Standardized evaluation of Hefei-Wuhu-Guangde high-speed maglev train project

As the epitome of rail transportation technology, the 600 km/h high-speed maglev system can effectively bridge the gap between high-speed wheel-rail system (with a maximum speed of 400 km/h) and aviation system (with a speed of 800 km/h or higher). However, the application of high-speed maglev systems is constrained by high costs, an imperfect industrial chain, and the lack of systematic planning and assessment methods. For this reason, there is an urgent need to establish an objective and quantitative assessment system for high-speed maglev projects to provide a basis for transportation mode selection and project decision making. In this paper, the German standardized evaluation method for investment on transportation infrastructure projects is used to conduct a standardized assessment of the macroeconomic benefits of the Hefei-Wuhu-Guangde high-speed maglev project in Anhui. The method is also compared with the assessment methods currently used in China to assess its applicability for assessing investment projects related to high-speed maglev transportation systems in China, and then to make suggestions for revising and optimizing the standardized evaluation method system for transportation investment projects in China.

1. Introduction

The high-speed maglev system with a maximum speed of 600 km/h can effectively fill the gap between the high-speed wheel-rail system and the aviation system. However, the application of the high-speed maglev system is hindered by high costs, incomplete industrial chains, and a lack of systematic planning and evaluation methods. Therefore, it is urgently needed to establish an objective and quantitative evaluation system for high-speed maglev projects to provide a basis for transportation mode selection and project decision making.

Currently, the „Economic Evaluation Methods and Parameters for Construction projects" [1] is applied in China as a general assessment method, which is limited in accurately evaluating the economic feasibility of high-speed maglev transportation systems. The method is supposed to be widely applicable to construction projects in various industries, but lacks support for new rail transit construction projects such as high-speed maglev transportation systems. The method does not include environmental impact factors such as carbon dioxide emissions and noise pollution in the evaluation system, making it unable to quantify the overall economic benefits brought by energy conservation and emission reduction. The method only provides reference for calculation methods and parameters, and has not formed a universal standard specification, resulting in insufficient consistency of evaluation results calculated by different evaluation agencies.

In this paper, a cost-benefit analysis using the German standardized evaluation method [2] for transportation infrastructure investment projects is being conducted. The German standardized evaluation is the legally mandated standard procedure in Germany for assessing the economic performance of transportation infrastructure. The impacts on society and the environment on Hefei-Wuhu-Guangde high-speed maglev

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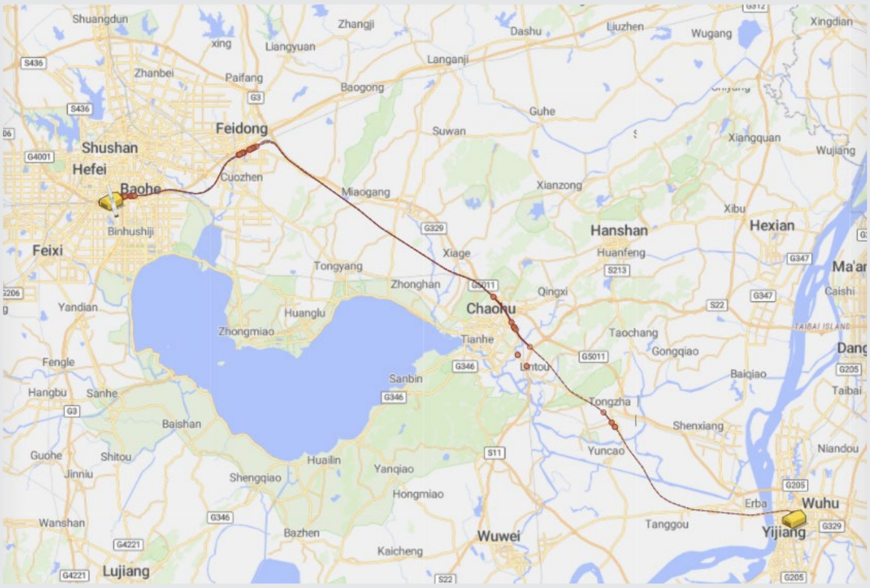
project are evaluated. The initially planned Hefei-Wuhu high-speed maglev line (see Figure 1) will serve as a maximum 600 km/h high-speed maglev demonstration line with planned regular operational velocity at 550 km/h. It is planned to be extended



1: The planned Hefei-Wuhu high speed maglev line

towards Hangzhou via Guangde after completion [3]. The Hefei-Wuhu line will be evaluated first, and based on this, the extension of the high-speed maglev line to Guangde within Anhui province will be analyzed. The assessment is based on the with- and without-principle used in standardized evaluation, and a comparative economic benefit analysis is performed according to the existing Shangqiu-Hefei-Hangzhou high-speed railway as a baseline.

