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Research on the Optimization Problem of Shared Bicycle Scheduling

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Abstract

With the increasing demand for green transportation in recent years, the utilization rate of various transportation tools has increased. Starting from 2023, with the end of the epidemic and the recovery of various industries, the demand for shared bicycles has become increasingly high. According to statistics, the number of shared electric bicycles in China in 2021 is close to 4 million, with a revenue scale of 9.36 billion yuan. Shared bicycles are the preferred means of transportation for last mile travel. With the increase of shared bicycle outlets, the mismatch between bicycle distribution and people's needs often occurs due to unreasonable scheduling of shared bicycles, which brings many inconveniences to bicycle users. In response to this issue, the optimal scheduling strategy for bicycles was studied to improve the utilization rate of bicycles and customer satisfaction. Firstly, divide the day into multiple time periods, analyze the available number of vehicles and customer demand at each station based on the usage data of bicycles during each time period, and determine the points of bicycle transfer in, transfer out, and balance. A integer programming model for the shared bicycle scheduling problem is established, with the bicycle scheduling scheme as the decision variable and the total scheduling cost minimized as the objective function, while the total number of bicycles remains unchanged. The model is solved using Lingo software. Finally, a simulation calculation was conducted using 10 stations around the Material College in Tongzhou District, Beijing to compare the bicycle utilization rate and customer satisfaction before and after scheduling. The results showed that after scheduling optimization, the bicycle utilization rate increased by an average of 7.73%, and the user satisfaction rate increased by an average of 20.2%. This solution provides a theoretical basis and decision-making reference for solving the problem of shared bicycle scheduling.

Keywords

Shared bicycles, Scheduling optimization, Integer programming, Optimize the utilization rate of scheduling bicycles, Customer satisfaction.

1. Introduction

Bicycle sharing is known as one of the four new inventions in the 21st century. It can be seen everywhere in people's lives, plays an important role in people's daily travel, and greatly alleviates the problem of "the last mile". According to statistics, among the users of shared bicycles, office workers occupy the dominant position. They ride shared bicycles from residential areas to bus or subway stations, and from bus or subway stations to work units, completing daily commuting. Due to the tidal nature of shared bicycles used by commuters, which means that there are significant differences in the number of people using bicycles in different directions during different periods of time, shared bicycle companies need to arrange staff to manually schedule bicycles every day, so that commuters have bicycles for work and off duty. Due to the fact that staff usually rely on experience to manually schedule shared bicycles, the scheduling plan is not very reasonable, resulting in a large number of working groups still unable to find shared bicycles.

The optimization problem of shared bicycles refers to the arrangement of personnel by enterprises to schedule shared bicycles, so that the demand for each supply point is basically balanced. Based on the research issues and solutions considered in these studies, they can be broadly divided into three categories.

Taking research methods as an example, Li Huanhuan et al [1] used multi-scale spatiotemporal graph convolutional networks for public transportation, taking taxis and shared bicycles as examples, to predict travel demand. Hu Yaqun et al[5] used K-means clustering to predict shared bicycles around urban rail stations. Jia Yongji et al[8] used robust optimization methods to study the location selection of multi-objective shared bicycle electronic fences. Yuan Xiaofeng et al[10] calculated the environmental benefits of shared bicycles in carbon emissions.

Taking practical applications as an example, Zhu Yawen et al[3] balance commercial behavior with public services based on the phenomenon of vehicle redundancy and combined with actual situations; Xie Tianlin et al[4] obtained results by studying international experience in the development of MaaS urban transportation systems; Luo Chenyong et al[6] analyzed the integrated bus stop shared bicycle access system.

Taking problem-solving programs as an example, Wang Dan et al[1] analyzed the return strategy of shared electric bicycles using a fast non dominated sorting genetic algorithm; Cheng et al[7] used the Leiden algorithm to identify shared bicycle activity communities by analyzing the case of Nanjing; Hu Ying et al[9] analyzed the riding quality based on the running trajectory of shared bicycles.

