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Research Article

Innovative Bike-Sharing in China: Solving Faulty Bike-Sharing Recycling Problem

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In China, based on the mobile Internet technology and global positioning system (GPS), innovative bike-sharing is different from traditional bike-sharing system with docking station, for its flexibility and convenience. However, innovative bike-sharing system faces operational challenges, especially in faulty bike-sharing recycling (FBSR) problem. In this paper, a framework is designed based on the optimization method to solve the FBSR problem so that it can minimize the total recycling costs by taking the route optimization and loading capacity ratio as constraints. The FBSR method combines the K-means method for clustering faulty bike-sharing with planning recycling route for operational decisions. Moreover, CPLEX solver is used to obtain the desired result of the FBSR model. Finally, a case study based on a certain area in Beijing, China, is used to verify the validity and applicability of the model. The results show that the value of loading capacity ratio and the number of clustering points greatly affect the results of FBSR problem. Four vehicles are designated to execute FBSR tasks required by different clustering points. This study is of considerable significance for the bike-sharing promotion in the last-mile situation to the real problems arising in the initial period.

1. Introduction

Bike-sharing systems are becoming increasingly popular in cities around the world because they are cheap, efficient, healthy, and green. In recent years, with the development of mobile Internet and global positioning system (GPS) becoming increasingly affordable [1], an innovative bike-sharing system without docking station emerged in 2015 in China. Bike-sharing system can effectively solve the last-mile problem in multimodal transportation; in addition, many Chinese cities show more cycling than the other international cities [2], which leads to wide spread of bike-sharing systems across China now. Spatial distribution of main dockless bike-sharing systems in China is shown in Figure 1.

Compared with traditional bike-sharing [3, 4], dockless bike-sharing is more flexible and more convenient for the users. Bicycles of bike-sharing systems are widely distributed, thus reducing travel distance from traveler to bicycle docking station. It is convenient for users to use bike-sharing; when users use bike-sharing for the first time, first, users should register directly in the app and scan their identification and give a deposit. Then, the smart bike-sharing app will show a map of all the bicycles around users and locate the closest bike. After that, users scan the Quick Response code with the app and within 10 seconds they can hear the click and hit on the road. However, with all the benefits of this innovative bike-sharing system, here come operational challenges.

It is worth noting that there are a large number of people cycling every day. It is unavoidable that bike-sharing may malfunction in its routine use, and accidents might take place due to its faults. According to some statistics, there are more than 10 million bicycles in bike-sharing systems, and faulty bicycles rate slightly less than 1%. If we calculate with rate of 1% faulty bicycles, there will be 100,000 faulty bicycles in China. Meanwhile, lots of bicycles will be scrapped usually in three years in China. These factors could cause the following: (a) the presence of the faulty bike-sharing severely threatens users' safety; (b) the service quality of bike-sharing system will affect the reputation of the companies; (c) faulty bicycles in the city have a very

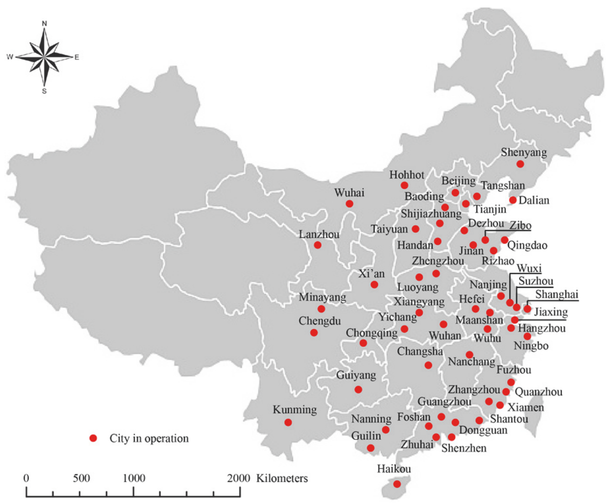


Figure 1: Spatial distribution of main dockless bike-sharing systems in China.

bad effect on the city appearance. Therefore, faulty bike-sharing recycling (FBSR) is a very significant issue that should be solved. Moreover, the distribution of bicycles of innovative bike-sharing system is rather dispersed since bike-sharing can park without docking station, whereas for traditional bike-sharing system, faulty bicycles are readily discovered and easily processed at bicycle docking station. Comparatively speaking, it is more difficult for the innovative bike-sharing system to recycle faulty bicycle than traditional bike-sharing. Thus, solving the FBSR problem is the key to reduce recycling costs for the authorities and operators with the means.

Therefore, this paper presents a framework design and optimization method to solve FBSR problem. Firstly, the K-means clustering method is used to divide the faulty bike-sharing into different service points. Then, a FBSR model is established to minimize the total recycling costs with loading capacity ratio as a constraint. At last, this method is verified based on a case study in Beijing, China.