According to the principles of the standardized evaluation of German transportation infrastructure investment projects, raw data related to project indicates are at first obtained. These cost-benefit indicators shall be quantified over original units and assessed quantitatively in monetary units. All of the evaluation indicates and related parameters need to be measured and transformed. In this section, the operational condition used to determine the indicates are described. The data sources, the parameters and the calculation methods for the indicates will be presented in detail in the subsequent sections.

In [6], the planned transport capacity of Shangqiu-Hefei-Hangzhou high-speed railway line (SHH line) is 60 million persons/year for each direction, which can be converted to an average of 164,000 persons/day. According to the passenger volume of SHH line released by Anhui Provincial Department of Transportation in July 2020, it is projected that the percentage of single-direction daily passenger flow from Hefei to Wuhu, which covers 147 kilometers of operating mileage, can be calculated as 16.9 % of the total passenger flow of the entire SHH line. Similarly, the percentage of single-direction daily passenger flow from Hefei via Wuhu to Guangde, which covers 282 kilometers of operating mileage, can be calculated as 20.7 % of the total passenger flow of the entire SHH line. According to the passenger volume ratio of the Hefei-Wuhu section, the daily passenger volume is expected to be 27,848 persons/day for each direction. The daily passenger volume of the Hefei-Wuhu-Guangde section will reach to 33,946 persons/day for each direction.

2. Standardized evaluation on the Hefei-Wuhu section

2.1. Capital value and maintenance costs of infrastructure

The capital value of the standardized evaluation method for the transportation infrastructure investment project is derived by using the annuity method, and the calculation results are obtained by studying following major infrastructures items:

- Construction preparation (road diversion, transport access, etc.)
- Station facilities (Hefei Station, Wuhu Station and Guangde Station including waiting halls, traffic sheds, platform canopies, platforms and barrier-free access, etc.)
- Railroad track works (substructure and superstructure)
- Road maintenance (roads and highway bridges)
- Buildings and other facilities (vehicle maintenance sites, main/traction substations, etc.)
- Traction power supply system (power supply system, traction system, etc.)
- Operation control system (central control system, on-board system, etc.)
- Infrastructure communication system (backbone transmission network, backbone cable, etc.)

According to internal data from Shanghai maglev demonstration line, the investment costs per unit length of the infrastructure engineering and construction project for high-speed maglev and high-speed wheel-rail system within 200 kilometers of operating mileage are determined. The unit investment costs of „buildings and other facilities“ are the sum of „other operational production equipment and buildings“ and „temporary facilities and beam making plant costs“. The service life of the infrastructure items is taken from the German standardized evaluation 2016+ edition.

The annuity factor of the infrastructure associated with the engineering and construction investment costs is related to the service life of the respective infrastructure and its interest rate adopts the same value, which is currently set as 1.7 %[1)] in German standardized evaluation. From this, the capital value of the infrastructure related to the engineering and construction can be calculated by the product of the investment costs and the annuity factor.

- Investment costs = investment costs per unit length · 147 km
- Capital value = investment costs · annuity factor

The formula for calculating the annuity factor is:

$$AF = (1+i)^n \cdot i/[(1+i)^n - 1]$$

In the formula, *AF* is the annuity factor, *i* is the annual interest rate, and *n* is the service life of the infrastructure.

