Original Research Article

Comparison and Selection of Sewage Deep Tunnel Engineering Schemes Based on Value Engineering

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Abstract: In recent years, urban development, population expansion, and water pollution have become more and more serious. The main cause of reclaimed water pollution in Wuhan is that the combined drainage system is still retained, which makes the overflow pollution of the drainage system and the problem of regional waterlogging particularly prominent. The use of a sewage deep tunnel system to replace the traditional confluence system can basically eliminate overflow pollution. At the same time, applying value engineering to the decision-making stage of sewage deep tunnels for scheme comparison and optimizationcan effectively reduce costs, increase revenue, and enhance use functions.

Keywords: Sewage deep tunnel; Value engineering; Cost control.

1. Introduction

In recent years, Wuhan has developed rapidly, and the phenomenon of water pollution has become increasingly serious. The main reason for water pollution in Wuhan is that the combined drainage system is still retained, which leads to insufficient sewage treatment capacity and a lack of a complete sewage discharge system, resulting in particularly prominent overflow pollution and regional waterlogging problems in the drainage system. The impact of the decision-making stage of engineering projects on the cost of engineering far exceeds that of later design and construction. The author believes that value engineering can be applied to the decision-making stage of sewage deep tunnels for scheme comparison and optimization, which can effectively reduce costs, improve functional value, and avoid situations where the budget exceeds the estimate, the budget exceeds the estimate, and the settlement exceeds the budget.

2. Overview of Deep Tunnel Engineering for Pollutant Discharge

2.1 Research Background

Urban drainage system is an essential facility system. Its function is to collect sewage and surface runoff generated by domestic and industrial activities and transport them to sewage treatment plants, avoiding the accumulation of sewage and endangering the health of cities and residents. It can protect the environment, improve residents' lives, promote urban development, and ensure the normal operation of urban production, people's health, and normal life are not disturbed[1]. (Figures 1 and 2)

However, with the rapid development of Wuhan city, the total discharge of sewage is also increasing. The original combined drainage system can no longer meet people's needs, and regional waterlogging and overflow pollution problems are becoming increasingly frequent. Compared with the combined drainage system, the deep

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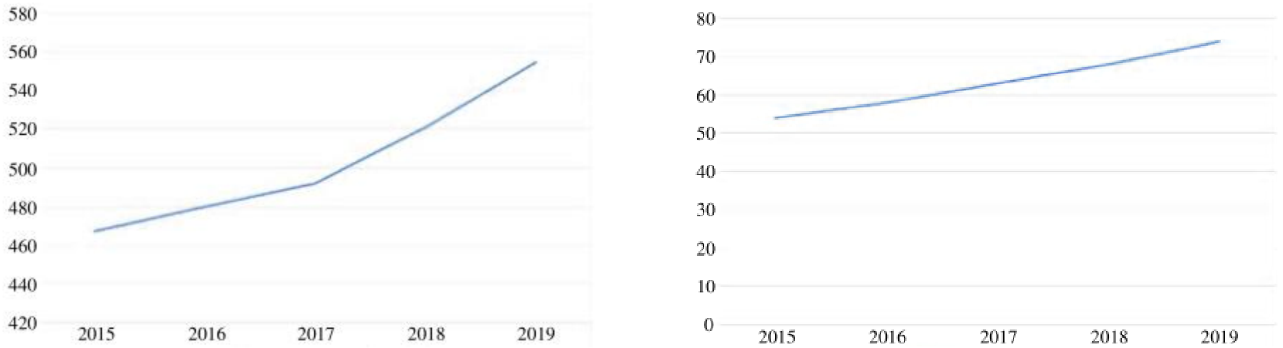
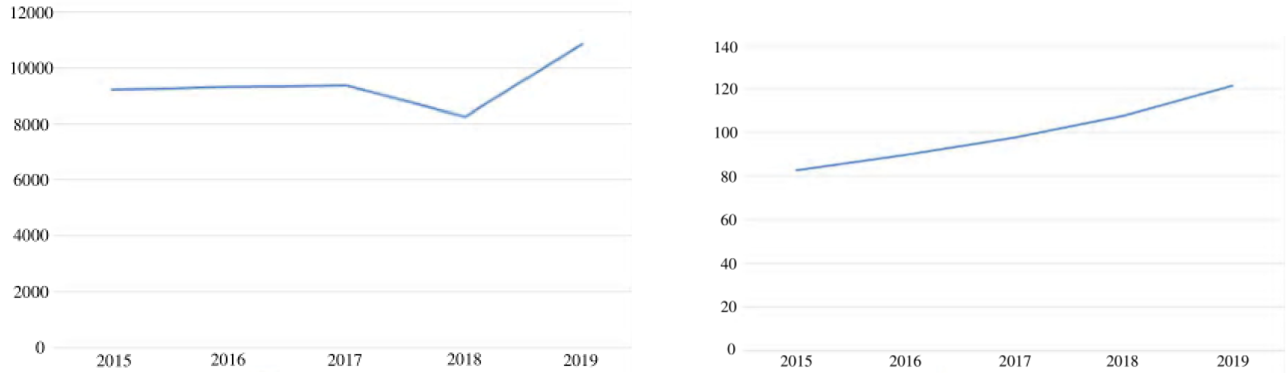
tunnel drainage system has advantages such as saving land resources, improving the interception ratio of the drainage network system, solving initial rain pollution, and providing more flexible scheme selection for the operation of sewage treatment plants. It can effectively solve the problem of overflow pollution and comprehensively improve the drainage standards of the entire basin. (Figures 3 and 4)