The remaining part of this paper is organized as follows. The relevant literature is reviewed in Section 2. The framework design of faulty bike-sharing recycling is presented in Section 3. Section 4 describes the modeling methodologies and model specifications. In Section 5, the empirical results of the models and the effects of the explanatory variables are presented. The final section provides a summary of the research findings with possible extensions of the research.

2. Literature Review

Since a bike-sharing system was first introduced in the 1960s [5], lots of bike-sharing systems have been implemented throughout the world [6, 7], and now the bike-sharing system has become a necessary for city transportation. According to research by different scholars, the bike-sharing system has potentials due to the following reasons: (a) reducing traffic congestion and fuel use [8]; (b) behavioral shifts towards increased bicycle use for daily mobility [9]; (c) a growing perception of the bicycle as a convenient transportation mode [1].

The existing literature on bike-sharing systems is mainly focused on the traditional bike-sharing system with docking stations including development policies and safety issues [10–12], operation scales and the operator[8, 13], and benefit on the environment [14–18]. In order to improve the user experience for bicycle use and reduce the operating costs, many researchers study rebalancing operations. Chemla et al. [19] were the first to introduce rebalancing operations for bike-sharing system and proposed tabu search algorithms for solving it. Schuijbroek et al. [20] presented unified dual-bounded service level constraints that add inventory flexibility and vehicle routing for static rebalancing in bike-sharing systems. Ghosh et al. [21] developed an optimization formulation to reposition bikes using vehicles while considering the routes for vehicles and future expected demand to improve bike-sharing availability and reduce the usage of private vehicles. Pfrommer et al. [22] proposed a heuristic algorithm for solving the dynamic rebalancing problem with multiple vehicles and presented a dynamic pricing strategy that encouraged users to return bikes to empty stations. However, the bike-sharing system in a city does not have the restriction of fixed docking stations. So the existing studies cannot solve the FBSR in China.

Recently, the new bike-sharing system without docking station has attracted attention from a few scholars. Reiss and Bogenberger [23] created a demand model to obtain an optimal distribution of bikes within the operating area, based on a detailed GPS-data analysis for the bike-sharing system. Caggiani et al. [24] suggested a method to use the revenue collected by a congestion price policy to implement a bike-sharing system. Pal and Zhang [25] proposed a hybrid nested large neighborhood search with variable neighborhood descent algorithm, which can solve static rebalancing problems for bike-sharing system. Caggiani et al. [26] proposed an operator-based bike redistribution methodology that started from the prediction of the number and position of bikes over operating area and ended with a decision support system for the relocation process. Cheng and Gao [27] studied the revenue changes of the platform after the bike-sharing platform adopted the monthly strategy and obtained the best monthly subscription pricing to maximize the platform revenue. However, compared with bike-sharing scale in China, these studies were based on case studies that are of much smaller scale. Therefore, FBSR problem deserves more attention.

In addition, Cervero et al. [28] found that the single strongest predictor for bicycle use is the availability of a bike. The FBSR is one of the important means to ensure the availability of bike-sharing. However, up to now, there is no research on faulty bike-sharing recycling in the literature. Thus, this study bridges this gap by reporting a solution algorithm that addresses this issue and helps bike-sharing companies to reduce operating costs particularly in Chinese cities.

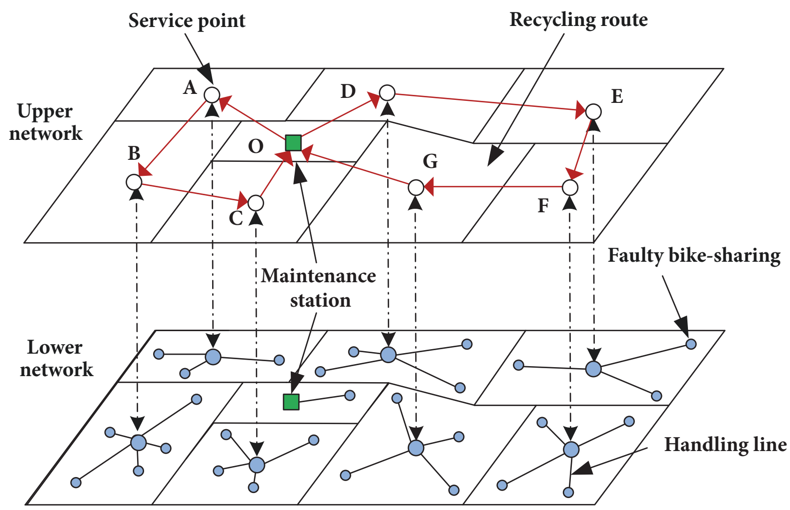


Figure 2: Multilevel faulty bike-sharing recycling network.

3. Framework Design of FBSR

3.1. Faulty Bike-Sharing Definition and Classification. In this paper, three types of bicycle as faulty bicycles are defined as follows.

