



Energy consumption analysis of straddle monorail transit in the operational phase based on grey relational method

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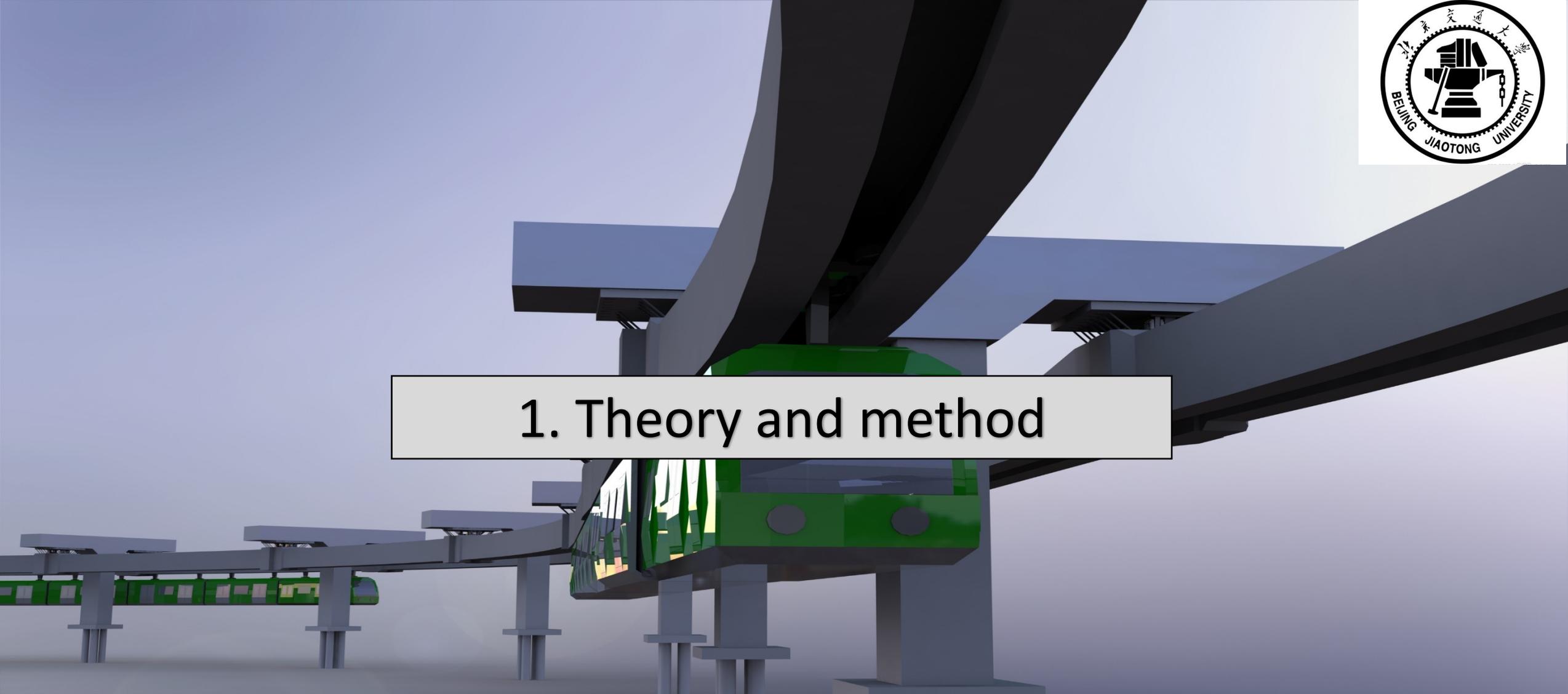


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1. Theory and method





1. Theory and method:

1.1 Grey relation theory

- Grey correlation analysis is to compare the relationship of statistical sets of each study sequence and analyze the correlation degree among multiple factors through quantitative analysis of each factor in the system.
- In the system, if the trend of two factors is consistent, the degree of correlation between them is high. Otherwise, it is lower.
- The calculation steps of grey correlation degree are as follows: determine the analysis sequence, dimensionless sequence, calculate the correlation coefficient, calculate correlation degree and then rank correlation degree.

