Cost allocation model of power pipeline access corridor based on group decision and spatial proportion method

Lingyun Li*, Xinju Guo, Dapeng Li, Xuayng Li, Tiejun Zhou
State Grid Henan Economic Research Institute, Henan, China

*Corresponding author e-mail: 595910434@qq.com

Abstract. With the continuous acceleration of the urbanization process, more and more cities begin to lay down utility tunnels that can effectively improve the utilization efficiency of urban space. Based on this, this paper firstly studies the construction cost composition and operation and maintenance cost composition of the utility tunnels, and then, considering all stakeholders involved in the electrical cables into utility tunnels, establishes the allocation model of the electrical cables into utility tunnels cost based on the group decision model and the spatial proportion method. Finally, some sections of Qingdao utility tunnels are selected as examples for verification. The results show that the model has strong practicability and can effectively solve the problem of cost allocation of electrical cables into utility tunnels.

Key words: Utility Tunnels; Group Decision Model; Spatial Proportion Method; Cost Allocation Model.

1. Introduction
The electrical cables into utility tunnels plays an important role in improving the safety, reliability and service life of the electrical cables. However, there are multiple stakeholders involved in the electrical cables into utility tunnels, and the investment is large and the operation cost is high, so it is necessary to explore a reasonable cost allocation model for the access.

Most of the existing studies focus on the technical level of utility tunnels, but there are few studies on the cost allocation of electrical cables into utility tunnels. Literature [1] puts forward the charging mechanism of utility tunnels based on two modes of electrical cables into utility tunnels. At present, there are three methods for the cost apportionment of underground utility tunnels, namely proportional apportionment [2], principal-agent theory [3], and game theory [4]. Literature [5] puts forward the cost allocation method of electrical cables into utility tunnels on the basis of considering the balance of interests of multiple subjects.

To sum up, the current research perspective on the cost allocation of electrical cables into utility tunnels is relatively single. Therefore, this paper uses group decision making and spatial proportion method to comprehensively consider multiple stakeholders and pipeline space to build the cost allocation model of electrical cables into utility tunnels, so as to improve the enthusiasm of electrical cables into utility tunnels.
2. Overview of cost allocation of electrical cables into utility tunnels

2.1. Relevant stakeholders of the utility tunnels

(1) Government
At present, the urban utility tunnels which has been built or under construction in China is basically financed by various government financial means. In the later stage of operation, charging is seldom used to raise funds, but finance is mainly used to ensure the operation of the utility tunnels.

(2) Pipeline unit
At present, most of the underground utility tunnels in China adopts the mode of government-invested construction pipe gallery and free use of pipeline units. However, it is not a long-term plan to rely solely on the government investment mode to build the underground utility tunnel, which will bring too much debt to the government. Therefore, in accordance with the user-paid principle, pipeline unit should be one of the subjects of cost allocation.

2.2. Basic principles of cost allocation for electrical cables into utility tunnels
The cost sharing process of the electrical cables into utility tunnels mainly involves two problems: the cost sharing ratio between the government and the pipeline unit, and the determination of the cost sharing ratio between the power pipeline unit and other pipeline units. Therefore, according to the principle of "beneficiary pays", if the external benefits are all benefited by the public, the government, as the agent of the public, should bear more than 50% of the expenses. Therefore, in this paper, the apportionment ratio of the government's access fee is set at 0.5. The daily maintenance fee will be apportioned according to the principle of "user pays"[6]. Based on the existing experience, the government apportionment ratio of 0.3 is more appropriate [7]. The remaining part shall be apportioned among pipeline units in a certain proportion.

3. Cost allocation method for electrical cables into utility tunnels

3.1. Calculation of electrical cables into utility tunnels cost
Electrical cables into utility tunnels costs can be divided into two parts, construction costs and operational costs. Construction costs mainly include construction and installation costs, equipment and equipment purchase costs, other construction costs and unforeseeable costs; Operational cost including utility tunnel facilities maintenance and utility tunnel facilities operating cost, operating expenses including wages and welfare funds, management fee and utilities, etc.

