Research on Critical Success Factors of Utility Tunnel Project Based on Grounded Theory and DEMATEL

Qi Yu*, Yisheng Liu

1School of Economics and Management, Beijing Jiaotong University, Beijing, 100044, China

*Corresponding author’s e-mail: 19120648@bjtu.edu.cn

Abstract. The success of the utility tunnel project depends on many influencing factors. Establishing a complete conceptual model and identifying the critical success factors can provide effective scientific support for the development of the utility tunnel project. Based on a large number of case data, grounded theory is used to carry out multi-level decoding, to identify the success factors of the utility tunnel project, and a model of "consciousness orientation-objective conditions-internal driving factors" is constructed. The DEMATEL analysis model is used to calculate the Influence Degree, Influenced Degree, Center Degree, Cause Degree of each factor. Combining the quadrant diagram method, we finally get four critical success factors of professional technology maturity and development, government support, financial guarantee and pipeline entrance mechanism. At the same time, corresponding countermeasures and suggestions are put forward to promote the development of utility tunnel.

1. Introduction

Utility tunnel refers to the urban underground public tunnel used to lay municipal pipelines for electricity, communication, radio and television, water supply, drainage, heating, gas, etc. [1]. It is a modern, scientific and dense city infrastructure [2]. China is accelerating the pace of construction of utility tunnel. The ‘Key Tasks for New Urbanization Construction in 2019’ issued by the National Development and Reform Commission specifically mentions the need to guide various regions to build utility tunnels in accordance with local conditions.

Rochart et al. first proposed Critical Success Factors (CSFs) in 1982, and defined CSFs as those factors that must be done well to ensure the success of the project, and those factors that must be controlled at all times to ensure that the goals are achieved [3]. Since then, the concept of CSFs has been widely used in various industries. China’s utility tunnel construction technology is single, investment cost is high, management experience is insufficient and overall planning layout is lacking, which limits the development of the utility tunnel [4]. Therefore, it is particularly necessary to summarize the key success factors of the utility tunnel project.

Meng Sun analyzed the influencing factors and mechanism of the development of utility tunnel in China, and determined a series of influencing factors such as management system, financing methods, underground space legislation, management mode, construction and operation and maintenance costs [5]. Based on the stakeholder theory, Li Ma obtained 14 influencing factors for the pricing of PPP projects in utility tunnel [6]. Xiaoyan Jiang and others used the SEM model to analyze the influencing factors of pipeline units’ willingness to enter the utility tunnel [7]. However, the current research focuses on the specific aspects of the utility tunnel, and has not established a complete theoretical model for the success of the entire project. Research methods also have certain limitations. For providing guidance
and reference for the development model of utility tunnel construction in China, the grounded theory and the DEMATEL model are introduced to identify the key success factors of the utility tunnel project.

2. Analysis of success factors based on grounded theory

2.1. Data collection
The basic information used in grounded theory comes from multiple sources, including literature, books, newspapers, interviews, and so on. The scope covers utility tunnel projects in countries all over the world. And the projects have the characteristics of long operation time, good project quality, and good maintenance effects, which ensure the quality of the project and further ensure the reliability of the key success factors. A total of 20 cases are selected here (Table 1).

| Country      | Project                                                      |
|--------------|--------------------------------------------------------------|
| Germany      | Hamburg Water Supply Utility Tunnel, Bupperudal Utility Tunnel |
| Russia       | Moscow Utility Tunnel                                        |
| France       | Besançon Utility Tunnel, Paris Utility Tunnel                |
| Finland      | Helsinki Utility Tunnel                                     |
| Netherlands  | Amsterdam Zeidas Utility Tunnel                              |
| United States| White Plains Utility Tunnel                                  |
| Japan        | Kudansaka Utility Tunnel, Yodocho Utility Tunnel, Hibiya Utility Tunnel |
| Spain        | Madrid Utility Tunnel, Barcelona Olympic Venues Utility Tunnel |
| Singapore    | Singapore Marina Bay Utility Tunnel                          |
| United Kingdom| Beijing Tiananmen Square Utility Tunnel, Beijing Zhongguancun Utility Tunnel, Guangzhou University Town Utility Tunnel, Suzhou Moon Bay Utility Tunnel, Zhuhai Hengqin New District Utility Tunnel Project |