In this work, the high-speed maglev project is set as the with-case, and the existing high-speed wheel-rail project

1) Average value related to economic service life of equipment

Table 1: Annual capital value of high-speed maglev and high-speed wheel-rail infrastructure

Infrastructure investment project	Service life [Year]	Annuity factor	High-speed maglev investment costs per unit length [10,000 RMB/km·year]	High-speed wheel-rail investment costs per unit length [10,000 RMB/km-·year]	High-speed maglev capital value [10,000 RMB/year]	High-speed wheel-rail capital value [10,000 RMB/ year]
Station	60	0.0267	98	109	384.72	427.47
Line track works	75	0.0237	8,418	8,409	29,316.89	29,285.54
Road maintenance	60	0.0267	350	800	1,374.59	3,141.91
Buildings and other facilities	60	0.0267	912	712	3,581.78	2,796.30
Traction power supply system	30	0.0428	1,808	590	11,382.99	3,714.58
Operation control system and communication system	20	0.0594	865	465	7,553.07	4,060.32
Track girder sound absorption	25	0.0494	35	35	254.34	254.34
Purchase fee for tools and apparatus and production furniture	15	0.0761	60	60	671.11	671.11
Total					**54,519.49**	**44,351.58**

between Hefei-Wuhu is set as the without-case. It is assumed that both the with- and without-case have the same track length and the same service life of the subsystem, and the same value of 1.7 % is used for the interest rates. Therefore, the annuity factor for an infrastructure item for with-case and without-case is the same, since the same service life is applied. The total annual asset values of high-speed maglev and high-speed wheel-rail infrastructure are shown in Table 1.

After obtaining the capital value of the infrastructure, the next step is to calculate the maintenance costs of the transportation infrastructure, where only the infrastructure related to engineering and construction needs to be considered. Because the maintenance rates for high-speed maglev are different from those for conventional wheel-rail systems, the maintenance rates are taken from the operational experience of the Shanghai maglev demonstration line. The maintenance costs ratio for high-speed wheel-rail is taken from German standardized evaluation. The calculation of annual maintenance costs for the infrastructure of the high-speed maglev and high-speed wheel-rail projects are shown in Table 2.

It can be seen that although the investment costs of the high-speed wheel-rail system are lower than that of the high-speed maglev system, its maintenance costs are higher than that of the maglev system, especially the traction power supply system, which is 4.7 times that of the maglev system. The annual capital value and annual maintenance costs of infrastructure calculated from the table above will be used as evaluation indicates for the final national economic evaluation.

2.2. Public transportation operating costs

As an important evaluation indicator for the total public transport operating costs, the costs of train fleets include the acquisition costs (asset value) of vehicle itself and the maintenance costs related to time and operating mileage. In this project, the followings aspects need to be considered in the calculation of the maintenance and operating costs of train fleets:

- Depreciation costs and interest rate
- Maintenance and other expenses

Table 2: Annual maintenance costs of high-speed maglev and high-speed wheel-rail infrastructure

Infrastructure investment project	High-speed maglev investment costs [10,000 RMB/year]	Maintenance costs ratio for high-speed maglev [‰]	Maintenance costs of high-speed maglev [10,000 RMB/ year]	Investment costs of high-speed wheel-rail [10,000 RMB/year]	Maintenance costs ratio for high-speed wheel-rail [‰]	Maintenance costs of high-speed wheel-rail [10,000 RMB/ year]
Station	14,400	10.0	144.00	16,000	9.0	144.00
Line track works	1,237,446	1.0	1,237.45	1,236,123	0.5	618.06
Road maintenance	51,450	10.0	514.50	117,600	9.0	1,058.40
Buildings and other facilities	134,064	10.0	1,340.64	104,664	9.0	941.98
Traction power supply system	265,776	3.0	797.33	86,730	14.0	1,214.22
Operation control system and infrastructure communication system	127,155	3.0	381.47	68,355	9.0	615.20
Track girder sound absorption	5,145	0.5	2.57	5,145	0.5	2.57
Purchase fee for tools and apparatus and production furniture	8,820	31.0	273.42	8,820	31.0	273.42
Total	**1,844,256**		**4,691.37**	**1,643,437**		**4,867.85**

Table 3: Difference between vehicle asset values and maintenance costs

		High-speed maglev project	High-speed wheel-rail project	Difference
Vehicle as-set value	Vehicle investment costs [10,000 RMB]	850,500	672,000	178,500
	High-speed maglev project	**High-speed wheel-rail project**	**Difference**	**7,645.03**
Mainte-nance costs of train fleets	Traffic performance related maintenance rate [10,000 RMB/10,000 km]	0.08250	0.08778	-0.00528
	[10,000 RMB/year]	**24,654.44**	**26,232.33**	**-1,577.89**