a. China's sewage discharge volume (billion cubic meters) **b. The total length of drainage pipelines in China**

Figure 1 Schematic diagram of china's drainage system situation.



a. Wuhan drainage pipeline length (kilometers) **b. Wuhan's sewage discharge volume (100 million cubic meters)**

Figure 2 Schematic diagram of the drainage system in Wuhan city.

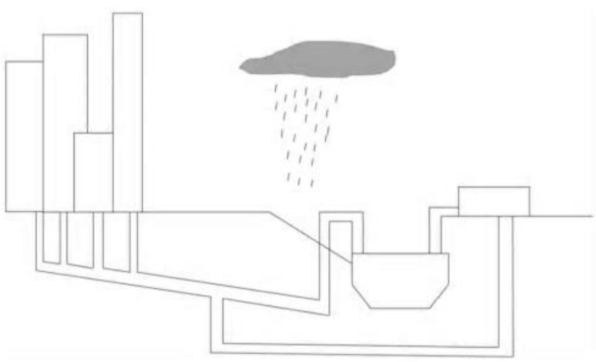


Figure 3 Combined drainage system.

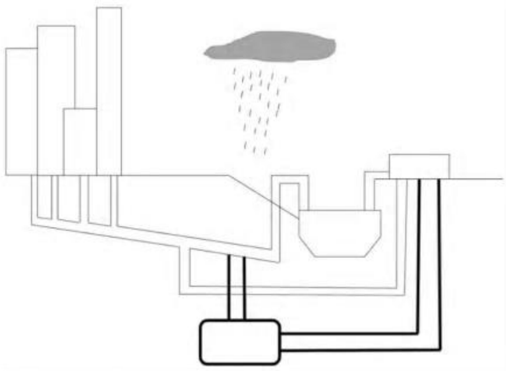


Figure 4 Sewage deep tunnel system.

2.2 Purpose and Significance

The drainage system in Wuhan is significantly underdeveloped compared to developed countries. When the amount of rainfall is too large, once the drainage system cannot be timely discharged, it can cause regional waterlogging. At the same time, waterlogging and surface runoff can bring pollutants accumulated in the drainage pipes into the waterlogging, causing overflow pollution and serious damage to the urban water environment and residential environment[2].

