Youbike.
Rental system (D_2)	Payment methods (C21)	There are a variety of payment options available to rent a Youbike such as credit cards, easy cards, and mobile devices.
	KIOSK (C_{22})	The KIOSK rental system is easy to use for registration.
	Price (C_{23})	The rental price is satisfactory and reasonable.
	Information (C_{24})	The information is convenient to obtain in mobile devices such as, number of available Youbike in each station, locations of the rental stations, or number of available docks for return
Infrastructure (D_3)	Number of docks (C_{31})	The number of docks is sufficient for returning the Youbike.
	Number of Youbike (C_{32})	The number of Youbikes is sufficient for those who want to rent a Youbike.
	Bike tracks (C_{33})	The network of bike tracks is adequate.
	Rental stations (C_{34})	The locations of rental stations are convenient for rentals and returns.
Safety (D_4)	Bike safety (C_{41})	The Youbike has sufficient equipment to protect riders, such as

	brakes, reflectors, lights, rear mirror, etc.
Information security (C_{42})	The personal information required for registration is safe and will not be leaked to others.
Environmental safety (C_{43})	Passengers feel safe when they ride a Youbike on the street or bike track.

4.2. Building The Influential Network Relationship Map

First of all the DEMATEL technique was used to construct the structure of the influential relationships in the decision-making problem, and examine the 14 criteria for improving the service quality within four dimensions of the bike-sharing system. Based on the first part of questionnaires, the grey direct relation average matrix is obtained as shown in Table 2 with the zero in the diagonal elements. The normalized grey initial influence relation matrix can be calculated. Then, the grey total-influence matrix is derived. The grey total influence relation matrix includes an infinite series of direct and indirect effects for the grey matrix. To ensure the reliability of the collected data, the significant confidence level is calculated for the questionnaire and is found to be 97.3%, greater than acceptable level of 95% Also, the sum of the influence exerted on (r_i–s_i) and received (r_i+s_i) for each dimension and criteria is calculated with the results shown in Table 3. The table shows that the relationships between the four dimensions and 14 criteria are based on the users' cognition and that the sum of the influence exerted on and received from other dimensions and criterion, respectively. As shown in Table 3, "infrastructure" and "rental system" have positive net influence values (r_i–s_i) in the causal dimensions. "Bike" and "safety" with negative values of (r_i–s_i) can be grouped into affected dimensions. The (r_i+s_i) values that indicate the total influence exerted on and received between the dimensions/criteria also show larger values for "infrastructure" and "rental system". Thus, it can be said that "infrastructure" and "rental system" play major roles in the evaluation system. Managers should consider those two dimensions as goal areas for directions for improvement.