- Management costs of train fleets and scrapping expenses

The acquisition costs of each vehicle are calculated with the annuity method. The acquisition costs of a single high-speed wheel-rail trainset are RMB 21.0 million. According to internal calculation, the acquisition costs of a single high-speed maglev vehicle is 1.5 times that of high-speed wheel-rail vehicle. The acquisition costs for a maglev trainset are RMB 31.5 million. In [5], 40 high-speed wheel-rail trains of 8-cars formation is required, and 27 maglev trains of 10-car formation are required for the same passenger capacity. According to the standardized evaluation, the annuity coefficient is related to the service life of vehicle (see Table 3-2, Annex 1 of the German Standardized evaluation). The service life of vehicles in this project is 35 years, and the corresponding annuity rate is calculated as 0.0428 for a period of 30 years, with consideration of the residual value rate after depreciation. The asset value of train fleets can be calculated on this basis (see Table 3).

In standardized evaluation, there are two types of the maintenance costs of vehicles need to be considered: that determined by service time and that determined by operating mileage. Since the data is not available, the maintenance costs of train fleets are calculated based on operating data from Shanghai maglev demonstration line. Since only the material costs are considered, the rate of maintenance costs is set as 0.3 %, which is far from underestimated. Therefore, the maintenance costs for train fleets are calculated based on the annual traffic performance obtained from the internal operating experience, in which the maintenance rate is RMB 825/10,000 passenger-kilometer for high-speed maglev trains, and RMB 877.8/10,000 passenger-kilometer for high-speed wheel-rail trains. According to the estimated one-way passenger flow from Hefei to Wuhu and the length of Hefei-Wuhu line given in Chapter 1, the annual traffic performance is calculated as 2,988.42 million passenger-kilometer. Based on this calculation, the maintenance costs of train fleets are presented in Table 3.

Since trains only stop at the starting and ending stations in this project, the energy consumption costs depend on the operating mileage during train operations. Given that the unit energy consumption is 90.07 Wh/seat-km for high-speed maglev, and 74 Wh/seat-km for 300 km/h wheel-rail trains (from Shanghai maglev demonstration line), the total energy consumption can be calculated based on the annual traffic performance. It should be noticed that the unit energy consumption for the 600 km/h high speed maglev train can be higher that of the Shanghai maglev demonstration line. Based on these rates, it is possible to calculate the energy consumption and the costs. The electricity price per kWh is converted from 0.12 EUR/kWh [2] to 0.876 RMB /kWh. According to [7], the energy consumption of maglev trains is about 30 % more than that of the state-of-the-art high-speed trains, conforming to the estimated costs of this project.

According to [5], there are 60 pairs of train runs are operated every day with 40 trainsets. Each trainset is provided with one crew, consisting of five members (including one driver), and the total number of staffs for high-speed rail is 200. In case of 40 pairs of high-speed maglev trains running every day, provided with 27 crews (five members per crew), the total number of staffs is 135. According to the operating data, it is given that the total personnel expenditure of Shanghai-Hangzhou maglev line with 350 employees will reach RMB 100,280,000 in 2022, with a per capita expenditure of RMB 286,500 for each staff (including the management). The same personnel rate of a staff is applied for both high speed maglev trains and wheel-rail trains.

According to the above calculation results, the balance of public transportation operating costs can be obtained, including the balance in the asset value of train fleets, the maintenance costs, staff costs and energy consumption costs (see Table 4).

2.2.3. Assessment of saving on travel time

Based on running time calculation, the average running time for a single train run of high-speed maglev and wheel-rail train is 18.67 min and 31.38 min respectively. The high-speed maglev train saves 12.72 min for a one-way trip. In total, 4,308,428.19 hours of travel time are saved for the maglev project per year.