Using a sewage deep tunnel system to replace the traditional combined flow system, constructing deep tunnels to discharge sewage can basically eliminate overflow pollution. Compared with the combined flow system, it can reduce land occupation, increase interception times, reduce initial rain pollution, reduce the impact of ground construction on the surrounding environment, flexibly regulate the operation of sewage treatment plants, and effectively improve the drainage standards of the entire basin, which is in line with the current situation and future development direction of Wuhan, Beneficial for assisting in promoting urban construction.

2.3 Current Situation of Domestic and International Construction

2.3.1 Current Situation of Foreign Pollutant Discharge Deep Tunnel Construction (Table 1)

Table 1 Introduction to representative deep tunnel projects abroad[3].

Region	Name of sewage deep tunnel	Completion time	Project scale	Type of deep tunnel	Major function
Tokyo, Japan	Edogawa Deep Drainage Tunnel	2006	An underground pipeline with a total length of 6.3km and an inner diameter of 10m, 5 vertical shafts with a diameter of 30m and a depth of 60m, and an underground reservoir with a length of 177m, a width of 77m, and a height of 20m.	Flood control type	Relieve waterlogging
Sydney, Australia	Delicate North Sewage Storage Tunnel	2002	Total length of 16km, buried depth of 40-100m, diameter of 3.8-6.6m.	Flood control type	Control pollution
Chicago, USA	Tunnel and Reservoir Engineering Plan (TARP)	2006	Total length 176km, pipeline diameter 2.4-10m.	Multifunctional	Relieve waterlogging and control pollution
Milwaukee, USA	Milwaukee Deep Tunnel Storage System	1994	The total length is 45.8km, with a pipeline diameter of 5.1-97m and a burial depth of 41-91m.	Multifunctional	Relieve waterlogging and control pollution

2.3.2 Current Situation of Domestic Sewage Discharge Deep Tunnel Construction (Table 2)

Table 2 Introduction to representative deep tunnel projects in China[3].

City	Name of sewage deep tunnel	Construction progress	Project scale	Target function
Guangzhou	Donghao Yong Deep Tunnel Drainage Engineering Test Section	Construction and construction	The main tunnel is 1.77km long, the branch tunnel is 1.39km long, the pipeline radius is 3m, and the burial depth is 30-40m.	Relieve waterlogging and control pollution
Shenzhen	Nanshan Drainage Deep Tunnel System Project	Plan to initiate construction	The total length is 4.1km, the pipeline diameter is 6.2m, and the burial depth is 30-40m.	Control pollution, flood control and drainage
Shanghai	Deep Drainage and Storage Tunnel System Engineering for Hongkou Port Zoumatang Section	Feasibility study	The total length is 31.5km, the pipe diameter is 8m, and the burial depth is 30-60m	Relieve waterlogging and control pollution
Wuhan	Sewage transmission system project in the core area of Dadong Lake	Plan to initiate construction	The total length is 17.6km, with a main tunnel diameter of 3-3.4m, a branch tunnel diameter of 1.5m, and a burial depth of 29.93-42m.	Control pollution and improve discharge capacity

3. Composition and characteristics of Sewage Deep Tunnels Structure

3.1 Composition of Sewage Deep Tunnel Structure

The main structure of the sewage deep tunnel system includes five parts: deep tunnel pipelines, inflow shafts, drainage pump sets, ventilation equipment, and sludge discharge facilities[4].

(1) Deep tunnel pipelines can be subdivided into primary to tertiary pipelines. The sewage in the shallow drainage pipeline is first collected and concentrated by the third level pipeline, and then transported to the first level deep pipeline through the second level pipeline. The buried depth of the first level pipeline is greater than 30 meters, and it is a main tunnel that can avoid the existing urban water and electricity network; The diameter span of the first level pipeline in the sewage deep tunnel system is relatively large, ranging from a few meters to more than ten meters, which is common. It can provide additional scheduling space for the drainage system to transport and regulate the strong and weak precipitation runoff or collected sewage in the city.