The main formulas for grey relation analysis are shown in the following equations:

$$xi(k) = \frac{X_i(k)}{X_i(l)}$$

$$k = 1, 2, \dots, n; \quad i = 0, 1, 2, \dots, m. \quad (1)$$

$$\xi_i(k) = \frac{\min_i \min_k \Delta_i(k) + \rho \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \rho \max_i \max_k \Delta_i(k)} \quad (2)$$



2. Energy consumption analysis and data source

2.1 Energy consumption intensity indexes

Total energy consumption index 1:

$$E_1 = \frac{E_{Total}}{PKT} \quad (3)$$

Where, E_1 is the total energy consumption per passenger-kilometer with the unit kwh/passenger-kilometer; E_{Total} is the total energy consumption with the unit of ten-thousand kwh; PKT is the passenger kilometers travelled with the unit of ten-thousand passenger-kilometer.

2.2 Energy consumption intensity indexes

Total energy consumption index 2:

$$E_2 = \frac{E_{Total}}{VKT} \quad (4)$$

Where, E_2 is the total energy consumption per vehicle-kilometer with the unit kwh/vehicle-kilometer; E_{Total} is the total energy consumption with the unit of ten-thousand kwh; VKT is the vehicle kilometers travelled with the unit of ten-thousand vehicle-kilometer.

2.3 Energy consumption intensity indexes

(1) Traction energy consumption index 1:

$$E_3 = \frac{E_{Traction}}{PKT} \quad (5)$$

Where, E_3 is the traction energy consumption per passenger-kilometer with the unit kwh/passenger-kilometer; $E_{Traction}$ is the traction energy consumption with the unit of ten-thousand kwh; PKT is the passenger kilometers travelled with the unit of ten-thousand passenger-kilometer.

2.4 Energy consumption intensity indexes

(1) Traction energy consumption index 4:

$$E_4 = \frac{E_{Traction}}{VKT} \quad (6)$$

Where, E_4 is the traction energy consumption per vehicle-kilometer with the unit kwh/vehicle-kilometer; $E_{Traction}$ is the traction energy consumption with the unit of ten-thousand kwh; VKT is the vehicle kilometers travelled with the unit of ten-thousand vehicle-kilometer.



2.5 Energy consumption type and influence factors

- The energy consumption of straddle monorail or subway operation studied in this paper is mainly divided into two categories: one is traction energy consumption, the other is the other energy consumption, including ventilation, lighting, and other energy consumption.
- According to the actual characteristics of each project, this paper selects five factors, including the line length, annual passenger volume, the actual number of vehicles per day, average speed, and number of stations.