The per capita GDP of Anhui Province reached RMB 73,603 in 2022 [4]. According to [1], the unit value of saving travel time can be obtained by using the following formula:

Unit value of saving travel time [RMB/h] = annual per capita GDP [RMB/year]/2000

Hence, the unit value of saving travel time in 2022 is RMB 37/h. The product of the unit value of saving travel time and the annual travel time savings is the

Table 4: Balance in total public transportation operating costs

	High-speed maglev project [10,000 RMB/year]	High-speed wheel-rail project [10,000 RMB/year]	Difference [10,000 RMB/year]
Vehicle asset value (2022)	36,426.29	28,781.26	7,645.02
Maintenance costs of train vehicles (2022)	24,654.44	26,232.33	-1,577.88
Staff costs (2022)	3,867.75	5,730.00	-1,862.25
Energy consumption costs (2022)	23,579.01	19,372.12	4,206.89
Total (2022)	**88,527.49**	**80,115.71**	**8,411.78**

Table 5: Time-saving benefits for passengers

	High-speed maglev project	High-speed wheel-rail project [10,000 RMB/year]	Difference [10,000 RMB/year]
Passenger time cost	23,403.35	39,344.54	-15,941.19
Total	**23,403.35**	**39,344.54**	**-15,941.19**
Evaluation value			**+15,941.19**

Table 6: Environmental improvement benefits

	High-speed maglev project [10,000 RMB/year]	High-speed wheel-rail project [10,000 RMB/year]	Difference [10,000 RMB/year]
Difference in CO_2 emissions	12,120.79	9,958.24	2,162.55
Difference in other waste emissions	1,884.17	1,548.00	336.17
Total	**14,004.96**	**11,506.24**	**2,498.72**
Evaluation value			**-2,498.72**

time-saving benefits for passengers (see Table 5).

2.2.4. Other motor vehicle traffic costs and accident costs

As there is currently no data available to support the Hefei-Wuhu high-speed maglev project, these indicators are not taken into consideration. Due to the absence of the data, the potential benefits of the project may not be fully considered, and this factor must be taken into account in the final analysis.

The evaluation of accidental loss costs is mainly based on the analysis of two aspects of accidental losses, namely the economic losses and personnel casualties, and the comparison of the accident rates related to transportation capacity with and without the project.

Given that, the accident rates of high-speed rail and high-speed maglev are extremely low and similar, the difference between the two cases is set to zero.

2.2.5. Emission costs (environmental improvement benefits)

The positive and negative effects on the environment should also be considered in the evaluation, and the implementation of project engineering can reduce individual motorized transportation and have positive effects on emissions reduction.

In the calculation of the German standardized evaluation, carbon dioxide and other waste emissions depend on the consumed electric energy, where the unit emission of carbon dioxide is 414 grams/kWh [2], corresponding to the emission costs of 149 euros/ton, equivalent to RMB 1,087.70/ton; the conversion parameter for the unit emission costs of other waste is 0.96 cents/kWh [2], equivalent to RMB 0.07 yuan/kWh. Combined with the energy consumption of train operation in 2.2., the emission costs can be calculated, and the evaluation results are shown in Table 6.

2.3. Standardized evaluation of the extended line Hefei-Huwu-Guangde

After conducting standardized evaluation for the Hefei-Wuhu line, the cost-benefit ratio was found to be less than 1, indicating that the project may not be profitable. To address this, the 147 km Hefei-Wuhu line will be extended to Guangde to examine whether increasing the length of the route and the corresponding passenger traffic volume can improve the cost-benefit ratio. The reason for extending the line to Guangde is that it is the last station in Anhui Province, which has similar basic socio-economic conditions. Moreover, in China, maglev demonstration lines are usually decided at the provincial level, so if it is extended to the neighboring province of Zhejiang, the feasibility and consistency of the evaluation cannot be guaranteed.

Except for the increase in the length of the line and the annual traffic volume, the other parameters and calculation methods are the same as those in section 2.2 for the Hefei-Wuhu segment, so the calculation steps and tables are omitted in this section.

3. Results of standardized evaluation for the Hefei-Wuhu-Guangde high-speed maglev project

According to the calculations in Chapter 2, the results of various evaluation indicators and the final standardized evaluation for the

Table 7: Evaluation indices for standardized evaluation and calculation of cost-benefit indices for Hefei-Wuhu section

Evaluation index	Evaluation indices [10,000 RMB/year]
Travel time change (time-saving benefits for passengers)	+15,941.19
Difference in traffic costs of other motor vehicles	0
Difference in total public transportation operating costs	-8,411.78
Annual capital value of infrastructure for high-speed wheel-rail project	+44,351.58
Infrastructure maintenance costs of high-speed maglev project	-4,691.37
Infrastructure maintenance costs of high-speed wheel-rail project	+4,867.85
Difference in contingency costs	0
Difference in emission costs (environmental improvement benefits)	-2,498.72
Total	49,558.74
Annual capital value of infrastructure for high-speed maglev project	54,519.49
Cost-benefit difference	-4,960.75
Cost-benefit index	**0.91**