There have been many research results on the scheduling problem of shared bicycles, and most of them have been conducted from a theoretical perspective, with few studies combining specific scenarios. This article will conduct research on the optimization of shared bicycle scheduling in a specific region. Taking Haro bicycles as an example, through investigation data, analyze the current problems in the use of bicycles; Establish an optimization model for the problem and solve it using Lingo software to obtain the optimal scheduling plan. To improve bicycle utilization and user satisfaction, solve the problem of unreasonable scheduling of shared bicycles, and enhance the experience of office workers in using shared bicycles.

2. Problem Description and Analysis

2.1. Problem Description

When the number of shared bicycles is fixed, the problem exhibited by shared bicycles is that there are several shared bicycle stations in a certain area, and the maximum and minimum demand for bicycles at each station during each time period is obtained through statistics. Before peak hours, shared bicycle companies can use scheduling vehicles to schedule bicycles parked at various stations in this area, ensuring that the number of bicycles at each station is within the maximum and minimum demand range. They can transport bicycles from redundant stations to stations with insufficient bicycles, so that the number of bicycles parked at each station is within the demand range during that period. Assuming that bicycle scheduling is only conducted in the early stages of each peak period and can be completed quickly (i.e. without considering the time and distance involved in bicycle scheduling). It is known that the cost of each single vehicle during the scheduling process is fixed; Given the number of bicycles parked at each station at the beginning of a certain period of time, how can scheduling vehicles be arranged to schedule bicycles within the area so that the supply and demand of each bicycle station in the area can basically reach a balance and the total scheduling cost is minimized?

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2.2. Problem analysis

The main purpose of the bicycle scheduling problem is to transport excess bicycles from parking points with a higher number of bicycles than the demand to stations with a lower number of bicycles than the demand, in order to achieve a balance between supply and demand among various stations. This not only ensures that customers have a car available during peak usage periods, but also alleviates the problem of road congestion and redundancy caused by no one available during low usage periods, improving the utilization rate of bicycles and customer satisfaction.

3. Model establishment

3.1. Model Assumptions

(1) The total number of bicycles in the area is fixed.

(2) Without considering the time cost of single vehicle scheduling (assuming scheduling can be completed quickly and without considering the priority between stations), the scheduling cost of each vehicle between any two stations is a known constant.

(3) Within each time period, the demand for individual vehicles at each demand point follows a uniform distribution, with a known distribution interval.

(4) At the beginning of each time period, the number of bicycles stored at each station is known.

(5) At the beginning of each time period, stations where the number of bicycles stored falls within the demand range are not scheduled.

(6) After the completion of bicycle scheduling, the number of bicycles at each station should be within the demand range, not exceeding the maximum demand and not less than the minimum demand.

3.2. Symbol Description

Based on the above problem description and model assumptions, first define the symbols, as shown in Table 1.

Table 1 Symbol Definition

symbol	Description
A	Collection of all shared bike stations
A^+	Collection of shared bicycle call out points
A^-	Collection of shared bicycle transfer points
B_i^-	The lower limit of shared bicycles required for site i
B_i^+	Upper limit of shared bicycles required for site i
G_i^-	Number of bicycles at station i before scheduling
G_i^+	Number of bicycles at station i after scheduling
M_{ij}	Dispatching cost per single vehicle from station i to station j
T_i	Station i's bicycle utilization rate

3.3. Determination of bicycle transfer out and transfer in points

Because each station has different demand for bicycles at different time periods, to determine whether bicycles at a certain station should be transferred in or out, a comparative analysis should be conducted based on the distribution of demand at that station and the number of bicycles at that station at a certain time.

For a certain station i, assuming that the demand distribution interval obtained from historical data is $[B_i^- B_i^+]$, and at the beginning of a certain period of time, the number of single car parking at that station is G_i^-, then the type of the site can be determined according to the following rules.