Table 2 Initial direct influence matrix

	C_{11}	C_{12}	C_{13}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}
C_{11}	0.00	[1.08, 1.85]	[2.20, 2.88]	[0.58, 1.25]	[0.68, 1.33]	[1.18, 1.98]	[0.25, 0.85]	[0.1, 0.65]	[0.28, 0.85]	[0.13, 0.70]	[0.15, 0.70]	[1.93, 2.78]	[0.15, 0.70]	[0.43, 1.10]
C_{12}	[0.98, 1.75]	0.00	[1.20, 2.08]	[0.48, 1.08]	[0.23, 0.85]	[0.45, 1.10]	[0.00, 0.50]	[0.05, 0.60]	[0.18, 0.75]	[0.03, 0.55]	[0.10, 0.65]	[0.63, 1.33]	[0.03, 0.55]	[0.50, 1.20]
C_{13}	[1.15, 1.98]	[1.25, 2.03]	0.00	[0.13, 0.70]	[0.25, 0.78]	[0.60, 1.28]	[0.00, 0.50]	[0.05, 0.60]	[0.10, 0.70]	[0.43, 1.05]	[0.13, 0.65]	[0.83, 1.50]	[0.00, 0.50]	[0.65, 1.33]
C_{21}	[0.33, 0.95]	[0.23, 0.80]	[0.23, 0.80]	0.00	[1.40, 2.23]	[1.25, 1.85]	[0.53, 1.18]	[0.13, 0.65]	[0.13, 0.65]	[0.13, 0.65]	[0.35, 1.00]	[0.40, 1.05]	[1.70, 2.45]	[0.20, 0.80]
C_{22}	[0.73, 1.38]	[0.20, 0.80]	[0.28, 0.85]	[1.43, 2.23]	0.00	[0.38, 1.00]	[1.13, 1.83]	[0.00, 1.05]	[0.00, 0.50]	[0.00, 0.50]	[0.05, 0.60]	[0.75, 1.43]	[1.95, 2.70]	[0.18, 0.80]
C_{23}	[1.00, 1.75]	[0.50, 1.20]	[1.08, 1.80]	[1.33, 2.03]	[0.58, 1.25]	0.00	[0.15, 0.75]	[0.60, 1.18]	[0.75, 1.33]	[0.38, 1.00]	[0.43, 1.05]	[0.80, 1.48]	[0.50, 1.15]	[0.38, 1.00]
C_{24}	[0.33, 0.95]	[0.05, 0.60]	[0.13, 0.70]	[0.63, 1.33]	[0.88, 1.58]	[0.35, 0.93]	0.00	[0.73, 1.45]	[1.33, 2.05]	[0.55, 1.18]	[1.55, 2.33]	[0.30, 0.95]	[0.70, 1.43]	[0.28, 0.95]
C_{31}	[0.10, 0.65]	[0.00, 0.50]	[0.00, 0.50]	[0.10, 0.70]	[0.25, 0.85]	[0.25, 0.95]	[0.78, 1.48]	0.00	[0.28, 3.45]	[0.70, 1.35]	[1.65, 2.40]	[0.25, 0.85]	[0.08, 0.60]	[0.25, 0.85]
C_{32}	[0.18, 0.75]	[0.03, 0.55]	[0.28, 0.75]	[0.13, 0.70]	[0.25, 0.95]	[0.33, 1.23]	[1.13, 1.83]	[2.38, 3.10]	0.00	[1.03, 1.80]	[1.65, 2.35]	[0.33, 0.95]	[0.13, 0.70]	[0.43, 1.08]
C_{33}	[0.30, 0.95]	[0.03, 0.55]	[0.28, 0.83]	[0.13, 0.70]	[0.25, 0.85]	[0.33, 0.95]	[0.73, 1.43]	[0.83, 1.58]	[1.18, 1.98]	0.00	[1.55, 2.35]	[0.83, 1.25]	[0.03, 0.55]	[1.75, 2.55]
C_{34}	[0.30, 0.90]	[0.03, 0.55]	[0.08, 0.60]	[0.48, 1.20]	[0.38, 1.00]	[0.38, 1.05]	[1.43, 2.15]	[1.95, 2.68]	[1.90, 2.65]	[1.55, 2.30]	0.00	[0.53, 1.18]	[0.30, 0.90]	[1.38, 1.95]
C_{41}	[1.85, 2.65]	[0.83, 1.50]	[1.13, 1.85]	[0.40, 1.05]	[0.63, 1.23]	[0.68, 1.33]	[0.58, 1.08]	[0.03, 0.55]	[0.18, 0.75]	[0.28, 0.83]	[0.08, 0.65]	0.00	[0.50, 1.05]	[1.10, 1.90]

C_{42}	[0.18, 0.75]	[0.03, 0.55]	[0.00, 0.50]	[1.38, 2.05]	[1.25, 1.95]	[0.38, 1.05]	[0.95, 1.68]	[0.13, 0.65]	[0.00, 0.50]	[0.03, 0.55]	[0.05, 0.60]	[0.33, 0.88]	0.00	[0.18, 0.75]
C_{43}	[0.58, 1.23]	[0.05, 0.60]	[0.55, 1.18]	[0.25, 0.80]	[0.08, 0.65]	[0.18, 0.75]	[0.25, 0.85]	[0.20, 0.80]	[0.40, 1.10]	[2.00, 2.85]	[1.25, 1.80]	[0.73, 1.43]	[0.20, 0.75]	0.00