(i) Fault of cycling: it happens when the users unlock the bicycles and find that the bicycle cannot be used; then the users will send the information through the mobile phone app. When the bike-sharing system server receives the information of the faulty bicycle status and location, the bike-sharing company will have it repaired.

(ii) Fault of communication: it happens when bicycles are identified as faulty bike-sharing owing to GPS equipment damage, and the system server will prohibit users from using this bicycle (ignoring GPS equipment lost contact while cycling).

(iii) End of the service life: if a bicycle has reached the state's mandatory write-off standard (generally three years in China), the bike-sharing system server will identify the bicycle as faulty bike-sharing. Then this bicycle will be forced to scrap, prohibiting users from cycling.

3.2. Recycling Rules. Multilevel faulty bike-sharing recycling network is shown in Figure 2, which is divided into upper network and lower network. The lower network shows that faulty bike-sharing in multiple locations within a certain area will be concentrated at clustering service point in the area, where blue dots indicate faulty bike-sharing in some locations and the lines among some dots stand for handing line. The upper network indicates that the clustering service points of each area are obtained, where dots indicate service point, red line shows the line direction, and the green one represents maintenance station. The FBSR model can be applied to the best routes so that total recycling costs are minimized.

For the description, ground rules are established as follows.

(1) A number of maintenance stations are established in a city. Each maintenance station is in a fixed location. The maintenance station provides faulty bicycles maintenance service in a certain area, and faulty bicycles are recycled once a day. It should be noted that the faulty bicycles will not be classified. The faulty bike-sharing information is collected at a fixed time every day; if there are any updates about faulty bike-sharing, they will be dealt with the next day.

(2) Within each local area, faulty bicycles are clustered for different service points according to their locations, which are made in lower network such as point A in Figure 2. To perform a task, a service vehicle will be parked in the clustering service point where the faulty bicycles are carried back by hands. Then service vehicle will move on to the next service point such as point B in Figure 2 after the task is completed at point A. Finally, the faulty bike-sharings of each clustering service point are sent to maintenance point along the planned best line.

(3) There are a number of recycling vehicles in maintenance station. These vehicles traverse all service points from maintenance station in order to recycle all faulty bicycles. It is worth noting that the service point is not fixed, and the service point should have enough space for recycling vehicle to park.

Therefore, there are two key issues to deal with to complete one FBSR in an area:

(i) How to determine the number and the location of bike-sharing service points that are available for recycling vehicles.

(ii) How to determine routes for recycling vehicles to traverse all service points from maintenance station.

3.3. Recycling Framework. Based on the analysis of faulty bike-sharing definition, classification, and recycling rules, the flowchart of faulty bike-sharing recycling is shown in Figure 3. There are four steps in the framework of FBSR, which are the data collection and processing, the faulty bike-sharing clustering, the planning of recycling route, and the performing of recycling task. The details of recycling framework can be described as follows.

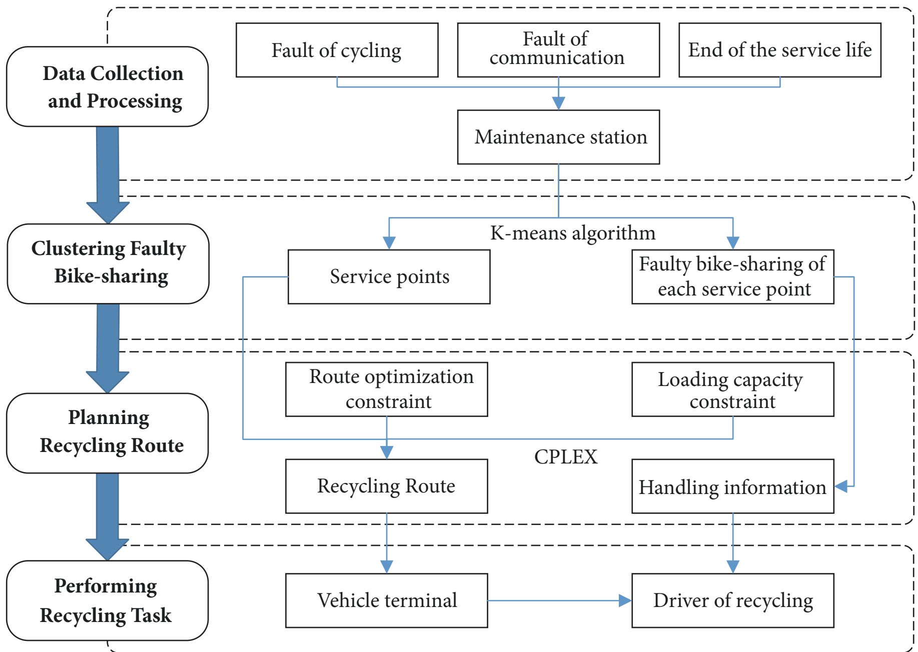


Figure 3: Flowchart of faulty bike-sharing recycling.