(2) The sewage deep tunnel system collects rainwater or sewage through vertical shafts and transports the sewage from the shallow drainage system to the deep drainage system. The interior of the vertical shaft will adopt energy dissipation measures such as vortex falling and water drop to guide the water flow to fall significantly, avoiding the water flow from converting large gravitational potential energy into internal energy and damaging the pipeline. When the staff carry out maintenance and repair work, they also enter the pipeline through a vertical shaft.

(3) The drainage pump group is responsible for lifting the water inside the sewage deep tunnel pipeline to the surface sewage treatment plant, and can also be used for scheduling work between different water storage areas in the sewage deep tunnel.

(4) Ventilation facilities are mainly used for situations such as heavy precipitation to avoid the formation of compressed air chambers when a large amount of rainwater flows in, occupying the water flow space in the tunnel, reducing the amount of water transported, and affecting the water flow transportation. Therefore, it is necessary to set ventilation holes to discharge excess gas.

(5) The buried depth of the sewage deep tunnel system pipeline is relatively deep, and the water flow in the deeper strata is prone to carrying solid particles, leading to sediment deposition and blockage of the pipeline, occupying a large amount of pipeline water storage space. Effective inspection and dredging measures need to be arranged to regularly remove the sediment inside the pipeline.

3.2 Characteristics of Deep Sewage Tunnels

The deep tunnel for sewage discharge transfers the work of regulating, storing, and transporting sewage underground, which can greatly save land resources. At the same time, the construction of the deep tunnel can greatly improve the capacity of the drainage network to discharge sewage, thereby increasing the interception ratio of the drainage network system and allowing for flexible scheduling of sewage treatment plant operations. The sewage deep tunnel effectively solves the problem of sewage overflow, realizes initial rainwater treatment, controls non-point source pollution, and prevents overflow pollution and urban waterlogging in rainstorm weather.

Due to the fact that the sewage deep tunnel project is located in the deep underground space and has a large amount of work, the initial project cost investment is relatively high, and it is suitable for areas with high building density and difficult demolition. Due to the problem of deep burial, the power consumption of the lifting pump station during operation is high, resulting in high operating costs and high cleaning and maintenance costs.

4. Cost composition of sewage deep tunnels

The cost of sewage deep tunnel engineering can be divided into direct fees, indirect fees, and taxes based on the type of cost. The direct cost consists of direct engineering cost and measure cost, while the indirect cost consists of regulatory fee and enterprise management fee. The taxes include business tax, value-added tax, etc. The detailed composition is shown in Figure 5[5].