Table 3 Sum of influences exerted on and received by dimensions and criteria

$\boldsymbol{T_C}$	*r*	*s*	*r*+*s* (Crisp)	*r*-*s* (Crisp)
Bike (D_1)	[0.593, 1.239]	[0.606, 1.239]	[1.119, 2.478]	[-0.646, 0.634]
Functions (C_{11})	[2.758, 5.089]	[2.545, 4.882]	[5.303, 9.971] (7.962)	[-2.124, 2.544] (-2.113)
Appearance (C_{12})	[1.531, 3.843]	[1.496, 3.619]	[2.927, 7.463] (4.586)	[-2.088, 2.448]
Comfortable ride (C_{13})	[1.772, 4.028]	[2.301, 4.506]	[4.073, 8.534] (6.102)	[-2.735, 1.727]
Rental System (D_2)	[0.687, 1.329]	[0.679, 1.317]	[1.366, 2.646]	[-0.630, 0.650]
Payment methods (C_{21})	[2.148, 4.389]	[2.327, 4.637]	[4.475, 9.026] (6.710)	[-2.489, 2.062]
KIOSK (C_{22})	[2.113, 4.371]	[2.315, 4.571]	[4.428, 8.942] (6.621)	[-2.457, 2.057]
Price (C_{23})	[2.694, 4.961]	[2.341, 4.575]	[5.035, 9.536] (7.439)	[-1.808, 2.620]
Information (C_{24})	[2.724, 4.922]	[2.691, 4.797]	[5.415, 9.719] (7.816)	[-2.033, 2.231]
Infrastructure (D_3)	[0.858, 1.444]	[0.777, 1.365]	[1.635, 2.809]	[-0.507, 0.667]
Number of docks (C_{31})	[2.737, 4.667]	[2.599, 4.545]	[5.336, 9.212] (7.410)	[-1.808, 2.068]
Number of Youbikes (C_{32})	[3.095, 5.067]	[3.157, 5.128]	[6.252, 10.95] (8.678)	[-2.033, 1.910]
Bike tracks (C_{33})	[2.923, 5.000]	[2.535, 4.620]	[5.458, 9.620] (7.773)	[-1.697, 2.465]
Rental stations (C_{34})	[3.682, 5.694]	[3.084, 5.109]	[6.766, 10.80] (9.431)	[-1.420, 2.610]
Safety (D_4)	[0.616, 1.231]	[0.692, 1.323]	[1.309, 2.555]	[-0.707, 0.539]
Bike safety (C_{41})	[2.559, 4.792]	[2.773, 5.019]	[5.332, 9.811] (7.829)	[-2.460, 2.019]
Information security (C_{42})	[1.541, 3.699]	[2.035, 4.179]	[3.576, 7.879] (5.327)	[-2.638, 1.665]
Environmental safety (C_{43})	[2.402, 4.488]	[2.583, 4.828]	[4.985, 9.315] (7.253)	[-2.426, 1.904]

The above network-influence relationships can be visualized by mapping the dataset of (r_i+s_i) and (r_i–s_i) as an INRM within the four dimensions, as illustrated in Fig. 1. The arrows indicate the directions of influence. Fig. 1 shows the dimensions with the positive net influence grouped as causes while the negative net influences are grouped as effects. The INRM indicates that "safety" is the final affected dimension, while the other three dimensions have an interactive relationship. The figure also shows that the very close locations between "rental system" and the "bike" mean a strong interdependency within the two dimensions.