Step 1 (data collection and processing). There are three types of faulty bike-sharing in the section above. For type 1, the system server will directly set it as faulty bike-sharing to be processed. For type 2, when the location information of bike-sharing is lost, the system needs to record the last received location information. Type 1 and type 2 bicycles will be stored in the faulty bike-sharing database. For type 3, when a bike-sharing company launches bicycles in the city every time, the system server will set the time of the bicycles' service life, after which the time of service life of these bicycles will be stored in the faulty bike-sharing database by system server. By confirmation and processing of three types above, the bike-sharing company will have these faulty bikes fixed.

Step 2 (faulty bike-sharing clustering). Faulty bike-sharing clustering is represented by lower network as shown in Figure 2. The system will use the K-means algorithm to cluster the faulty bicycles to different service points in each area according to the result of data collection and processing. Based on the different service point, the faulty bicycles are carried to this location by manual handling and wait for company trucks to carry them in each clustering service point along the planned route driving to maintenance point.

Step 3 (planning recycling route). Planning recycling route is represented by the upper network as shown in Figure 2. Every recycling route is planned based on the result of faulty bike-sharing clustering. Meanwhile, recycling route optimization tries to achieve minimum total recycling costs with route optimization and vehicle capacity as constraints. The recycling vehicles start from the maintenance station, collect all the faulty bicycles, and finally return to the station.

Step 4 (performing recycling task). According to the result of Step 2 and Step 3, the recycling route and the faulty bike-sharing location information are sent to the vehicle terminal so that every driver of recycling vehicle can perform the task of recycling faulty bicycles.

It is worth noting that Step 2 and Step 3 are the key scientific problems. The FBSR aims at recycling all faulty bicycles and traversing all service points while optimizing the routes for recycling vehicles in order to reduce the costs of recycling.

4. Model Formulation

Based on framework design of faulty bike-sharing recycling, the FBSR model in this paper mainly consists of two parts: faulty bike-sharing clustering and recycling route modeling.

4.1. Faulty Bike-Sharing Clustering. K-means algorithm [27] is a method commonly used to automatically partition a dataset into k groups. We use it to cluster the faulty bicycles to different service points in an area. Suppose that a data set $\{x_1, \ldots, x_N\}$ consists of N observations of a random 2-dimensional Euclidean variable x. The objective is to partition the dataset into some number K of clusters, given the value of K. First, introduce a set of 2-dimensional vectors c_k, where $C = \{c_k, k = 1, \ldots, K\}$; c_k represents the center of the kth cluster. Second, find an assignment of data points to clusters, so that the sum of the squares of the distances of each data that points to its closest vector c_k is a minimum.

$$\min \quad SSE = \sum_{n=1}^{N} \sum_{k=1}^{K} r_{nk} \left\| x_n - c_k \right\|^2 \tag{1}$$

$$r_{nk} = \begin{cases} 1, & x_n \in c_k \\ 0, & x_n \notin c_k \end{cases} \quad (2)$$

where SSE (sum of squares for error) is the sum of the distances from the data points to the clustering points, binary indicator variables $r_{nk} \in \{0, 1\}$, and k describes which cluster the data point x_n is assigned to, so that if x_n is assigned to cluster k, then $r_{nk} = 1$, and $r_{nj} = 0$ for $j \neq k$.

4.2. Recycling Route Modeling. We develop a recycling route model, where the decision-maker (the transit authority or operator) wishes to determine recycling route while minimizing total recycling costs. It is assumed that the result of faulty bike-sharing clustering remains unchanged throughout that period. Consider a network rooted at depot (the maintenance station) named $\{0\}$ and let the depot be denoted as node 0; S_0 is the set of nodes including the maintenance station and service points; that is, $S = S_0 \backslash \{0\}$. We suppose that travel time of recycling vehicles retains their characteristics throughout that period. Consider a maintenance station that consists of H vehicles, $h = 1, \ldots,$ H. Identical recycling vehicles with capacity cap_h serve the route for all service points, $\forall i \in S_0, \forall j \in S_0, i \neq j$, starting from depot ($i = 0$) and ending at depot ($j = 0$). The travel time (ignoring dwell time) of each vehicle between successive points i and j is denoted by t_{ij}. In order to model FBSR problem, we make assumptions as follows:

(i) All route cycles are repeated with identical characteristics.

(ii) The round-trip distance between the two service points is the same.

(iii) The location of the faulty bicycle without positioning is accurate.