2.2. Open coding
Open coding refers to the process of conceptualizing and categorizing collected data. Through the fragmentation of a large amount of data, the valuable sentences in the data are extracted, the sentences describing the same phenomenon are merged and classified. Finally, 18 categories were obtained, that is, the success factors of utility tunnel. The open decoding process is shown in Table 2.

| Step         | Content                                                                 |
|--------------|-------------------------------------------------------------------------|
| A1           | maturity of professional technology, A2 government plan, A3 city planning, A4 cost control, A5 project construction requirements, A6 income stability, A7 improvement of laws and regulations, A8 financial assistance from financial organizations, A9 sufficient construction period, A10 complete facilities, A11 suitable geographical environment, A12 sustainable development, A13 good design concept, A14 rich experience in construction, A15 design diversity, A16 government supervision, A17 property management, A18 risk control, A19 scientific research, A20 policy guidance, A21 safety management system, A22 sufficient construction funds, A23 government-enterprise communication, A24 special department management, A25 pipeline entry order, A26 good economic foundation, A27 technology development, A28 supervision and inspection measures, A29 pipeline entry way, A30 project plan feasibility, A31 reasonable use of construction materials, A32 fire fighting measures, A33 location selection, A34 clear normative measures, A35 co-construction with other projects, A36 new financing model, A37 increase in the level of urbanization, A38 safety facilities, A39 eliminate differences between parties, A40 construction form changes, A41 improve the cost sharing |
mechanism, A42 promotion of new technology, A43 engineering quality, A44 design of pipeline entering the gallery, A45 pipeline quality, A46 tackling ability, A47 selection of construction mode, A48 organized development, A49 significant economic benefits, A50 gallery enthusiasm, A51 project plan design, A52 waterproof design, A53 maintenance plan, A54 seismic design, A55 infrastructure construction integration, A56 developer quality

**Category**

- A1 professional technology maturity and development (A1, A14, A40), A2 government support (A2, A5, A20), A3 risk management (A18, A39), A4 cost control (A4, A35, A41), A5 laws and regulations environment (A7, A34), A6 complete infrastructure (A10, A37), A7 project decision (A11, A19, A30, A33, A47), A8 operation and maintenance management (A17, A24, A53), A9 safety management (A21, A32, A38), A10 design feasibility (A13, A15, A44, A51, A52, A54), A11 project quality level (A9, A31, A43, A45), A12 economic benefits (A6, A12, A49), A13 financial guarantee (A8, A22, A26, A36), A14 pipeline entrance mechanism (A23, A25, A29, A50), A15 overall planning (A3, A48, A55), A16 supervision mechanism (A16, A28), A17 personnel quality (A46, A56), A18 technology application (A27, A42)

2.3. **Spindle decoding**

Spindle decoding refers to the process of connecting various categories derived from open decoding through the use of Canonical model: causal conditions → phenomenon → context → intermediary conditions → action/interaction strategies → results [8]. Table 3 shows the process of generating the main category ‘government function’ through the Canonical model. The final result of the spindle decoding is shown in Table 4.

| Causal Conditions | Phenomenon | Context | Intermediary Conditions | Interaction Strategies | Results |
|-------------------|------------|---------|-------------------------|------------------------|---------|
| A5 project construction requirements | B2 government support | A20 policy guidance | A2 government plan | B15 overall planning | The government supports the construction of the utility tunnel and strictly supervises the project |

| Main Category | Subcategory |
|---------------|-------------|
| C1 government function | B2 government support, B15 overall planning, B16 supervision mechanism |
| C2 technology development and application | B1 professional technology maturity and development, B18 technology application |
| C3 environmental drive | B5 laws and regulations environment, B6 complete infrastructure, B13 financial guarantee |
| C4 project construction | B7 project decision, B10 design feasibility, B11 project quality level, B17 personnel quality |
| C5 action strategy | B3 risk management, B8 operation and maintenance management, B9 safety management, B14 pipeline entrance mechanism |
| C6 benefit-oriented | B4 cost control, B12 economic benefits |