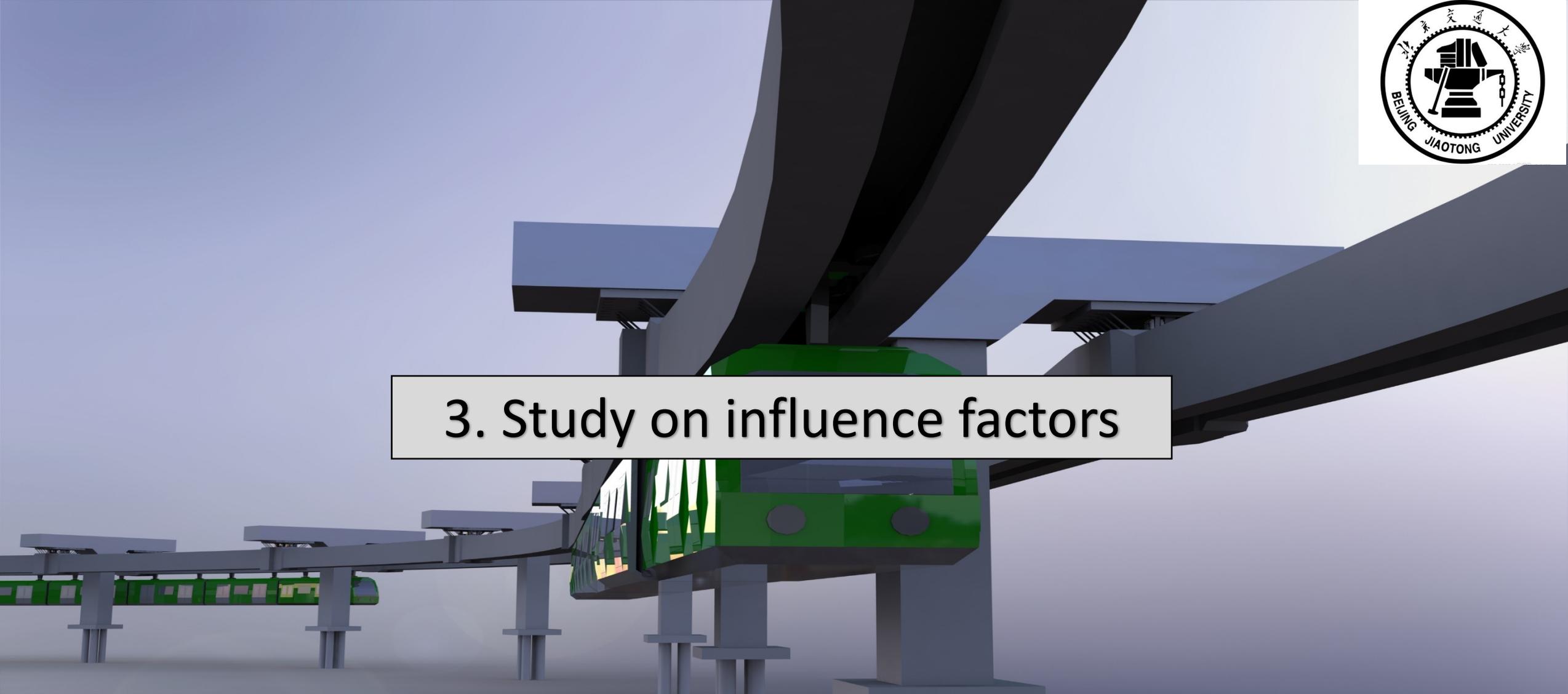


2.6 Data source and software use

- The annual traction energy consumption, total energy consumption, and other characteristic data of Chongqing monorail Line 2 and Line 3 in this paper are all from *China Urban Rail Transit Almanac 2019*. *China Urban Rail Transit Almanac 2019* has compiled the operating data of China's urban rail transit in 2018
- Excel and Origin software were used for data statistics and analysis.



3. Study on influence factors





3.1 Operation energy consumption of monorail transit lines in Chongqing.

Table 1 Operation energy consumption of monorail transit lines in Chongqing

Order	Name	E_1 (kwh/passenger-kilometer)	E_2 (kwh/passenger-kilometer)	E_3 (kwh/vehicle-kilometer)	E_4 (kwh/vehicle-kilometer)
1	Line 2	0.0703454477	2.926269645	0.04488406457	1.8671126553
2	Line 3	0.062078766	2.959887457	0.03861695	1.841238668