Thus, the optimization problem is

$$x_{ijh} \begin{cases} 1 & \text{if vehicle } h \text{ traverses arc } (i, j) \\ 0 & \text{otherwise} \end{cases}$$
$$y_{ih} \begin{cases} 1 & \text{if vehicle } h \text{ serves node } i \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

$$\text{Minimize} \quad C_m \sum_{i \in S_0} \sum_{j \in S_0} \sum_{k \in H} t_{ij} x_{ijh} \quad (4)$$

$$\text{Subject to} \quad \sum_{i \in S_0} x_{ijh} = y_{hj} \quad \forall j \in S_0, \ h \in H \quad (5)$$

$$\sum_{j \in S_0} x_{ijh} = y_{hi} \quad \forall i \in S_0, \ h \in H \quad (6)$$

$$\sum_{k \in H} y_{hi} = 1 \quad \forall i \in S \quad (7)$$

$$\sum_{i} y_{hi} d_i \leq cap_h \quad h \in H \quad (8)$$

$$y_{hi} \in \{0, 1\} \quad \forall i \in S_0, \ h \in H \quad (9)$$

$$x_{ijh} \in \{0, 1\} \quad \forall i, j \in S_0, \ h \in H \quad (10)$$

The objective function minimizes the total recycling costs. It is multiplied by C_m, which indicates recycling vehicles operating costs per unit time. d_i indicates the number of bicycles handled by hands at node i.Constraint (6) states that if a vehicle h decides to serve node j which is serviced by only one vehicle, then it should travel along the arc from that node i, that is, arc(i, j). Constraint (7) states that a vehicle h has traversed arc(i, j) from node i which is serviced by only one vehicle; then it should travel along the arc leading to node j. Constraint (6) and constraint (7) ensure that the path of each vehicle is successive. Constraint (8) ensures that every node is serviced by only one vehicle, whereas constraint (9) ensures that the vehicle capacity is not exceeded. In order to model the entire process of FBSR, the formulation can easily accommodate fixed costs by modification of the objective function as follows:

$$C_m \sum_{i \in S_0} \sum_{j \in S_0} \sum_{h \in H} t_{ij} x_{ijh} + C_n \sum_{i \in S_0} \bar{t} n_i \quad (11)$$

The objective includes two components. The first refers to the objective function (5). The second refers to the expectation of the sum of manual handling costs, where C_n indicates faulty bicycles manual handling costs per unit time, $\bar{t}$ is the average time of handling each faulty bicycle, and, based on formula (1), n_i is the number of faulty bicycles in the ith service points.

Let us define

$$\bar{t} = \frac{2 \times SSE}{\bar{v} \sum_{i \in S} n_i} \quad (12)$$

where $\bar{v}$ is the average velocity of handling each faulty bicycle. It is multiplied by 2 because each vehicle must return to the clustering points after service. Objective function (11) is now

$$C_m \sum_{i \in S_0} \sum_{j \in S_0} \sum_{h \in H} t_{ij} x_{ijh} + C_n \frac{2 \times SSE}{\bar{v}} \quad (13)$$

In order to improve the utilization rate of recycling vehicles, we propose a constraint to restrict load capacity as follows:

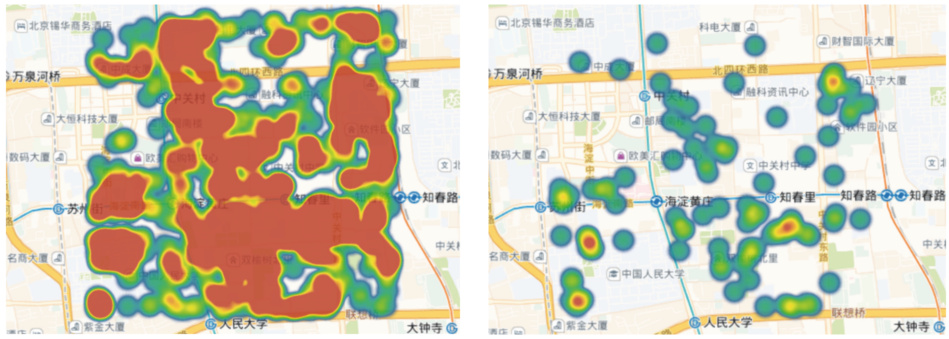
$$\sum_{i \in S} y_{hi} n_i \geq \lambda cap_h \quad \forall h \in H \quad (14)$$

where λ is the coefficient of load capacity ratio.

Besides, in order to avoid the loop in the route, it is sufficient that problem includes the following bonding constraint:

$$U_{ih} - U_{jh} + |S| \cdot x_{ijh} \leq |S| - 1 \quad \forall i, j \in S_0, \ h \in H \quad (15)$$

where U_{ih} is the auxiliary variable to eliminate the constraint of loop for hth vehicle.



(a) (b)

Figure 4: Heat map of bike-sharing.

In the process of problem solving, the recycling route model belongs to 0-1 integer programming model. Considering the scale of the problem, it can be solved by CPLEX solver with branch and bound approach for its advantages of the direct and concise input and strong computation ability.