In the service life of the pipeline, it can be replaced once. The cost calculation formula of utility tunnels construction is as follows:

\[ C_1 = C_{11} + C_{12} + C_{13} + C_{14} \]  

Where, \( C_{11} \) is the construction and installation project cost, \( C_{12} \) is the equipment and equipment purchase cost, \( C_{13} \) is other project construction cost, \( C_{14} \) is unforeseeable cost.

The operation and maintenance cost of the utility tunnels consists of four parts: the maintenance cost of the facilities, wages and benefits, management fee and water and electricity fee. Its calculation formula is as follows:

\[ C_2 = C_{21} + C_{22} + C_{23} + C_{24} \]

Then the total cost of the integrated pipe gallery is:

\[ C = C_1 + C_2 \]

3.2. Cost allocation model for electrical cables into utility tunnels
(1) Construction cost allocation method
One of the important objectives of cost allocation of utility tunnels is to maximize the overall benefit of pipeline unit. The group decision method can take the overall benefit of pipeline unit (decision
population) into account by establishing the group decision utility model, this paper determines the cost allocation ratio between pipelines from the perspective of group decision.

1) Establish a group decision model

The utility function established by the construction pipeline unit $i$ on the basis of fairness and rationality is $U_i (i = 1, 2, L, n)$. $U_i$ is the function related to the cost allocation ratio $w_i$ of each pipeline unit. Then the group utility function $U$ is:

$$U = u(u_1, u_2, L, u_n)$$

The weighted aggregate function as the utility of an individual decision maker is as follows:

$$U = \lambda_1 u_1(w_1) + \lambda_2 u_2(w_2) + L + \lambda_n u_n(w_n) = \sum_{i=1}^{n} (\lambda_i u_i(w_i))$$

Where, $\lambda_i$ is the weight of each decision maker, and $\lambda_i$ satisfies $\sum \lambda_i = 1$.

The cost apportionment of each pipeline unit should not exceed alternative costs $M_i$ or departmental benefits $B_i$. The cost $X_i$ apportionment of each pipeline unit can be obtained as follows:

$$X_i = C_i + w_i(K - \sum_{i=1}^{n} C_i) \leq \min[B_i, M_i]$$

Where, $K$ is the total cost to be apportioned, and $C_i$ is the separable cost of the project.

Then, the $w_i$ constraint conditions are:

$$w_i \leq \frac{\min[B_i, M_i] - C_i}{K - \sum C_i}$$

The decision-making model of underground utility tunnels is obtained as follows:

$$\max U = \sum_{i=1}^{n} (\lambda_i u_i(w_i))$$

Its need to meet the conditions are

$$0 \leq w_i \leq \frac{\min[B_i, M_i] - C_i}{K - \sum C_i}$$

$$\sum_{i=1}^{n} \lambda_i = 1$$

The above formula shows that the weight coefficient $i$ of each pipeline unit is related to the group decision model $w_i$. Therefore, in order to solve the allocation ratio $w_i$ of each department in the group decision model, the weight coefficient $\lambda_i$ of each pipeline unit should be determined first.

2) Determine the weight coefficient $\lambda_i$

Assume that all pipeline units have an opinion on all weights and are responsible. The delegate process contains the following three formulas:

Formula 1 (delegate) : Each member of the group has a delegation group, which is composed of the other $n-1$ departments in the group. The department formulates a weight $P_{ij}$ for each department within the delegation group, $0 \leq P_{ij} \leq 1 (i = 1, 2, L, n)$ satisfies, $P_{ii} = 0 \sum_{i=1}^{n} P_{ij} = 1 (i = 1, 2, L, n)$.

Formula 2 (decision rule) : Each delegate has a linear additive group utility function, where the weight coefficient is determined by formula 1.

Formula 3 (substitute) : Replace the utility function of the department $i$ with the utility function of the department’s delegate group $i$. 


Where, $P_{ij}$ is the role that the pipeline unit $i$ believes the pipeline unit $j$ plays in the group utility function or the proportion that the pipeline unit $i$ should share in the remaining cost of $j$. According to formula 1, $P$ can be regarded as the one-step transition probability matrix of a Markov process with $n$ states, and $P$ is a finite Markov chain. In this way, we can solve $\lambda_j$:

$$\lambda_j = \sum_{j=1}^{n} \lambda_i P_{ij} \sum_{j=1}^{n} \lambda_j = 1; \quad \lambda_j > 0 \quad (11)$$

The unique weight $\lambda_j$ can be obtained from the above equation.