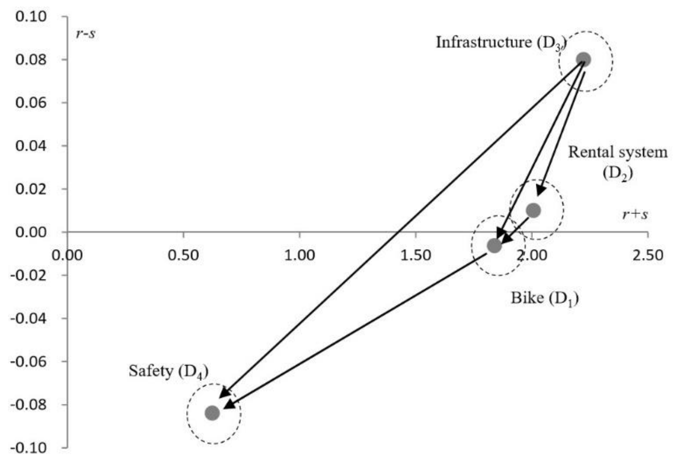

Fig. 1 The INRM of evaluation system

4.3. The Influence Weights in the Evaluation System

The grey DANP combines the DEMATEL technique with the concepts of ANP and Grey Theory to derive the influence weights as well as to consider the interdependency and feedback effects between the dimensions and the criteria. The influence weights reflect the importance of the users' cognition of direct and indirect influences within the system. A higher value means greater significance to those considering to riding a public bike. We can derive the unweighted super-matrix. However, the original ANP method treats the degree of influence between dimensions as equal, thus divide the values of the super-matrix by a number of dimensions in each cluster. However, this assumption could be irrational, as observed from the results of the grey DEMATEL, where the influence is different between dimensions. This shortcoming can be fixed in this proposed model. The grey influence weights (i.e., grey global weights) can be calculated from the infinite power of the limited grey weighted super-matrix until convergence of the super-matrix. In this steady-state super-matrix each row possesses the same value which indicates the global weight of each criterion. The DANP method allows us to derive the local weights of the assessed sub-systems at their respective hierarchical levels, and the global weights, which helps to understand the absolute weight of the individual sub-systems in the overall perspectives, as shown in Table 4. The results reveal that infrastructure (D_3) is the most important dimension, followed by safety (D_4), rental system (D_2) and bikes (D_1), respectively. Function (C_{11}), information (C_{24}), number of bikes (C_{32}) and bike safety (C_{41}) are the most importance criteria in each sub-system.

Table 4 Influence weights of system dimensions and factors

Dimension	Local Weight	Ranking	Criteria	Local Weight	Ranking	Global Weight
D_1	[0.224, 0.237]	4	C_{11}	[0.375, 0.407]	1	[0.089, 0.091]
			C_{12}	[0.217, 0.294]	3	[0.051, 0.066]
			C_{13}	[0.345, 0.365]	2	[0.082, 0.083]
D_2	[0.247, 0.251]	3	C_{21}	[0.238, 0.254]	2	[0.060, 0.063]
			C_{22}	[0.236, 0.250]	4	[0.059, 0.062]
			C_{23}	[0.244, 0.251]	3	[0.061, 0.062]
			C_{24}	[0.256, 0.270]	1	[0.063, 0.067]
D_3	[0.260, 0.276]	1	C_{31}	[0.220, 0.241]	4	[0.061, 0.063]
			C_{32}	[0.247, 0.292]	1	[0.068, 0.076]
			C_{33}	[0.226, 0.242]	3	[0.062, 0.063]
			C_{34}	[0.247, 0.289]	2	[0.067, 0.075]
D_4	[0.252, 0.253]	2	C_{41}	[0.360, 0.384]	1	[0.091, 0.097]
			C_{42}	[0.270, 0.290]	3	[0.068, 0.075]
			C_{43}	[0.344, 0.346]	2	[0.087, 0.089]

4.4. Weighted-gap Analysis of The Public Bike System

Data from the second part of the survey was used to explore the gaps to the aspiration levels through seeking to understand the lagged items of service quality. Modified VIKOR was then applied to the weights derived from grey DANP analysis to evaluate the weighted-gap for each criterion. The performance was expressed as a linguistic variable which was then transformed into the grey value. The weighted-gaps for the Youbike system can be calculated by following the steps of the modified VIKOR method. **Table 5** represents the weighted-gaps for each criterion and each dimension. The results indicate how much the weighted-gap in each dimension or criterion needs to improve to achieve the aspiration level. Comparison can be made with **Table 5** that also shows the crisp values. The results indicate that the environmental safety (C_{43}) has the largest weighted-gap (0.157), followed by bike safety (C_{41}) (0.132). In other words, users deemed those items to be most in need of improvement at the current stage. Surprisingly, payment method (C_{21}) and price (C_{23}) demonstrated better performances with smaller weighted-gaps of 0.055 and 0.066, respectively. Based on the weighted-gaps in each criterion, we can derive the weighted-gap for each dimension which are shown in **Table 6**. The results show that infrastructure (D_3) has the largest weighted-gap (0.437) while the rental system (D_2) has the smallest weighted-gap (0.291). The above weighted-gap analysis combined with the influential weights and INRM results provide very useful information that can help decision-makers find the direction where improvement is needed. We will discuss some management implications in Section 5.