5. Case Study

In this section, a real-world bike-sharing from an area of Beijing, China, was selected as a case study. The test area is a square area that has a side length of 2.6 km and Haidian Huang Zhuang subway station is selected as areal maintenance station. We set the number of recycling vehicles in a maintenance station as 4, and the capacity of each vehicle is 30 bicycles. There are 1900 bicycles (Figure 4(a)) in this area, and we randomly select 95 bicycles (5% of the total) as faulty bike-sharing, which is shown in Figure 4(b). Red indicates that faulty bicycles are dense, followed by orange, and blue means fewer bicycles in heat map.

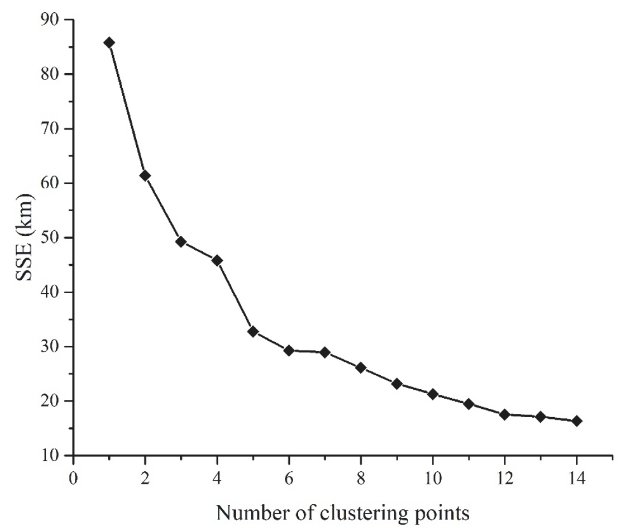


Figure 5: The SSE graph of K-means.

5.1. Result of Faulty Bike-Sharing Clustering. We set up 1 to 14 groups clustering experiment. The times of iterations of each clustering algorithm are not more than 20, which proves that the computation is highly efficient. The *SSE* graph of K-means is shown in Figure 5. We show different clustering points in the x-axis and *SSE* of different clustering points in the y-axis. From the chart, it can be seen that the *SSE* of the clustering is stable when we select 12 clustering points, which is 17.531 km. We first select 12 clustering points for experimental analysis.

Latitude and longitude coordinates of the clustering centers are obtained by the K-means algorithm and their locations on a map are shown in Figure 6. From the diagram, it can be seen that the clustering points distribute relatively equally in this area, due to the fact that faulty bikes are distributed relatively evenly.

5.2. Recycling Route Analysis. Considering the result of faulty bike-sharing clustering by K-means algorithm of 12 service points, $|S| = 12$. Travel time t_{ij} between every clustering point is obtained by Google Maps (see Tables 4, 5, and 6), which is calculated based on the shortest time of driving. The coefficient of load capacity ratio λ is 0.7. The recycling vehicle operating costs C_m are 5.5 Renminbi (RMB) per minute, and the faulty bicycles manual handling costs C_n are 0.5 RMB per minute. The average velocity of handling each faulty bicycle $\overline{v}$ is 60 m/min. The optimal results of the FBSR model are solved with the CPLEX solver, as shown in Table 1.

In this example, we can see that the total costs are 677 RMB from the FBSR model. In Table 1, travel time is derived from the recycling route model; carrying time is derived from the clustering results for each service point. It can be seen clearly that each route of total time is between 112 min and 206 min, which demonstrates that the results of faulty bike-sharing clustering and recycling route are reasonable. In addition, the number of bicycles loaded is 24, 23, 25, and 23 for each vehicle; capacity ratio of each vehicle is more than 76.7%. According to the FBSR model, each vehicle achieves an optimized recycling route of FBSR with the vehicle load capacity constraint.

The comparison experiment for the coefficient of load capacity ratio was conducted. Figure 7 shows the number of bicycles loaded for the different capacity ratio, and the higher the coefficient of load capacity ratio is, the more average

Table 1: The optimal result of FBSP model.

Vehicle	Capacity ratio	Route	Travel time/min	Carrying time/min	Total time/min	Total costs/RMB
1	80%	0 → 1 → 4 → 2 → 10 → 0	17	95	112	141
2	76.7%	0 → 5 → 9 → 7 → 0	17	176	193	181.5
3	83	0 → 11 → 3 → 12 → 0	24	182	206	223
4	76.7%	0 → 6 → 8 → 0	12	131	143	131.5
Total			70	584	654	677