Table 8: Evaluation indices for standardized evaluation and calculation of cost-benefit indices for Hefei-Guangde section

Evaluation index	Evaluation indices [10,000 RMB/year]
Travel time change (time-saving benefits for passengers)	+40,060.92
Difference in traffic costs of other motor vehicles	0
Difference in total public transportation operating costs	-11,930.37
Annual capital value of infrastructure for high-speed wheel-rail project	+85,082.63
Infrastructure maintenance costs of high-speed maglev project	-8,999.77
Infrastructure maintenance costs of high-speed wheel-rail project	+9,338.31
Difference in contingency costs	0
Difference in emission costs (environmental improvement benefits)	-5,842.94
Total	107,708,78
Annual capital value of infrastructure for high-speed maglev project	104,588.41
Cost-benefit difference	3,120.36
Cost-benefit index	**1.03**

cost-benefit analysis of the final evaluation index can be obtained. All the indicators used in the evaluation include those measured in monetary units or converted into monetary units, covering all the benefits and impacts on passengers, operators, the environment, and the entire society. Among them, the standardized evaluation results for the Hefei-Wuhu section in the early stage of the project are shown in Table 7.

The results show that for the planned Hefei-Wuhu high-speed maglev transportation project, its annual national economic benefits are lower than the annual infrastructure cost. The ratio of annual benefit to costs is 0.91. Therefore, in order to ensure project revenue, it is necessary to consider extending the maglev line to Guangde. The standardized evaluation results of the project's extension to Guangde in the later stage are shown in Table 8.

The results show that for the planned Hefei-Guangde high-speed maglev transportation project, its annual national economic benefits exceed the annual infrastructure costs. The overall benefit is 1.077 billion yuan per year, while the costs is 1.046 billion yuan per year. The cost-benefit ratio is 1.03, which means that the overall benefits generated by the project exceed the costs by 1.03 times.

4. Conclusions

This research project evaluated the feasibility of the Hefei-Wuhu-Guangde high-speed maglev project using the German standardization assessment method for national economic evaluation. It also explored the differences between the German and Chinese assessment methods, as well as the possibility of applying the German standardization assessment method in China.

The analysis results showed that the planned Hefei-Wuhu high-speed maglev transportation project would lead to lower annual national economic benefits than the annual infrastructure costs when compared to existing high-speed rail systems. The overall annual benefit was 496 million yuan/year, while the costs was 545 million yuan/year, resulting in a benefit-cost ratio of 0.91. Therefore, the Hefei-Wuhu high-speed maglev project did not demonstrate an advantage over the high-speed rail system. To ensure project profitability, it was necessary to extend the maglev route to Guangde, which would increase the benefit of saving travel time. After extending the route, the final annual benefit of high-speed maglev was 1.077 billion yuan/year, while the costs were 1.046 billion yuan/year. The cost-benefit ratio was 1.03, indicating a balanced profitability based on a conservative calculation with a certain potential that can be realized by more detailed contemplation to get better results. The induced traffic volume from private transportation and railway systems was not considered in this study. In addition, a high-speed maglev line of only 282 kilometers is not sufficient to present its advantages over aviation. Longer operational lines, such as from Beijing to Shanghai, would be more attractive.

The German standardization assessment can be applied in China by establishing a detailed cost structure and calculating the required parameters, indicators, and future trends. Furthermore, different public transportation projects of various scales and volumes should be analyzed using this method. The important factors that affect decision-making results should be investigated, and the method and conditions for sensitivity analysis should be determined. Finally, suitable parameters, indicators, and assessment methods for China's national conditions should be determined to optimize resource allocation and achieve objective, fair, and transparent evaluations and decisions for public transportation projects.

In subsequent research, a software platform for parameter analysis and system optimization should be established to maximize the benefit / cost ratio and derive the optimal planning and design solutions. Critical variables and parameters for the system that need to be achieved to ensure profitability should also be studied to provide guidance for future system optimization and engineering development.

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