3.2 Operational data of straddle monorail transit lines in Chongqing.

Table 2 Operational data of straddle monorail transit lines in Chongqing

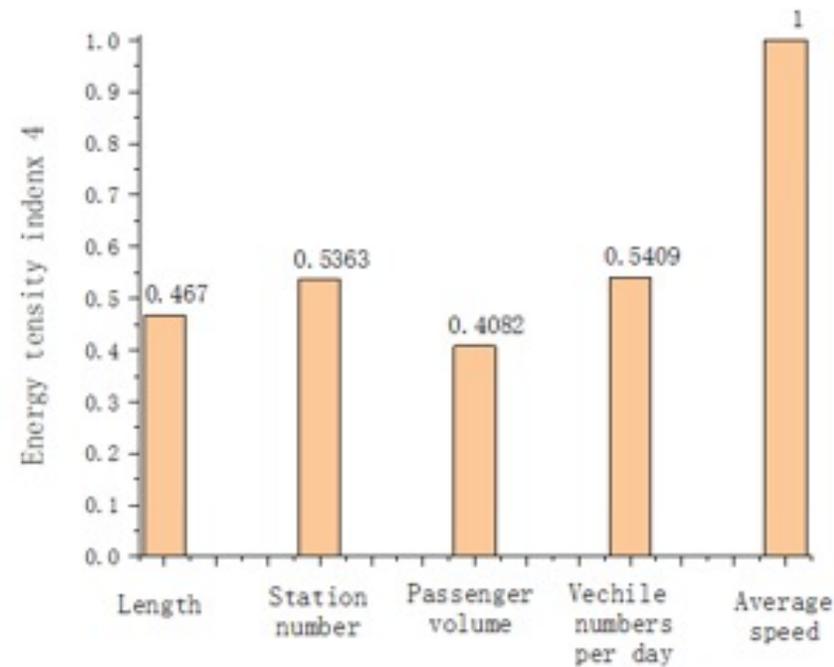
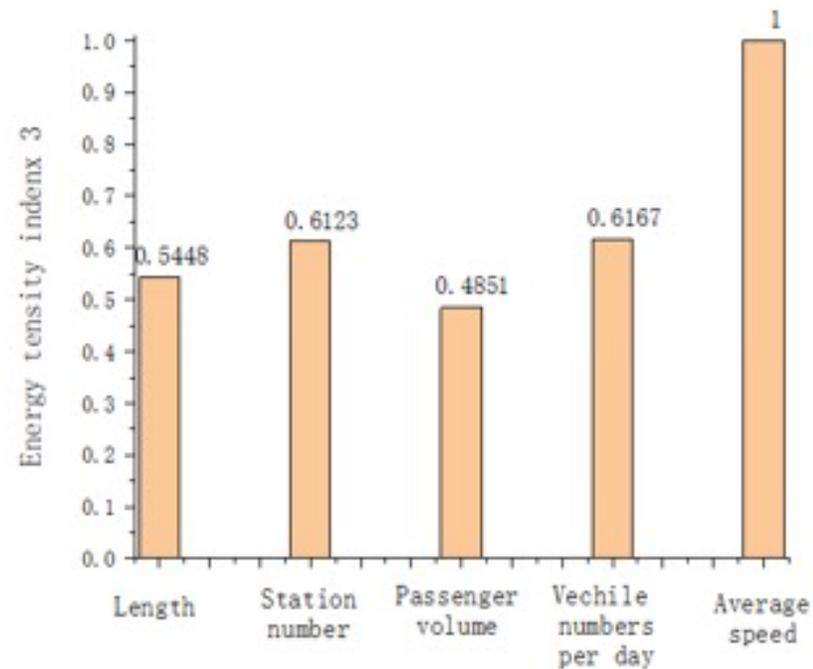
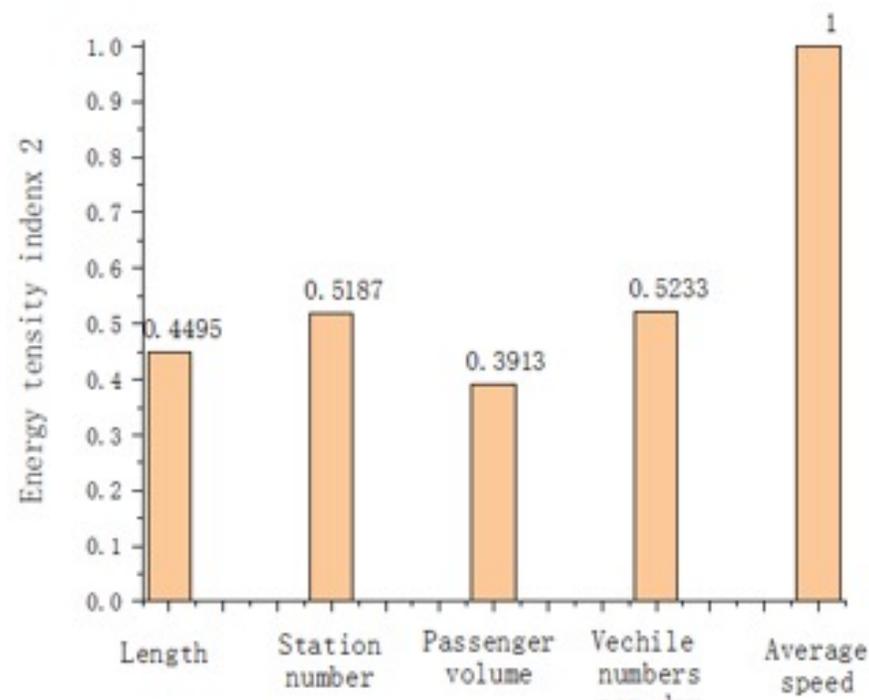