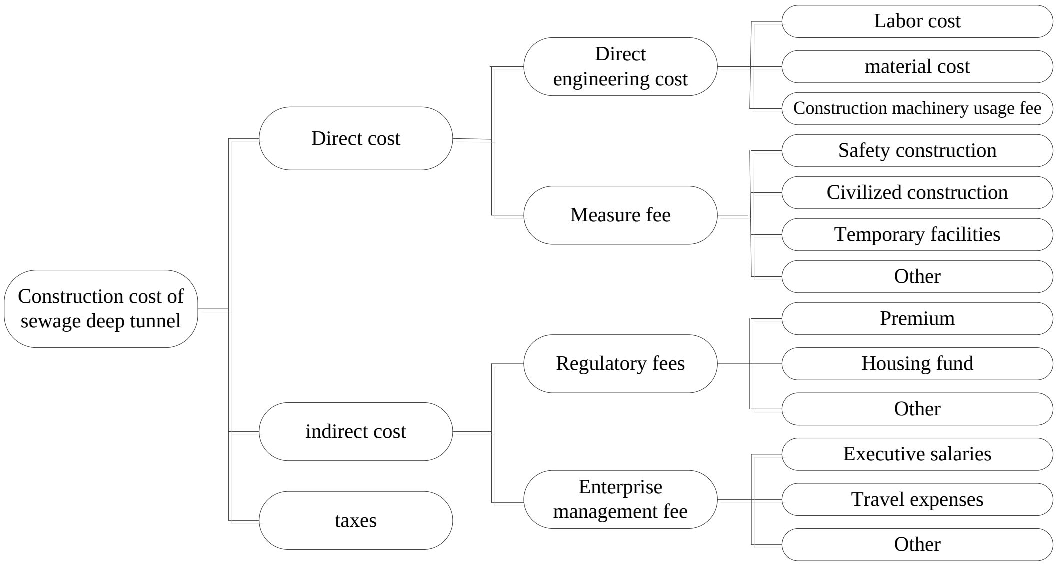


Figure 5 Construction cost diagram of sewage deep tunnel.

From the perspective of construction equipment and measures, it can be divided into pipe segment costs, secondary lining costs, shield tunneling machine costs, excavation equipment costs, other engineering equipment costs, waste soil treatment costs, excavation labor costs, vertical shaft construction costs, entrance and exit tunnel protection costs, etc. The specific proportions of each cost are shown in Table 3[6].

Table 3 Cost composition of pollutant discharge deep tunnel

Project	Segment	Secondary lining	Shield	Excavation equipment	Other engineering equipment	Waste soil treatment	Excavation labor costs	Vertical shaft construction	Entry and exit tunnel protection	Other
Cost proportion	34-38	12-15	17-19	9-15	5-8	7-16	5-11	7-18	4-10	4-8

In summary, we can see that sewage deep tunnels have a large amount of construction, multiple equipment used, and a complex cost structure. Combined with the cost of existing sewage deep tunnel projects in China, it can be seen that the budget for such projects generally ranges from 1.5 to 3 billion yuan. Therefore, the cost of such projects is generally high, and budget control and scheme optimization are particularly important.

5. The Application of Value Engineering in Deep Sewage Tunnels

5.1 Theoretical Basis of Value Engineering

5.1.1 Definition of Value Engineering

Value Engineering(VE) is an economic management method that strives to reduce product costs as much as possible, achieve the core functions of the product, thereby increasing product value and improving enterprise efficiency. The relationship formula of value engineering is: $V = \frac{F}{C}$

Among them, V represents the value coefficient, which refers to the benefits of the product itself, F represents the functionality, which refers to the value of the product in use, and C represents the cost, including the costs required for manufacturing and usage. In summary, the value of a product is a comprehensive reflection of its functionality and cost. The core of value engineering is to increase the value of the target, that is, to enhance the target functionality and reduce the target cost[7].

5.1.2 Value Engineering Work Procedure

The process of value engineering can be divided into four stages, and the specific steps, content, and corresponding core issues are shown in Table 4.

Table 4 Value Engineering Work Procedures[7].

Stage	Steps	Explanation	Core issues
Preparation stage	Selecting Value Engineering Objects	Clear target constraints and analysis scope should be established	Analyze what?
	Form a value engineering analysis team	Generally composed of project leaders, professional technical personnel, and personnel familiar with value engineering	Who will analyze it?
	Develop feasible work plans	Specific executor, execution date, work objectives	What is the plan？
Analysis phase	Collect relevant information and organize it	Throughout the entire process of value engineering work	What information to collect？
	Function definition and organization	Clarify functional requirements and draw functional system diagrams	What is the cost？
	Function evaluation	Clarify target costs and identify areas for functional improvement	What is the value？
Innovation stage	Propose multiple solutions	Propose various class solutions that can achieve functionality	Is there a better solution？
	Conduct a comprehensive evaluation of the plan	Comprehensively evaluate the possibility of each plan achieving the specified goals from various aspects such as technology, economy, and society	What is the cost and value of the new solution？
	Compile proposals	Write the selected plan in writing and compile it into a book	Can the new plan meet the requirements？
Implementation phase	Plan approval (experiment)	Approval by the competent department	
	Plan implementation and inspection feedback	Develop an implementation plan, organize implementation, and track inspections	
	Evaluation of scheme effectiveness	Identify the technical and economic achievements obtained after implementation	

5.1.3 Analysis Methods of Value Engineering

The sewage deep tunnel project has a large scale and complex content. When carrying out value engineering work, it is not possible to analyze all the links, processes, etc. In order to make the research of value engineering targeted and achieve the expected results, it is necessary to select the target objects in a key and sequential manner. The following are common methods for selecting target objects in value engineering.