3) Determine the investment allocation ratio

Assume that $U_i(w_i) = 1 - w_i^2$

Then the group utility function is:

$$U = u(u_1, u_2, L, u_n) = \lambda_1 u_1(w_1) + \lambda_2 u_2(w_2) + L + \lambda_n u_n(w_n) \quad (12)$$

$$U = \lambda_1 (1 - w_1^2) + \lambda_2 (1 - w_2^2) + L + \lambda_n (1 - w_n^2), \text{satisfy} \sum_{i=1}^{n} w_i = 1 \quad (13)$$

By constructing the Lagrangian function:

$$L(w_i, r) = [\lambda_1 (1 - w_1^2) + \lambda_2 (1 - w_2^2) + L + \lambda_n (1 - w_n^2)] + r(w_i - 1) \quad (14)$$

According to the optimal conditions:

$$\frac{\partial U}{\partial w_i} = 0; \frac{\partial U}{\partial r} = 0, i = 1, 2, L, n \quad (15)$$

The final cost allocation ratio is obtained:

$$w_i = \frac{1}{\lambda_i} \times \frac{1}{\frac{1}{\lambda_1} + \frac{1}{\lambda_2} + L + \frac{1}{\lambda_n}} (i = 1, 2, L, n) \quad (16)$$

(2) Operation and maintenance cost allocation method

The ratio of the effective area occupied by the pipeline in the pipeline corridor to the cross-sectional area of the utility tunnels is used as the apportionment factor for the cost apportionment. Assuming that a total of $m$ pipeline units enters the utility tunnels, the allocation factor $w_{i1}$ of space proportion of the corridor fee of the $i$th pipeline unit is

$$w_{i1} = \frac{(1 - \delta^e) S_i}{S} \quad (17)$$

$$S_i = S_{i0} + S_{i1} = S_{i0} + \frac{1}{m} (S - \sum_{i=1}^{m} S_{i0}) \quad (18)$$

Where: $\delta^e$ is the proportion of the government's contribution to the gallery fee; $S_i$ is the effective occupied area of the class $i$ pipeline in the pipe gallery; $S$ is the cross-sectional area of tunnels passage; $S_{i0}$ is the cross-sectional area of the class $i$ pipeline; $S_{i1}$ is the operating space required for class $i$ pipelines. It is generally considered that pipeline units share an utility tunnels space other than the cross-sectional area of all pipelines.

4. Case analysis

4.1. Basic parameters of the case

This paper takes Qingdao high-tech Industrial Development Zone utility tunnels project as an case. There are six types of pipelines in Qingdao High-tech Zone utility tunnels project: electric power, communication, water supply, medium water, heat and industrial pipelines.
The investment of the underground utility tunnels project in Qingdao High-tech Zone is estimated, and the estimated scope is 7 kilometers of branch utility tunnels and 3.5 kilometers of trunk utility tunnels.