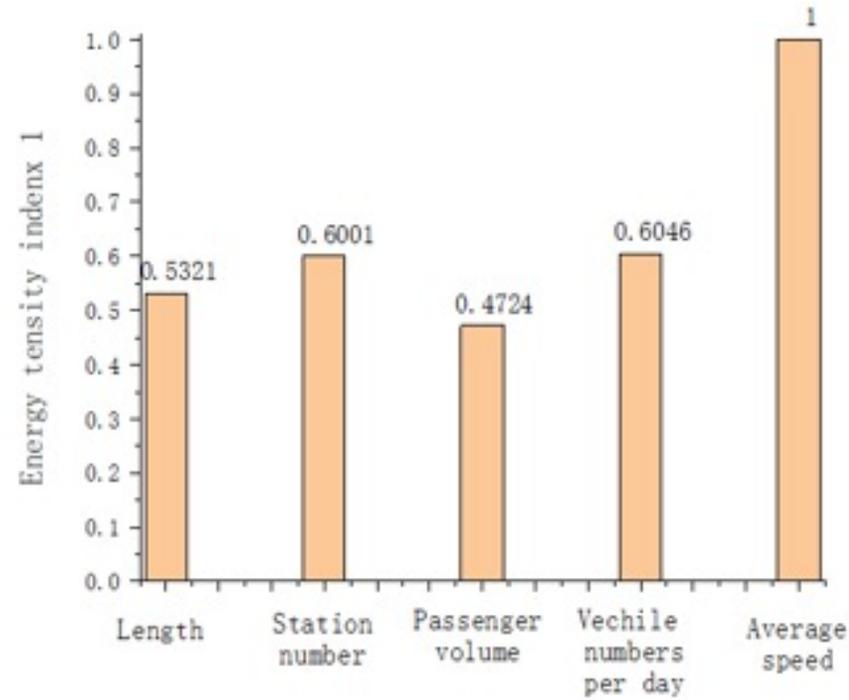
Order	Name	Length(kilometer)	Station	Annual passenger volume (ten-thousand passenger)	Actual number of vehicles per day	Average speed (kilometer/h)
1	Line 2	31.36	25	11547.14	463.29	31.85
2	Line 3	67.09	45	30365.76	825.87	34.80