$G_i^- < B_i^-$, So this site i is the entry point;

$G_i^- > B_i^+$, So this site i is the call out point;

$B_i^- < G_i^- < B_i^+$, So this site i is the balance point and does not need to be adjusted。

3.4. Model Establishment

The decision variable X_{ij} represents the number of bicycles transported from bicycle dispatch point (i) to bicycle receiving point (j), with the value being an integer. The bicycle dispatch optimization model can be represented as: The symbols in the formula are inconsistent with those defined earlier.

$$\min y = \sum_{i \in N^+} \sum_{j \in N^-} M_{ij} X_{ij} \quad (1)$$

$$B_i^- \le G_i^- - \sum_{j \in N^-} X_{ij} \le B_i^+ \quad (2)$$

$$B_i^- \le G_i^- + \sum_{j \in N^+} X_{ij} \le B_i^+ \quad (3)$$

$$X_{ij} \ge 0, \text{and is an integer, } \mathrm{i} \in \mathrm{N}^+, j \in N^- \quad (4)$$

The objective function (1) represents minimizing the total scheduling cost; Constraint (2) means that after single vehicle dispatching, the number of single vehicles at the call out point should be greater than the lower limit of demand at the point and less than the upper limit of demand at the point; Constraint (3) means that after single vehicle dispatching, the number of single vehicles at the transfer in point should be greater than the lower limit of demand at the point and less than the upper limit of demand at the point; Constraint (4) indicates that the variable value constraint is greater than zero and is an integer.

4. Example analysis

4.1. Data Acquisition and Statistical Analysis

This article utilizes the Hello Bike data from Tongzhou District, Beijing, to construct a simulation example. Data from 10 shared bicycle stations in the area were collected, spanning nearly 6 months from May 28, 2023, to October 20, 2023. The day is divided into two peak usage periods, morning and evening. The bicycle demand range for each station is calculated based on their usage data during these periods.

Initially, the bicycle usage data of each station over the past 6 months were statistically analyzed to understand the probability distribution patterns, and then the demand range for each station was calculated. Further, based on the initial bicycle inventory at each station for each period, the sets of bicycle dispatch and receiving points were determined. Taking data from 7 AM to 9 AM on July 24, 2023, as an example and using Python for data preprocessing, it was found that 8 out of 10 bicycle stations had an imbalance in supply and demand. The data for each bicycle station is shown in Table 2: the second column lists the station numbers; the third, fourth, and fifth columns represent the standard deviation, variance, and standard error of the stations, respectively; the sixth and seventh columns show the geographical coordinates of the stations; the eighth column shows the initial storage quantity (the quantity stored at 7 AM); the ninth and tenth columns represent the lower and upper limits of the station's demand, respectively; and the last column indicates the type of station, where "+" denotes a receiving point, "−" a dispatch point, and "0" a balanced point.

Table 2 Bicycle station data

Site serial number	name	lng	lat	Gi-	Bi-	Bi+	site type
1	Thatched cottage	116.620199	39.932631	79	29	65	-
2	Material College Road Subway Station	116.647476	39.933257	68	34	129	0
3	Bali Bridge Residential Area	116.600928	39.917043	30	35	62	+
4	Tongzhou Wanda	116.648007	39.911604	107	33	93	-
5	Tianci Liangyuan North District	116.650057	39.934116	20	28	37	+
6	Yongshun Home	116.643974	39.926844	24	28	58	+
7	Beijing Vocational College of Finance and Trade	116.654178	39.927147	46	17	38	-
8	Tongzh ou Beiguan Subway Station	116.667835	39.924675	33	23	65	0
9	Yunyunyuan Community	116.694743	39.917992	26	30	56	+
10	Xincheng Jiayuan	116.677295	39.885892	33	39	56	+

The bicycle utilization rate T can be calculated based on the minimum demand of shared bicycle customers at each site and the actual parked vehicles at the current time_ i. Furthermore, the usage of shared bicycles in Tongzhou District can be approximately determined. Based on a simple formula for calculating the utilization rate of bicycles, the current utilization rate of bicycles in Tongzhou District is 67.17%.

$$\text{Bicycle utilization} = \frac{\text{Customer demand}}{\text{The current number of bikes}} = \frac{G_i^-(\text{Call in point} + \text{Balance point}) + B_i^-(\text{Recall point})}{G_i^- * A}$$

Draw a scatter plot of each site based on its geographical location, as shown in Figure 1, where the horizontal axis represents the longitude of the site and the vertical axis represents the latitude of the site.