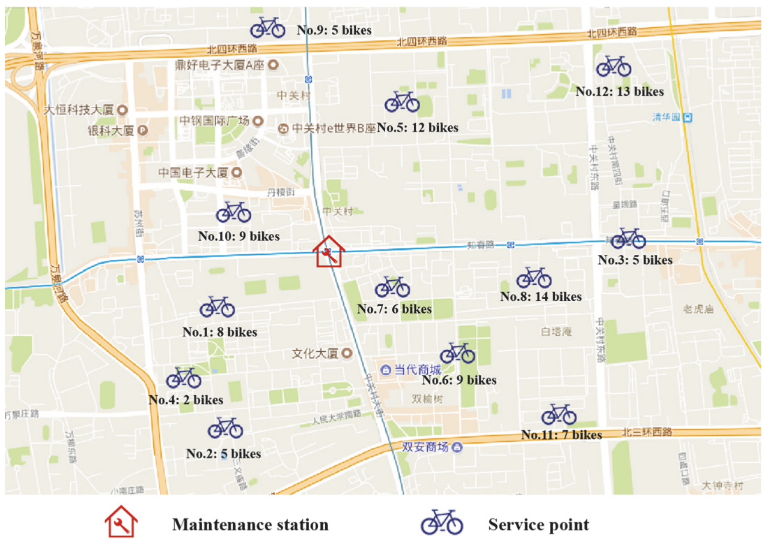


Figure 6: The graph of clustering centers by K-means.

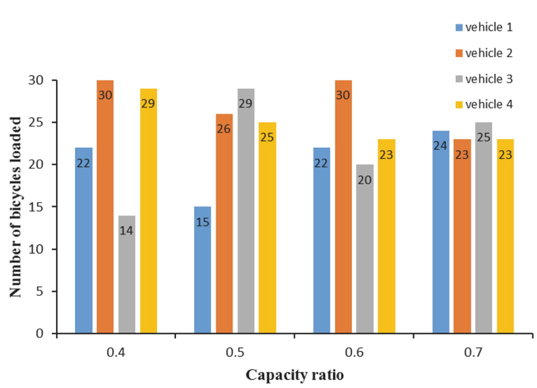


Figure 7: The number of bicycles loaded for the coefficient of load capacity ratio.

number of bicycles is loaded. It means that the load capacity constraint has an impact on the result of the FBSR model. In Table 2, we may observe travel time, carrying time, and total cost in several coefficients of load capacity ratios, which shows the optimal result of FBSP model for the different capacity ratio. We can find that travel time and capacity ratio have a positive correlation; that is, the lower the value of the capacity ratio is, the lower the travel time is and the lower the costs are. The lowest value of the capacity ratio is 0.4, which responds to the lowest travel time, 67, and the lowest costs, 660.5. And the highest value of the capacity ratio is 0.7, which responds to the highest travel time, 70, and the highest costs, 677. However, the value of capacity ratio will affect the fairness of the recycling task and the utilization rate of the recycling vehicles; as a result, decision-makers can consider adding the maximum coefficient as objective to FBSR model according to the actual situation of recycling.

Table 3 shows that different clustering points are selected for contrast experiments. According to the experimental results, we can see that the total costs of 10-node clustering points are always the highest with different load capacity rates. Then the results show that the total costs of 12 nodes are more than the total costs of 14 nodes when the coefficient of load capacity ratio is no more than 0.6, and the total costs of 14 nodes are more than those of 12 nodes when the coefficient of load capacity ratio is equal to 0.7. When the number of clustering points is less, the increase in manual operation time will lead to high cost. In addition, the increase in service points will result in an increase of the recycling distance and the higher costs of recycling vehicles operating. Hence, the appropriate recycling scheme should be selected according to the costs changes of C_m and C_n.

Table 2: The optimal result of FBSP model for the different capacity ratio.

λ	Vehicle	route	Travel time/min	Carrying time/min	Total costs/RMB
0.4	1	$0 \to 11 \to 2 \to 4 \to 1 \to 0$	67	584	660.5
	2	$0 \to 5 \to 12 \to 3 \to 0$			
	3	$0 \to 10 \to 9 \to 0$			
	4	$0 \to 8 \to 6 \to 7 \to 0$			
0.5	1	$0 \to 1 \to 4 \to 2 \to 0$	68	584	666
	2	$0 \to 5 \to 9 \to 10 \to 0$			
	3	$0 \to 8 \to 6 \to 7 \to 0$			
	4	$0 \to 12 \to 3 \to 11 \to 0$			
0.6	1	$0 \to 1 \to 4 \to 2 \to 11 \to 0$	69	584	671.5
	2	$0 \to 5 \to 12 \to 3 \to 0$			
	3	$0 \to 10 \to 7 \to 9 \to 0$			
	4	$0 \to 8 \to 6 \to 0$			
0.7	1	$0 \to 1 \to 4 \to 2 \to 10 \to 0$	70	584	677
	2	$0 \to 5 \to 9 \to 7 \to 0$			
	3	$0 \to 11 \to 3 \to 12 \to 0$			
	4	$0 \to 8 \to 6 \to 0$			

Table 3: The effects of the number of clustering points.