**Table 1. Summary Table of Investment Estimation of Utility Tunnels in Qingdao High-tech Zone (partial sections).**

| Name of unit works and expenses | Computational base | The standard | Total (10,000 ¥) | Name of unit works and expenses | Computational base | The standard | Total (10,000 ¥) |
|---------------------------------|--------------------|--------------|-----------------|---------------------------------|--------------------|--------------|-----------------|
| The total investment            |                    |              | 29200           |                                 |                    |              |                 |
| Construction and installation costs |                |              | 26950           | Project report preparation cost | Take a cost      |              | 2               |
| Branch integrated Pipe Gallery (M) |                |              | 15330           | Construction estimate preparation cost | The total investment | 0.10% | 0.4 |
| Ontology structure             | 7000              | 1.3          | 9100            | Evaluation cost of project estimate | The total investment | 0.12% | 0.5 |
| Foundation treatment           | 7000              | 0.16         | 1120            | Design,                          | Take a cost      |              | 16              |
| The groove supporting          | 7000              | 0.28         | 1960            | Project construction management cost |                    |              | 823             |
| Equipment installation         | 7000              | 0.45         | 3150            | Management cost of construction Unit | The total investment | 1.50% | 6 |
| Main utility tunnels(M)        |                   |              | 11620           | Project tendering agency cost     | The total investment | 0.70% | 2 |
| Ontology structure             | 3500              | 2.2          | 7700            | Design drawing review cost       | Design,           | 6%           | 0.8             |
| Foundation treatment           | 3500              | 0.24         | 840             | The supervision cost             | Take a cost      |              | 711             |
| The groove supporting          | 3500              | 0.28         | 980             | Bill of quantities compilation cost | Take a cost      |              | 100             |
| Equipment installation         | 3500              | 0.6          | 2100            | Completion final account establishment cost | The total investment | 0.5 |
| Purchase cost of equipment and apparatus | | | 18 | Completion final account audit cost | The total investment | 0.5 |
| Other expenses for project construction | | | 842 | Costs for venue and temporary facilities | The total investment | 0.60% | 2 |
| Technical consulting cost      | 19                |              |                 | Unforeseeable charge            |                    |              | 1390            |
The total investment of the underground utility tunnels project in Qingdao High-tech Zone is 292 million yuan, including 269.5 million yuan for construction and installation, 180,000 yuan for equipment and tools, 8.42 million yuan for other project construction, and 13.9 million yuan for unforeseen expenses. The technical and economic index of project construction cost is 27,800 yuan/meter.

**Table 2.** Operation and maintenance cost estimation of Utility Tunnels in Qingdao High-tech Zone (partial sections).

| project                        | Operating period |
|-------------------------------|-----------------|
|                               | 2019  | 2020  | 2021  | 2022  | 2023  | 2024  | 2041  | 2042  | 2043  |
| Operating costs               | 164   | 170   | 177   | 184   | 192   | 200   | ...   | 404   | 422   | 440   |
| Maintenance cost for pipe gallery facilities | 32    | 32    | 33    | 33    | 34    | 35    | ...   | 49    | 50    | 51    |
| Wages and benefits            | 58    | 60    | 64    | 67    | 70    | 74    | ...   | 168   | 177   | 186   |
| The management cost           | 52    | 54    | 57    | 60    | 63    | 66    | ...   | 152   | 159   | 167   |
| The electricity and water     | 23    | 23    | 24    | 24    | 25    | 25    | ...   | 35    | 36    | 37    |

The maintenance cost of pipe gallery facilities is mainly the maintenance cost of public parts. Refer to 5% of the depreciation amount in the current year. Construction engineering and installation engineering shall be depreciated in 50 years, while equipment purchase shall be depreciated in 5 years, and the maintenance cost of public facilities shall be determined in total. In a normal year, the total cost of public facilities maintenance is 320,000 yuan, and thereafter the annual growth rate is considered at 2%. According to the salary and welfare funds were estimated by 8 members. According to the average wage level of Qingdao society, the conservative estimate was 6,000 yuan/month/person (including welfare funds), and the annual growth rate was considered as 2% in the future. The management cost is calculated based on 90% of the total wages with reference to historical data of similar industries. The electricity cost is mainly for the lighting, monitoring, ventilation and central control room of the pipe gallery. It is calculated based on the number of square meters of pipe gallery and unit electricity cost, which will increase by 2% every year thereafter. It is concluded that the operation and maintenance cost of underground utility tunnels is 1.64 million yuan in 2019, and the economic and technical index of operation and maintenance cost is 156 yuan/meter, which increases by 2% every year thereafter, as shown in Table 2.