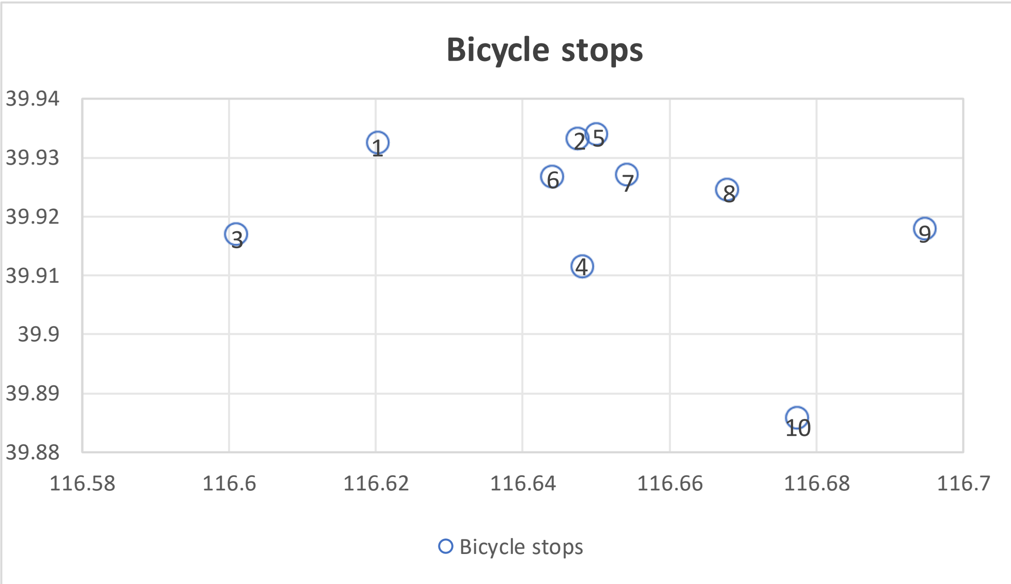

Figure 1 Distribution of bicycle stations

Figure 1 depicts the locations of 10 bicycle stations in Tongzhou District. Based on Baidu Maps, the distance and fixed cost of transporting bicycles between stations are calculated (assuming the cost of one vehicle per kilometer is one yuan), and the unit scheduling cost of transporting one bicycle between any two stations is calculated. Table 3 lists the unit scheduling costs from the point of single vehicle transfer out to the point of single vehicle transfer in (the results are rounded to two decimal places).

Table 3 Unit scheduling cost from the transfer out point to the transfer in point (unit: yuan/vehicle)

Entry point / Call out point	3	5	6	9	10
1	2.39	2.56	2.13	6.56	7.12
4	4.06	2.5	1.73	4.05	3.8
7	4.68	0.86	0.87	3.61	5.00

4.2. Model solving

Based on the model establishment, the optimal solution was obtained using Lingo software, as shown in Table 4 and Figure 2.