(1) Empirical analysis method. The empirical analysis method utilizes the intuitive understanding of personnel with rich practical experience in value engineering, comprehensively considers various influencing factors, distinguishes primary and secondary importance, and subjectively judges to determine the goals of value engineering. This method is simple and easy to operate, and can comprehensively consider and analyze problems, but it lacks quantitative analysis and has low accuracy[7].

(2) Percentage method. The percentage method is a quantitative analysis method. It is a method of selecting objects by quantitatively analyzing the proportion of several technical and economic indicators for each product or solution, and examining the comprehensive ratio of the percentage of indicators for each product or solution.

(3) ABC analysis method. The ABC analysis method belongs to the key analysis method. It divides all research objects into three categories: ABC, with 10-20% of component costs accounting for 70-80%, and such products are classified as Class A; The cost of components of 20% category accounts for about 20%, and such products are classified as Class B; The remaining components are classified as Class C. Through such sorting and division, key few components can be accurately identified, thereby improving the effectiveness of value engineering.

5.2 Mathematical Model of Value Engineering

This article applies value engineering to the scheme comparison and optimization of sewage deep tunnel engineering, quantitatively analyzing and comparing various schemes, which is divided into three steps in total[8].

(1) Evaluate the technical and economic scores of each plan.

Use weighted scoring method to score each scheme technically and economically. The sum of weights for each scheme's compliance score with various technical evaluations is the technical score of the scheme, and similarly, the sum of weights for each scheme's compliance score with various economic evaluations is the economic score of the scheme.

(2) Calculate the technical and economic indices for each solution[8].

The formula for calculating the technical index is:

$$Tl_i = TS_i / \sum_{i=1}^{m} TS_i \left(i = 1, 2, \cdots, m\right) \quad \text{(Eq.1)}$$

The calculation formula for economic index is:

$$El_i = \left(C^0 - C_i\right) / \sum_{i=1}^{m} \left(C^0 - C_i\right) \left(i = 1, 2, \cdots, m\right) \quad \text{(Eq.2)}$$

Where: Tl_i is the technical index of the i-th scheme, TS_i is the technical score of the i-th scheme, EL_i is the economic index of the i-th scheme, C_i is the engineering cost of the i-th scheme, C^0 is the engineering cost limit, i is the scheme number, and m is the number of schemes.

(3) Calculate the geometric mean of each scheme, compare and select the best, and propose optimization directions[8].

The solution with the highest geometric mean is the optimal solution, and the formula for calculating the geometric mean is:

$$K_i = \sqrt{Ti_i \times El_i} \left(i = 1, 2, \cdots, m\right) \quad \text{(Eq.3)}$$

Where K_i is the geometric mean of the i-th scheme.

5.3 Engineering Case Analysis

For the selection and evaluation of the plan, it is necessary to comprehensively consider the technical, economic, and social aspects of the plan, and then select a more reasonable and excellent plan. Due to the difficulty in quantifying social factors, when applying the value engineering method, only economic and technical indicators are generally calculated, and only qualitative analysis is conducted on the social aspects of the plan. A comprehensive balance is made between technical and economic indicators, and the best is selected from each plan.