Network	λ	Travel time /min	Carrying time /min	Total time /min	Total costs /RMB
10-node	0.4	65	710	775	712.5
	0.5	65	710	775	712.5
	0.6	65	710	775	712.5
	0.7	65	710	775	712.5
12-node	0.4	67	584	651	660.5
	0.5	68	584	652	666
	0.6	69	584	653	671.5
	0.7	70	584	654	677
14-node	0.4	69	546	615	652.5
	0.5	71	546	617	663.5
	0.6	72	546	618	669
	0.7	74	546	620	680

6. Conclusions

This paper introduces the framework design and optimization method to solve FBSR problem. In China, the number of bike-sharing systems grows rapidly due to its flexibility and convenience for the users. However, they face operational challenges such as FBSR problem. For this reason, we presented a framework design of FBSR to solve the problem of recycling faulty bike-sharing. Then, we propose FBSR optimization model that is able to minimize the total recycling costs through the K-means clustering method that is used to divide the faulty bike-sharing into different service points. It can provide bike-sharing company's managers with good insight into the design of a FBSR problem. The comparison among different service points can help decision-makers to choose the best solution. In addition, the vehicle capacity restriction should be included in a FBSR optimization model to improve the number of bicycles loaded for each vehicle.

A typical example solved by CPLEX solver was created to illustrate the proposed model. The results of a case study show that the model works well. It is indicated that the best route recycles the faulty bicycles according to the clustering points. Compared with the values of capacity ratio models in the FBRS model, we can find that travel time and capacity ratio have positive correlation. And the comparison experiment has shown that the number of clustering points has a significant impact on total recycling costs, which needs to be considered carefully in the FBSR model.

Table 4: 10-node travel time matrix for each point (unit: min).

t_{ij}	0	1	2	3	4	5	6	7	8	9	10
0	0	2	6	9	12	4	7	4	7	3	4
1	2	0	4	14	2	6	6	5	12	6	7
2	6	4	0	17	1	12	8	9	16	13	8
3	9	14	17	0	13	7	8	10	7	4	12
4	12	2	1	13	0	12	9	11	13	11	7
5	4	6	12	7	12	0	8	6	8	4	7
6	7	6	8	8	9	8	0	5	4	7	6
7	4	5	9	10	11	6	5	0	7	6	5
8	7	12	16	7	13	8	4	7	0	9	11
9	3	6	13	4	11	4	7	6	9	0	6
10	4	7	8	12	7	7	6	5	11	6	0

Table 5: 12-node travel time matrix for each point (unit: min).

t_{ij}	0	1	2	3	4	5	6	7	8	9	10	11	12
0	0	2	6	7	12	4	4	3	5	5	4	5	11
1	2	0	4	13	2	6	5	4	6	12	7	6	16
2	6	4	0	15	1	12	6	13	13	14	8	6	19
3	7	13	15	0	17	11	5	9	4	7	14	3	5
4	12	2	1	17	0	12	12	11	12	12	7	10	16
5	4	6	12	11	12	0	6	6	5	4	7	9	5
6	4	5	6	5	12	6	0	3	3	9	8	6	8
7	3	4	13	9	11	6	3	0	5	6	5	6	12
8	5	6	13	4	12	5	3	5	0	8	7	7	9
9	5	12	14	7	12	4	9	6	8	0	7	8	12
10	4	7	8	14	7	7	8	5	7	7	0	7	11
11	5	6	6	3	10	9	6	6	7	8	7	0	10
12	11	16	19	5	16	5	8	12	9	12	11	10	0

Table 6: 14-node travel time matrix for each point (unit: min).

t_{ij}	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
0	0	2	6	8	12	4	4	2	4	5	4	6	6	8	7
1	2	0	4	13	2	6	11	10	12	12	7	11	15	17	16
2	6	4	0	14	1	12	8	8	13	12	8	8	16	18	17
3	8	13	14	0	17	11	6	9	6	7	14	5	9	5	4
4	12	2	1	17	0	12	9	8	13	11	5	9	15	17	16
5	4	6	12	11	12	0	5	6	5	4	7	8	4	5	4
6	4	11	8	6	9	5	0	3	3	8	8	5	7	10	7
7	2	10	8	9	8	6	3	0	4	8	4	5	8	10	9
8	4	12	13	6	13	5	3	4	0	8	7	7	8	8	7
9	5	12	12	7	11	4	8	8	8	0	6	8	3	6	6
10	4	7	8	14	5	7	8	4	7	6	0	6	9	10	10
11	6	11	8	5	9	8	5	5	7	8	6	0	10	9	8
12	6	15	16	9	15	4	7	8	8	3	9	10	0	3	2
13	8	17	18	5	17	5	10	10	8	6	10	9	3	0	2
14	7	16	17	4	16	4	7	9	7	6	10	8	2	2	0

In the future, with bike-sharing systems growing in China, we will present a solution model for dealing with dynamic faulty bike-sharing recycling. In addition, random searching for faulty bicycle without GPS should also be considered by the researchers.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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