2.4. **Selective decoding**

In this part, the core category of ‘utility tunnel project success factors’ is determined, and the “story line” around the core categories is expanded. Benefit-oriented and government function are consciousness-oriented and promote project development and construction. Technology development and application and environmental drive are objective conditions that determine the possibility of project implementation. Project construction and action strategy are internal driving factors that directly
3. Critical success factors identification

3.1. DEMATEL model

The DEMATEL method is based on the use of matrix computing tools and chart theory, assessing the relationship between the influencing factors in the system and interaction, and thus identifying key factors affecting the system [9]. The calculation steps are as follows:

The sequence number of the success factors is set to \( b_1, b_2, \ldots, b_n (n=18) \) according to Table 2. Eight experts were invited to score the factors. The scoring rules are as follows: no effect is 0, weak influence is 1, moderate influence is 2, strong influence is 3 [10]. The method of adopting average data is processed to get a direct impact matrix \( Z = (b_{ij})_{n \times n} \).

Next, we start to calculate the comprehensive influence matrix. Comprehensive influence matrix is set to \( T, T = Z + Z^2 + Z^3 + \ldots + Z^n = (E - Z)^{-1} \) \( (E)_{n \times n} \), \( t_{ij} \) represents the integrated influence of factor \( b_i \) to factor \( b_j \), \( E \) is a unit matrix.

\[
Z = \max_{1 \leq i \leq n} \frac{Z}{\sum_{j=1}^{n} b_{ij}}
\]

DEMATEL method analyzes factors from four indicators: Influence Degree \( (x_i) \), Influenced Degree \( (y_i) \), Center Degree \( (m_i) \), Cause Degree \( (r_i) \). The calculation method is as formula 2.

\[
\begin{align*}
    x_i &= \sum_{j=1}^{n} t_{ij} (1 \leq i \leq n) \\
    y_j &= \sum_{i=1}^{n} t_{ij} (1 \leq j \leq n) \\
    m_i &= x_i + y_i (1 \leq i = j \leq n) \\
    r_i &= x_i - y_i (1 \leq i = j \leq n)
\end{align*}
\]

Finally, we take Center Degree as the abscissa, Cause Degree as the ordinate, and \( o (a, 0) (a \text{ takes the mean value of the Center Degree}) \) as the intersection of the abscissa and ordinate axes to establish a Cartesian coordinate system. The factors in the first quadrant are the critical success factors.
3.2 Data analysis

Calculated according to the DEMATEL model, the normalized direct influence matrix Z is shown in Table 5, and the calculation results of the four indicators of the comprehensive influence matrix are shown in Table 6. From the quadrant causality analysis diagram (Figure 2), the critical success factors are professional technology development and maturity (b1), government support (b2), financial guarantee (b13), and pipeline entrance mechanism (b14).

