Investigation of the Factors Influencing the Rehabilitation of Underground Pipes in Old Neighborhoods Using DEMATEL-ISM

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Abstract. Renovating underground pipelines in old residential areas can better meet the living needs of residents and improve the quality of urban development. To ensure the smooth implementation of the underground pipe rehabilitation project in old districts, This paper presents a model of the factors influencing the renovation of underground pipelines using DEMATEL-ISM, analyses the key influencing factors in the rehabilitation process and its hierarchical structure, and clarifies the role of the factors in the path. The results show that policy and regulation support, government financing difficulties, transformation scale, and pipeline data integrity are the deep-rooted influencing factors of underground pipeline transformation in old districts, and corresponding countermeasures are proposed to promote the overall process of underground pipeline transformation in old districts in China.

Keywords: old neighborhoods; underground pipelines; DEMATEL-ISM

1 Introduction

Underground pipelines in old districts have a long construction time, irrational layout, lack of routine maintenance, and generally are dilapidated and seriously aged, which can no longer meet the needs of residents' daily lives. At present, several cities have launched renovation projects in old neighborhoods, but the preparation and implementation of the renovation project face many difficulties, and the overall renovation process is slow.

Statistics show that there are nearly 160,000 old neighborhoods in China, with more than 42 million households, involving hundreds of millions of residents. The comprehensive transformation process of old neighborhoods is a weak link in urban construction and management, with irrational planning of old pipelines, difficulties in coordinating the work of multiple departments, and pressure on supporting funds[1]. There are problems such as inaccurate pipeline mapping, inadequate pipeline protection measures, and difficult coordination of construction progress in the implementation of pipeline transformation[2]. Some scholars have proposed appropriate countermeasures to the existing problems combined with practical case analysis, such as adhering to the

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mass line[3], learning from the excellent experience of foreign countries, establishing diversified funds, and introducing market-oriented mechanisms[4]. However, the current research is relatively small, mainly focuses on the analysis of actual cases, and lacks the analysis of overall macro influencing factors[5].

Therefore, this paper identifies and summarizes the factors influencing the underground pipeline renovation in ancient counties through a literature review and expert interview, introduces the decision experimental evaluation laboratory (DEMATEL) and the interpretative structural model (ISM), constructs the model of the influence factors, identifies the main influence factors, and studies the relationship between the influence factors, to provide a certain theory and corresponding optimization path for the practical work of underground pipeline renovation.

2 Identification of Influencing Factors

Through combing the literature and cases related to underground pipeline transformation in old neighborhoods, based on the tripartite subjects of government, enterprises, and owners, and dividing them into four stages of planning, design, construction, and operation and maintenance according to the theory of the whole life cycle of engineering projects, a total of 13 influencing factors have been identified, and modified by the review recommendations of experts who have been involved in the pipeline modification process. Ultimately, a system of influencing factors in the transformation of old neighborhoods has been constructed, and explanatory notes have been given to each of the factors, as shown in **Table 1**.

Table 1. Indicators of Pipeline Rehabilitation Impact Factors

Stages	Influencing factors	Symbols	Explanatory Notes
Planning	Policies and regulations support	X1	The degree of perfection of policies, regulations, technical norms, and industry standards
	Pipeline data integrity	X2	Extent of missing design drawings and construction information for old neighborhoods
	Sectoral coordination	X3	Coordination between municipal units and pipeline-owning departments
	Difficulty of government financing	X4	Difficulties in financing due to large project investments, long lead times, and low returns
	Community sensitization	X5	Efforts to publicize the community transformation policy
	Residents' cooperation	X6	Strength of residents' willingness and cooperation in underground pipeline reconstruction
Design	Scale of transformation	X7	Scale and extent of pipeline rehabilitation
	Comprehensive Design Difficulty	X8	Design difficulties for remodeling due to cost, schedule, and piping complexity