**4.2. Analysis of results**

(1) Construction cost allocation result based on group decision method

According to the model listed and the data of Qingdao High-tech Zone, the cost allocation ratio under the group decision method is calculated. Among them, the cost allocation ratio of water supply, medium water, heating, industrial, electric power and communication pipelines is 13.14%, 10.73%, 16.50%, 11.19%, 26.85% and 21.60% respectively. The corridor entrance fee payable by each pipeline unit is 0.24, 0.20, 0.31, 0.21, 0.50 and 0.400 yuan per meter respectively, as shown in Table 3.
Table 3. Allocation of construction cost of underground utility tunnels project in Qingdao High-tech Zone.

| Type of professional pipeline | $\lambda_i$ | $w_i$ | Separable expenses (10,000 ¥) | Non-separable expenses (10,000 ¥) | Total cost (10,000¥) | Cost sharing ratio (%) | Base (10,000 ¥/m) | Gallery Entry Fee (10,000 ¥/m) |
|------------------------------|-------------|-------|-------------------------------|----------------------------------|---------------------|-----------------------|----------------|-------------------------------|
| Water supply pipeline        | 0.13        | 0.20  | 2031                          | 539                              | 2570                | 13.14                 | 1.86           | 0.24                          |
| Water in the pipeline        | 0.13        | 0.19  | 1978                          | 121                              | 2099                | 10.73                 | 1.86           | 0.20                          |
| Heating pipe                 | 0.12        | 0.21  | 2184                          | 1043                             | 3227                | 16.50                 | 1.86           | 0.31                          |
| Industrial pipeline          | 0.15        | 0.18  | 1803                          | 387                              | 2190                | 11.19                 | 1.86           | 0.21                          |
| The power line               | 0.25        | 0.10  | 1032                          | 42201                            | 5252                | 26.85                 | 1.86           | 0.50                          |
| Communication line           | 0.22        | 0.12  | 1182                          | 13043                            | 4225                | 21.60                 | 1.86           | 0.40                          |
| A combined                   | 1.00        | 1.00  | 10211                         | 9353                             | 19564               | 100                   | -              | 1.86                          |

(2) Results of operation and maintenance cost allocation based on spatial proportion method

The cost of maintenance and repair of the utility tunnels has a great relationship with the space proportion occupied by the pipeline, so the space proportion method is adopted to carry out apportionment. The inspection cost, office cost and electricity cost of the pipe gallery are shared by the pipeline units, so the method of average allocation is adopted. The operation and maintenance costs of each pipeline unit in the first year are 26.39, 24.26, 30.05, 27.61, 29.20 and 26700 yuan respectively, as shown in Table 4. The method of apportionment of operating management fee in other years is the same as that in the first year.

Table 4. Allocation of operation and maintenance cost of underground utility tunnels in Qingdao High-tech Zone.

| Type of professional pipeline | The proportion (%) | Maintenance cost of pipe gallery facilities (10,000 ¥) | Operation and maintenance Fee (1)(10,000 ¥) | Inspection fee, office fee for daily maintenance, electricity fee (10,000 ¥) | Operation and maintenance Fee (2) (10,000 ¥) | Total (10,000 ¥) |
|-------------------------------|--------------------|------------------------------------------------------|--------------------------------------------|--------------------------------------------------------------------------------|-------------------------------------------|----------------|
| Water supply pipeline         | 13.62              | 32                                                   | 4.36                                       | 132                                                                           | 22.04                                     | 26.39         |
| Water in the pipe             | 6.95               | 32                                                   | 2.22                                       | 132                                                                           | 22.04                                     | 24.26         |
| Heating pipe                  | 25.05              | 32                                                   | 8.02                                       | 132                                                                           | 22.04                                     | 30.05         |
| Industrial pipe               | 17.43              | 32                                                   | 5.58                                       | 132                                                                           | 22.04                                     | 27.61         |
| Power cable                   | 22.38              | 32                                                   | 7.16                                       | 132                                                                           | 22.04                                     | 29.20         |
| Communication line            | 14.57              | 32                                                   | 4.66                                       | 132                                                                           | 22.04                                     | 26.70         |
| A combined                    | 100                | -                                                    | 32                                         | -                                                                             | 132                                       | 164           |

5. Conclusion

In this paper, the group decision model is used to consider the allocation of the construction cost of the utility tunnels, and the spatial proportion method is used to consider the allocation of the operation and maintenance cost of the utility tunnels. The model can effectively improve the enthusiasm of electrical cables into utility tunnels by comprehensively considering the different interest demands of related...
subjects. Through the analysis results of Qingdao utility tunnels, it shows that this method has strong practicability and can effectively solve the problem of cost allocation of electrical cables into utility tunnels.

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