Table 5. Direct influence matrix Z

|    | b1  | b2  | b3  | b4  | b5  | b6  | b7  | b8  | b9  | b10 | b11 | b12 | b13 | b14 | b15 | b16 | b17 | b18 |
|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| b1 | 0   | 1.75| 1.50| 2.25| 0.625| 2.625| 2.25| 1.875| 2.000| 2.500| 2.750| 1.875| 0.500| 1.625| 1.375| 0.250| 0.250| 3.000|
| b2 | 2.875| 0   | 1.375| 1.125| 2.750| 2.625| 2.500| 1.250| 1.875| 1.000| 1.750| 1.250| 2.250| 1.000| 2.750| 2.750| 1.250| 2.000|
| b3 | 0.625| 0.500| 0   | 2.125| 0.375| 0.750| 1.500| 1.375| 2.500| 1.750| 2.500| 1.750| 1.375| 0.625| 0.500| 0.875| 1.000| 0.625|
| b4 | 0.500| 0.625| 1.750| 0   | 0.250| 0.500| 2.375| 2.250| 1.750| 1.375| 2.500| 2.625| 1.625| 0.500| 0.625| 0.125| 0.625| 1.750|
| b5 | 1.000| 1.500| 1.875| 1.000| 0   | 0.750| 1.125| 1.250| 1.125| 1.125| 1.125| 1.875| 1.125| 1.125| 1.500| 0.750| 1.000| 1.875| 1.125|
| b6 | 0.875| 1.375| 1.000| 1.500| 0.875| 0   | 1.750| 1.250| 1.125| 1.125| 1.125| 1.625| 1.125| 1.000| 0.625| 1.625| 0.750| 0.375| 0.750|
| b7 | 0.625| 0.750| 2.000| 1.750| 0.375| 0.625| 0   | 1.875| 2.000| 2.250| 1.875| 2.250| 1.500| 1.250| 1.625| 0.625| 1.125|   |
| b8 | 0.500| 0.250| 1.750| 1.625| 0.625| 0.750| 0.750| 0   | 1.750| 0.875| 0.875| 2.500| 0.625| 1.125| 0.375| 0.625| 1.250| 1.000|
| b9 | 0.500| 0.375| 2.750| 1.750| 0.750| 0.625| 1.250| 1.250| 0   | 1.375| 2.750| 2.000| 1.125| 1.250| 0.375| 1.000| 1.875| 1.000|
| b10| 0.500| 0.750| 1.375| 2.125| 0.375| 0.375| 2.125| 1.750| 1.750| 0   | 2.500| 2.250| 1.125| 0.500| 1.250| 0.250| 0.375| 1.000|
| b11| 0.625| 0.750| 1.750| 2.125| 0.500| 1.125| 1.000| 1.500| 1.625| 0.750| 0   | 2.000| 1.000| 0.875| 0.500| 0.500| 0.375| 0.625|
| b12| 1.375| 2.250| 1.125| 1.625| 0.500| 0.750| 2.000| 1.375| 0.875| 1.375| 1.000| 0   | 1.750| 0.625| 0.750| 0.375| 0.500| 1.375|
| b13| 1.625| 1.375| 2.000| 2.125| 0.250| 1.375| 2.500| 1.875| 1.625| 1.500| 2.375| 1.625| 0   | 1.000| 1.375| 0.500| 1.250| 2.250|
| b14| 1.250| 1.500| 2.375| 1.500| 0.875| 0.625| 2.250| 2.750| 2.625| 1.625| 2.125| 1.625| 1.750| 0   | 2.375| 2.000| 1.250| 1.125|
| b15| 0.875| 1.500| 2.250| 1.875| 1.125| 1.125| 2.250| 1.500| 1.750| 1.250| 1.625| 1.875| 1.375| 1.250| 0   | 1.125| 0.500| 0.500|
| b16| 0.500| 0.125| 2.375| 1.500| 0.750| 0.625| 1.000| 2.000| 2.375| 1.500| 2.500| 1.625| 1.000| 1.500| 1.125| 0   | 1.875| 0.375|
| b17| 1.625| 0.875| 2.125| 2.000| 0.625| 0.750| 2.000| 2.000| 2.500| 2.125| 2.625| 2.000| 1.000| 1.875| 1.625| 1.375| 0   | 1.125|
| b18| 2.375| 1.375| 1.625| 1.625| 0.500| 0.625| 1.500| 1.875| 1.750| 1.500| 1.625| 1.625| 0.625| 1.875| 0.750| 0.750| 0.750| 0   |

4. Results discussion and suggestions

Through grounded theory and DEMATEL, we have completed the identification of the critical success factors of the utility tunnel project. These factors not only require the attention of all parties involved in the project during the decision-making, construction, and operation of the project, but also special development in future projects. To this end, the following suggestions are made based on factors.