Table 4 Optimal scheduling scheme

Call out point	Entry point	Dispatching vehicles
1	3	5
1	6	9
4	6	4
4	9	4
4	10	6
7	5	8

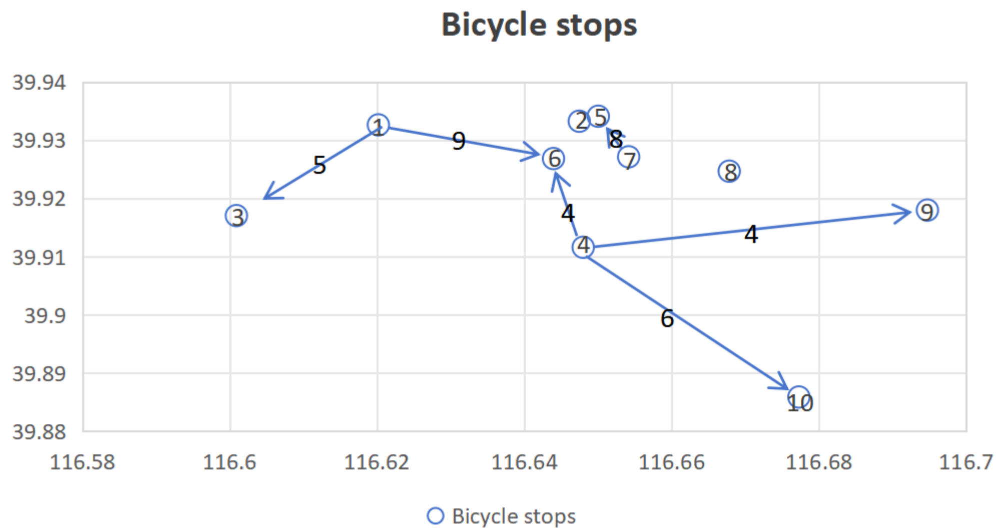

Figure 2 Schematic diagram of bicycle scheduling

According to simulation calculations, from 7:00 to 9:00 on July 24, 2023, the optimal scheduling plan for shared bicycles at ten nearby points in Tongzhou District, centered around the Material College, was compared and analyzed for changes in bicycle utilization and customer satisfaction before and after scheduling. Through simple calculations, it can be concluded that from the perspective of bicycle utilization rate, the bicycle utilization rate before scheduling from 7:00 to 9:00 on July 24, 2023 was 67.17%, and after simulating scheduling, the bicycle utilization rate was 74.90%. After scheduling optimization, the bicycle utilization rate increased by 7.73%. From the perspective of customer satisfaction rate, the customer satisfaction rate before scheduling from 7:00 to 9:00 on July 24, 2023 was 72.80%. After simulating scheduling, the customer satisfaction rate was 93%, and the satisfaction rate increased by 20.2%. It can be seen that after scheduling, the utilization rate and satisfaction rate are both positively increasing.

4.3. Simulation and analysis

(1)Analysis of cycle utilization

Using the 2023 data from 7:00 am to 9:00 am daily from 1 August to 30 August, we 2023 the simulation using the previous method, the daily changes in cycle utilization and customer satisfaction over the 30-day period are shown in tables 5，6 and Figure 3，4.

Table 5 30 changes in cycle utilisation during the period

Date	Before dispatch	After dispatch
1	66.91%	73.78%
2	65.45%	69.33%
3	66.73%	74.87%
4	68.21%	74.92%
5	67.59%	75.48%
6	68.85%	70.61%
7	67.44%	74.30%
8	69.02%	73.68%
9	68.18%	74.26%
10	67.96%	72.10%
11	67.50%	73.96%
12	68.17%	74.51%
13	67.49%	75.82%
14	68.33%	74.53%
15	68.89%	72.52%
16	67.47%	75.83%
17	69.32%	74.42%
18	68.71%	74.55%
19	66.88%	73.59%
20	67.07%	73.71%
21	68.35%	75.67%
22	67.20%	74.62%
23	67.61%	73.07%
24	68.55%	73.91%
25	68.32%	75.98%
26	67.79%	72.60%
27	67.82%	74.22%
28	68.03%	73.95%
29	70.72%	72.54%
30	69.46%	74.53%

Table 6 30 changes in customer satisfaction during the day

Date	Before dispatch	After dispatch
1	71.66%	92.31%
2	72.71%	95.63%
3	72.65%	94.18%
4	70.85%	92.58%