3.3 Grey relational analysis results.

Table 3 Grey correlation analysis results of energy consumption indexes of straddle monorail transit lines in Chongqing

Index	Length(kilometer)	Station	Annual passenger volume (ten-thousand passenger)	Actual number of vehicles per day	Average speed (kilometer/h)
E_1	0.5321	0.6001	0.4724	0.6046	1
E_2	0.4495	0.5187	0.3913	0.5233	1
E_3	0.5448	0.6123	0.4851	0.6167	1
E_4	0.4670	0.5363	0.4082	0.5409	1





3.3 Grey relational analysis results.

For all energy consumption indexes, the influence degree of each factor is in the order of average speed > the actual number of vehicles per day > number of stations > length > total passenger volume.



4. Ratio of traction energy consumption

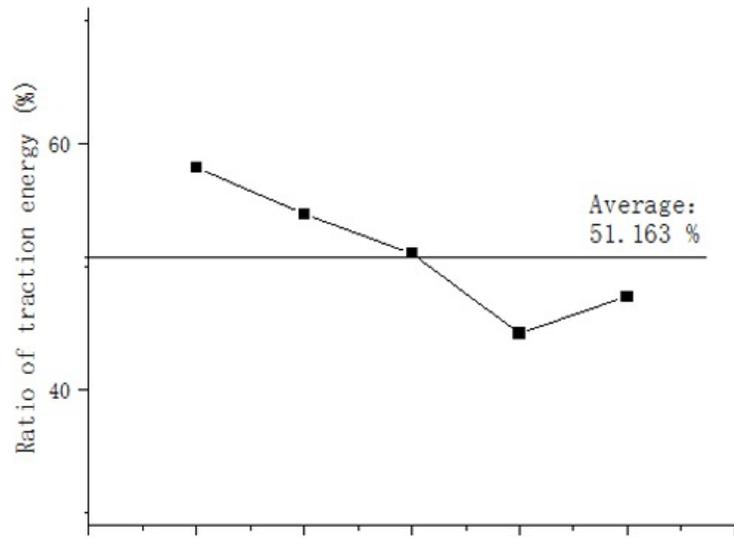


4. Analysis of ratio of traction energy consumption

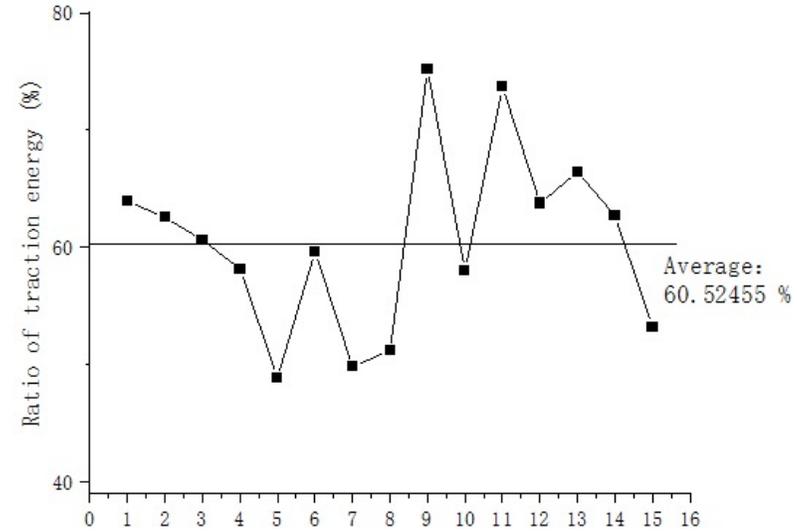
- The average ratios of traction energy consumption of subways in Chongqing, Beijing, Shanghai, and Guangzhou are 51.163%, 60.52455%, 60.43848%, and 50.87223%, respectively.
- For Chongqing monorail line 2 and Line 3, the ratios of traction energy consumption are 63.8052% and 62.2064%, and the average value is 63.0058%, which is higher than those of all subway lines.



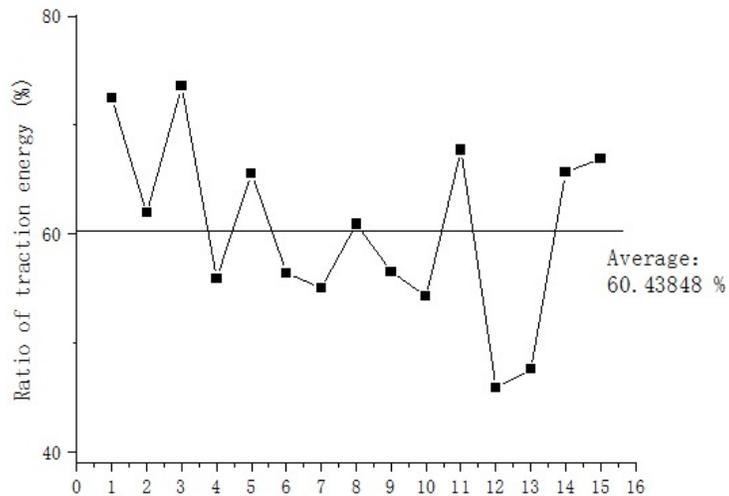
4. Analysis of ratio of traction energy consumption



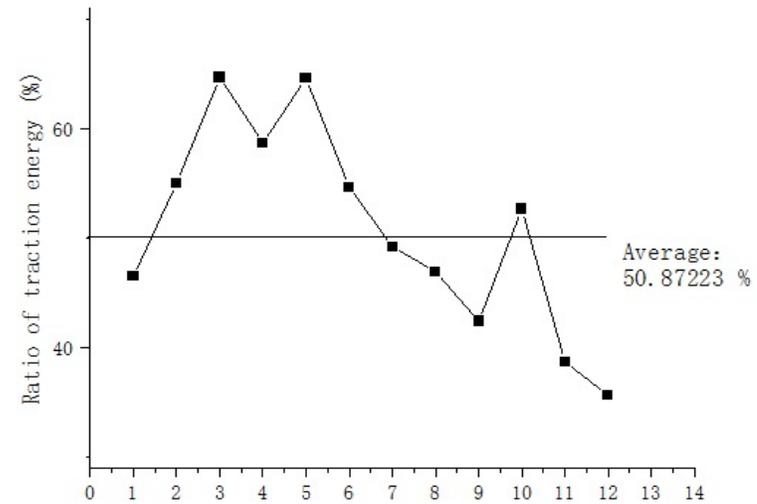
Chongqing Subway lines



Beijing Subway Lines



Shanghai subway lines



Guangzhou subway lines



5. Conclusions



4. Conclusions

- Through grey relational degree analysis, it is found that for the four energy intensity indexes of Chongqing monorail transit line 2 and Line 3, the order of influence degree of each factor is: average speed > the actual number of daily vehicles > number of stations > length > total passenger volume.
- It is found that the average ratio of traction energy consumption of Chongqing monorail transit is 63.0058%, and that of Chongqing metro is 51.163%. The average energy consumption ratio of Beijing metro is 60.52455%, that of Shanghai is 60.43848%, and that of Guangzhou is 50.87223%. Monorail transit has the highest energy consumption ratio.



Thank you!