We are currently selecting the optimal design scheme for a certain sewage deep tunnel. Based on the construction site conditions and relevant construction requirements, the designers have provided four design schemes. These four schemes have different line lengths, burial depths, and inner diameters due to different line choices. At the same time, the design drainage capacity, operating consumption, and difficulty in cleaning and cleaning of each scheme also vary. Among them, Plan A has many pipeline branches and excellent performance in various indicators. At the same time, the planned underground reservoir greatly enhances its drainage capacity and indirectly increases its cost. Plan B has reduced its drainage capacity and budget by modifying the route, canceling the underground reservoir, and other measures based on Plan A. The design of Plan C focuses more on economic benefits, so its drainage capacity is not excellent and just meets the design requirements of this project. Plan D is based on Plan C to strengthen its drainage capacity at the cost of paying some economic benefits. The value engineering team has set indicators such as drainage and sewage discharge capacity, operating consumption, cleaning difficulty, durability, planning rationality, technical difficulty, and construction progress for evaluation and comparison based on the collected data and relevant investigations. The amount of sewage deep tunnel engineering is large, and the design and construction difficulty is high, so the cost is limited to 2.2 billion yuan.

(1) Evaluate the technical and economic scores of each plan. (Table 5)

Table 5 Important weights of indicators and technical scoring table for schemes.

Evaluating indicator	Construction unit rating	Design unit rating	Expert group rating	Importance weight	Design quality rating	A	B	C	D
Drainage and sewage discharge capacity	39.6	41.6	42	04116	Design quality meets score S	10	8	7	9
Operating consumption	18.5	20.1	18.3	0.189		8	9	8	7
Cleaning difficulty	10.7	11.8	11	0.1115		8	8	6	6
Durability	15.6	15	15.4	0.1534		9	9	8	8
Planning rationality	8.5	6.6	7.8	0.0765		8	8	7	7
technical parameter	4.7	3.4	2.6	0.0347		7	8	7	6
Construction progress	2.4	1.5	1.9	0.0193		7	7	7	7
total	100	100	100	1					
Sum of rating weights						8.8906	8.2911	7.2029	7.8024

(2) Calculate the technical and economic indices for each solution. (Tables 6 and 7)

Table 6 Technical index table.

Scheme name	A	B	C	D
Scoring weight and	8.8906	8.2911	7.2029	7.8024
technical index	0.276	0.258	0.224	0.242

Table 7 Economic index table.

Plan Name	Main features (advantages and disadvantages)	Budget cost	Economic index
A	A total length of 12.4km, inner diameter of 4-6.4m, buried depth of 40-80m, and an underground capacity of 600000 m^3	2 billion 530 million	Exceeding the limit value
B	Total length 10.8km, inner diameter 3.8-6m, buried depth 40-65m	2 billion 40 million	0.32
C	Total length 11.3km, inner diameter 4-6 meters, buried depth 45-70m	1 billion 960 million	0.48
D	Total length of 12km, inner diameter of 4.3-6.8m, buried depth of 45-80m	2.1 billion	0.2

(3) Calculate the geometric mean of each scheme. (Table 8)

Table 8 Geometric average table.

Scheme name	B	C	D
Technical index	0.258	0.224	0.242
Economic index	0.32	0.48	0.2
Geometric mean	0.287	0.328	0.22

From the above calculation results, it can be seen that although Plan A has the highest technical index, its economic index is 0 due to its budget amount exceeding the limit value, so Plan A does not meet the actual requirements. Among the remaining plans, Plan C has the lowest technical index, but its budget amount is lower than other plans, making its economic index far higher than the other plans. Therefore, the comprehensive technical and economic indicators jointly evaluate the most balanced and optimal plan for each Plan C. Subsequent plan optimization can improve the functionality of the plan by improving cost optimization technology. In summary, it is feasible to apply value engineering theory to select the optimal scheme and provide directions for further optimization in the scheme comparison and optimization of sewage deep tunnels.

6. Conclusion

Urban expansion and population expansion will inevitably lead to excessive load on the drainage system. Building a sewage deep tunnel system can basically eliminate overflow pollution and urban waterlogging problems, which is conducive to assisting in promoting urban construction. Applying value engineering to the decision-making stage of sewage deep tunnels for scheme comparison and optimization can effectively reduce costs, improve profits, enhance usage functions, further leverage the advantages of sewage deep tunnels, and avoid weakening their disadvantages.

Conflict of Interest

The authors declare no conflict of interest.

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