5	73.92%	91.64%
6	72.63%	93.68%
7	71.01%	90.55%
8	73.42%	94.10%
9	74.22%	90.25%
10	72.43%	93.66%
11	72.34%	90.37%
12	73.76%	94.39%
13	73.19%	94.56%
14	74.04%	93.226%
15	72.30%	89.70%
16	73.77%	92.46%
17	70.51%	93.79%
18	73.48%	93.19%
19	72.83%	92.67%
20	74.47%	93.38%
21	74.23%	94.51%
22	73.86%	93.68%
23	71.32%	91.58%
24	74.80%	95.12%
25	73.44%	93.43%
26	72.67%	93.08%
27	76.11%	88.69%
28	72.54%	92.67%
29	72.39%	93.82%
30	75.16%	91.09%

Combined with the utilization rate of bicycle scheduling from 7:00 to 9:00 in 30 days, the data of shared bicycles during this period in 30 days were used for simulation calculation, the average utilization ratio of single vehicles before dispatching is 68% , and after dispatching is 73.93% . It can be seen that the utilization ratio of single vehicles after dispatching optimization has been significantly improved.

The average utilization of shared-bike stations around the Beijing Wuzi University is increased by 5.93% , it shows that the shared bikes before and after dispatching can make full use of the bikes in the area.

The combined function image can clearly show the utilization of shared bikes before and after the 30-day scheduling, as shown in Figure 3.

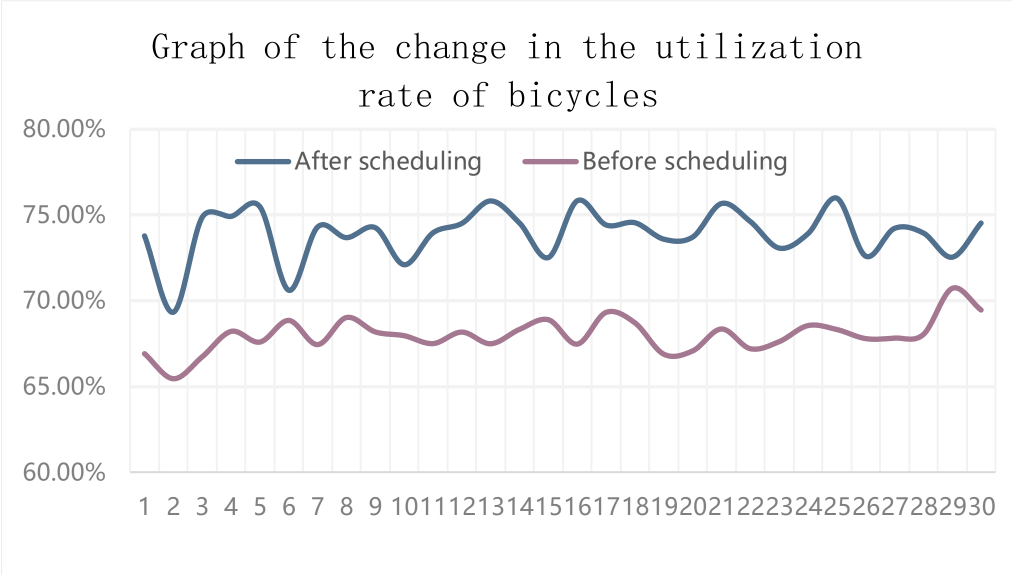

Figure 3 diagram of cycle utilization

Customer Satisfaction Analysi.

Using the simulation results of the 2023 from Aug. 1 to Aug. 30, the 2023 analyzed the change of customer satisfaction rate before and after scheduling. The results show that the average customer satisfaction rate is 73.09% before dispatching and 92.80% after dispatching optimization. The average customer satisfaction rate increases by 19,71% , which shows that the shared bikes before and after dispatching can improve the customer demand, make better use of bicycles.

The combined function image can clearly show the customer satisfaction before and after the 30-day schedule, as shown in Figure 4.