Table 5 Weighted-gaps of criteria

Criterion	Performance	Normalization	Weighted-gap	Crisp value
Functions (C_{11})	[3.117, 4.028]	[0.194, 0.377]	[0.073, 0.153]	0.115
Appearance (C_{12})	[2.956, 3.880]	[0.224, 0.409]	[0.049, 0.120]	0.076
Comfortable ride (C_{13})	[2.887, 3.806]	[0.239, 0.423]	[0.082, 0.154]	0.121
Payment methods (C_{21})	[3.334, 4.188]	[0.162, 0.333]	[0.039, 0.085]	0.050
KIOSK (C_{22})	[3.013, 3.918]	[0.216, 0.397]	[0.051, 0.099]	0.067
Price (C_{23})	[3.063, 3.955]	[0.209, 0.387]	[0.051, 0.097]	0.066
Information (C_{24})	[2.900, 3.825]	[0.235, 0.420]	[0.060, 0.113]	0.081
Number of docks (C_{31})	[2.732, 3.681]	[0.264, 0.454]	[0.058, 0.109]	0.077
Number of Youbikes (C_{32})	[2.654, 3.610]	[0.278, 0.469]	[0.069, 0.137]	0.101
Bike tracks (C_{33})	[2.288, 3.203]	[0.359, 0.542]	[0.081, 0.131]	0.106
Rental stations (C_{34})	[2.877, 3.803]	[0.239, 0.425]	[0.059, 0.123]	0.085
Bike safety (C_{41})	[2.843, 3.790]	[0.242, 0.431]	[0.087, 0.165]	0.132
Information security (C_{42})	[2.892, 3.829]	[0.234, 0.422]	[0.063, 0.125]	0.090
Environmental safety (C_{43})	[2.403, 3.345]	[0.331, 0.519]	[0.114, 0.179]	0.159

Table 6 Weighted-gaps of dimensions

Dimension	S_i	Qi	Gap (R_i)	Crisp value
Bikes (D_1)	[0.204, 0.428]	[0.239, 0.423]	[0.221, 0.425]	0.305
Rental System (D_2)	[0.201, 0.395]	[0.235, 0.420]	[0.218, 0.407]	0.291
Infrastructure (D_3)	[0.267, 0.500]	[0.359, 0.542]	[0.313, 0.521]	0.437
Safety (D_4)	[0.264, 0.470]	[0.331, 0.519]	[0.298, 0.495]	0.407

5. Discussion

One advantage of the proposed model is that it cannot only find the weighted-gaps for service quality for each criterion but it can also provide directions for improvement. For example, the results of cause and effect analysis (grey DEMATEL) combined with the INRM provide directions for improvement for managers. Observing the influence degrees in Table 3, we find that infrastructure has the highest net influence in the causal dimension while (according to the weighted-gaps for the evaluation criteria in Table 5) environmental safety (15.9%) has the largest weighted-gap, followed by bike safety (13.2%) and comfortable ride (12.1%). These results have important implications for Youike system managers that is to improve the service quality, good infrastructure is needed because this will directly and indirectly affect other evaluation criteria and lead to better performance. However, from the bike users' point of view, safety appears to be the most important item of concern (Table 5). This includes bike safety, information security and environmental safety including both software and hardware.

The influence weights and weighted-gaps provide other management implications. Table 4 shows that when people consider using public-bikes, functions (C_{11}), information (C_{24}), number of bikes (C_{32}) and bike safety (C_{41}) are the most important items respectively for each dimension. To increase income with the extra amount budgeted to improve the quality of the service of the Youbike system, the Taipei City government canceled its long-standing policy of the first 30 minutes being free in 2015. This new policy has been criticized by the media and public, claiming that it would reduce the people's intention to use the bikes. However, the gap analysis results in Table 5 indicate that weighted-gap of price is very small (0.066). This interesting result shows that changing the first 30 minute free policy could be the correct direction to improve the service quality. Obviously, people care more about improving the infrastructure rather than the cost. Rental system has the smallest weighted-gap which indicates that people are satisfied with the current system so priorities for its improvement can be set later.

6. Conclusion and Remarks

The success of bike-sharing programs depends on how well the users' needs are satisfied. The service quality of this mode of transport has proven to have a positive effect on intention to use. This study investigate the service quality of the bicycle sharing system. The proposed model considers the interdependency of the criteria and the uncertainty of decision-maker information. The aspiration level is used as the benchmark for improvement of service quality. Our empirical results show that infrastructure is a causal factor which needs immediate improvement.

The study results confirm the decision to build special bike lanes in downtown areas, a new policy of the Taipei City government. Another important finding is that the current fare has a negligible effect on service quality. Thus, cancelling the long-time policy of the first 30 minutes free should not reduce the service quality and is the correct direction to build a greener Taipei City.

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