4.1. Professional technology maturity and development (b1)

There are many technical difficulties in the utility tunnel project, such as the cross-processing of the utility tunnel and other underground facilities, the mutual interference of power and communication cable signals, and the setting of monitoring centers and feedback sites. Therefore, from the government's
point of view, it is necessary to gradually improve the professional standards of professional and technical personnel, encourage the sharing of technical experience of established projects, and popularize the concept of technological innovation in the education system. From the perspective of social participants, it is necessary to strengthen the introduction of professional and technical personnel, and pay attention to the update and development of technology.

4.2. Government support ($b_2$)
The government must establish a standardized and complete institutional framework as much as possible to ensure that the decision-making process is scientific and standardized. Second, the government should focus on ensuring funding sources. Regardless of whether it is in the form of financial leading investment or financing from the society, the construction of capital-related systems needs to be improved. Finally, the government should coordinate the relationship between the various participants and mobilize the public sector to actively cooperate.

In addition, the government should strengthen the supervision and management of construction safety and project quality, and pay attention to the maintenance of public facilities, civil buildings or other commercial buildings around the project. In the project operation stage, the government also has to perform the duties of supervision, such as on-site surveys, regular random inspections, report audits, and so on.

4.3. Financial guarantee ($b_{13}$)
Domestic and international utility tunnel projects mainly adopt full government funding and PPP financing models. As far as the domestic situation is concerned, attracting social capital to invest is a top priority. The initial investment demand of the utility tunnel project is large, and the short-term benefits are not obvious. Therefore, the selection of financing enterprises must be able to bear the long-term capital investment and not be dragged down by the funds. In project construction, attention should be paid to the reasonable allocation of funds, that is, cost control. After the project is completed, it is necessary to promptly attract pipeline operating companies to enter the utility tunnel to achieve capital return.

4.4. Pipeline entrance mechanism ($b_{14}$)
At present, the relationship between pipeline stakeholders is complicated, and the government's mandatory entry into the utility tunnel will cause the pipeline units to have a certain degree of resistance, thereby affecting the enthusiasm of entering the utility tunnel. An effective pipeline entrance mechanism can reduce the transaction cost of negotiations between stakeholders, avoid excessive disputes, and greatly promote the development of China's utility tunnel projects.

The pipeline entrance mechanism includes two aspects. One is the pricing mechanism. The government should formulate a reasonable pricing mechanism in accordance with the fiscal expenditure plan, comprehensively consider profitability, safety and applicability, and on the basis of fairness and justice, it must not only meet the interests of the government and pipeline units, but also share risks reasonably. The second is the incentive mechanism. There is a single method to reduce the corridor fee, and it will increase the government's financial burden. A variety of methods must be combined to increase the willingness of pipeline units to enter the utility tunnel. The government should establish a fair and trusting cooperative relationship with pipeline units, effectively implement various subsidy systems, and increase the trust level of pipeline units. The government should also strengthen the publicity of utility tunnel projects, increase public awareness, and strengthen the pipeline units' sense of social responsibility.

5. Conclusions
Through grounded theory, the success factors of 18 utility tunnel projects in 6 major categories were identified, and the conceptual model of ‘consciousness orientation-objective conditions-internal driving factors’ is constructed. Combining DEMATEL model, we finally get four critical success factors of
professional technology maturity and development, government support, financial guarantee and pipeline entrance mechanism. In the project decision-making, construction, and operation stages, the government should provide different types of support. Financial guarantee should focus on financing mode, cost control and capital return. The pipeline entrance mechanism should be improved from the two aspects of pricing mechanism and incentive mechanism. The maturity and development of professional technology require joint promotion by the government and social participants.

The limitation is that the direct influence matrix is easily affected by the subjective judgment of experts. In future research, more scientific data analysis methods need to be used to weaken this influence.

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