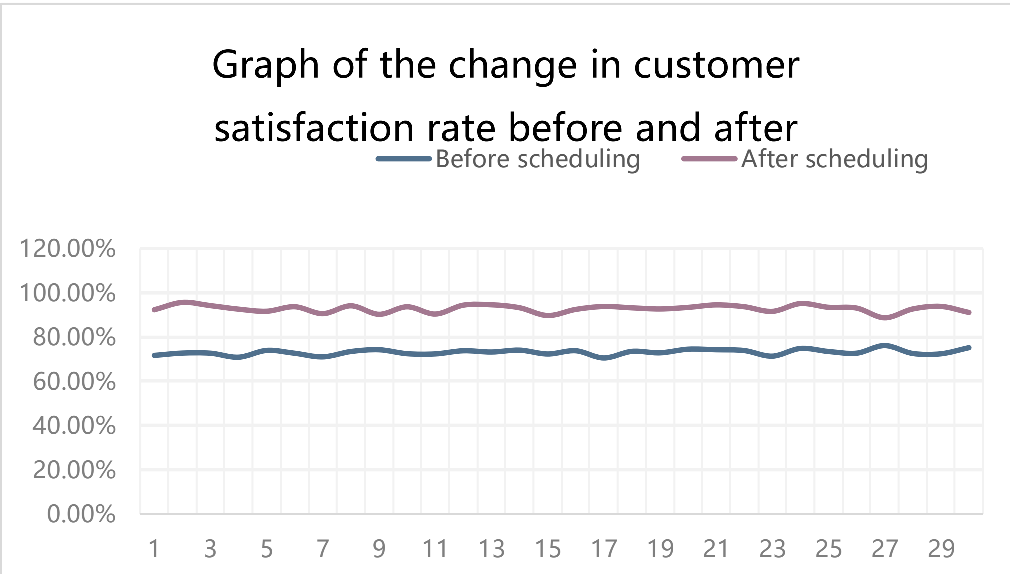

Figure 4 chart of customer satisfaction

For the investment and profit of enterprises

According to the optimal scheduling scheme given in this paper, the 2023 can meet the needs of at least 36 more users by scheduling the data from 7:00 to 9:00 on July 24, according to the market price of the shared bike, a fee of 1.5 yuan is charged for a 30-minute ride, and 0.5 yuan for every 15 minutes of a 30-minute ride. Assuming that the average car cost per user is 2 yuan, then you can earn 72 yuan more, because the transport cost of this paper is calculated by reference to the distance between the supply and demand points, while in real life, transport vehicles will have the optimal scheduling route, so the actual scheduling costs will be smaller, more profitable. So you have to work with the business, and then you have to adjust the model, based on the actual numbers, to increase bicycle utilization, customer satisfaction, and to generate significant revenue for the business.

5. Conclusion

In this thesis, we propose a series of solutions and prospects based on the study of the optimal scheduling of shared bicycles around Tongzhou District College of materials. By studying the existing bike-sharing scheduling problem, we find some key problems and challenges, such as the uncertainty of user demand, vehicle supply chain management and the daily vehicle damage, loss causes uncertainty about the type of site to change. Based on the analysis of these problems, we propose to establish a single-vehicle scheduling optimization model, and use Lingo software to solve it, to help bike-sharing enterprises more effectively dispatch vehicles, improve service quality, reduce resource waste, improve urban traffic congestion. Looking to the future, we believe that with the continuous improvement of technology and data, shared bike scheduling will usher in greater development space. We look forward to the future of bike-sharing scheduling systems to achieve more intelligent operations, through artificial intelligence, big data analysis and other technical means, to achieve accurate forecasting and dynamic scheduling, to bring users more convenient travel experience, but also for urban traffic management to bring greater benefits. Therefore, bike-sharing scheduling optimization is a subject worthy of continuous attention and research, we need to constantly explore innovative methods and technologies to promote the healthy development of bike-sharing industry, make greater contribution to the sustainable development of cities.

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