Construction	Construction technical requirements	X9	Retrofitting requirements for construction techniques, such as protection of high-risk pipelines for gas, electricity, etc.
	Construction impact area	X10	The impact of underground pipeline reconstruction on residents' daily travel
	Engineering Quality Management	X11	Manage team selection, material entry, site control, and completion inspection
	Funds disbursement	X12	Whether progress payments can be made promptly
Operation	Operations management	X13	Implementation of the operation and maintenance of the post-pipeline

3 DEMATEL-ISM Model

3.1 Theoretical Definitions

Decision-making Trial and Evaluation Laboratory (DEMATEL) is a systems analysis method that uses graph theory and matrix tools to determine the causal relationships and criticality between elements. The analysis process takes into account the logical relationships between the elements of the system and transforms the correlations quantitatively to analyze the degree of influence. Interpretative Structural Modelling (ISM) is a combination of qualitative and quantitative methods to obtain the influence relationships between the factors through multiple levels of extraction. It presents the results in the form of a hierarchical topology diagram that visualizes the causal hierarchy and ladder structure among the factors. Thus, the combination of these two methods makes it possible to identify the causal relationships and hierarchical structure between factors in complex systems with relatively little computational effort, thereby visually and effectively illustrating the internal correlations between the different influencing factors.

3.2 DEMATEL Model Construction

(1) To determine the mutual influence relationship between the factors, we invited 10 experts from multiple subjects of the underground pipeline renovation project in old neighborhoods to assess the strength of the relationship between the influencing factors. Using equation Eq.(1)to get the initial direct influence matrix A.

$$A = \left(a_{ij}\right)_{n\times n} \qquad a_{ij} = \frac{1}{m}\sum_{k=1}^{m} a_{ij}^{k} \tag{1}$$

Where a_{ij} = 4 is high impact, a_{ij} = 3 is relatively high impact, a_{ij} = 2 is medium impact, a_{ij} = 1 is low impact and a_{ij} = 0 is no impact.

(2) Normalise matrix A using Eq.(2) to obtain canonical effect matrix N. Cumulate direct and indirect effects using Eq.(3) to obtain combined effect matrix T.

$$N = A/\max\left(\sum_{j=1}^{n} a_{ij}\right) \tag{2}$$

$$T = \sum_{k=1}^{\infty} N^k = N(I - N)^{-1} \tag{3}$$

where $\max\left(\sum_{j=1}^{n} a_{ij}\right)$ is the maximum of the sum of the row elements of matrix A, I is the unit matrix.

(3) Using Eq.(4) calculate the influence Di and being affected Ci of each influencing factor, and using Eq.(5), calculate the mean Mi and cause Ri. where the cause is greater than 0 for the influencing factor and less than 0 for the resulting factor. Assessment of the causal attributes of each factor and ranking of them separately, as shown in **Table 2**.

$$D_i = \sum_{j=1}^{n} a_{ij} \qquad C_i = \sum_{j=1}^{n} a_{ji} \tag{4}$$

$$M_i = D_i + C_i \qquad R_i = D_i - C_i \tag{5}$$

Table 2. Calculated value of the DEMATEL model

Indicates	Di	Ci	Mi	Ri
X1	1.585	0	1.585	1.585
X2	1.067	0	1.067	1.067
X3	0.415	0.176	0.591	0.238
X4	1.563	0.642	2.205	0.921
X5	0.456	0.350	0.806	0.106
X6	0.438	0.971	1.409	-0.533
X7	1.536	0.90	2.433	0.639
X8	0.426	1.720	2.146	-1.294
X9	0.611	1.109	1.720	-0.498
X10	0.726	0.707	1.433	0.019
X11	0.203	1.216	1.149	-1.012
X12	0.212	0.445	0.657	-0.233
X13	0	1.005	1.006	-1.006

3.3 ISM Model Construction

(1) The total impact matrix M is obtained by summing the matrix T with the standard matrix using Eq.(6), introducing λ ($\lambda \in [0,1]$)to simplify the structure of the system. The reachable matrix K is obtained by rationalizing the matrix M using Eq.(7).

$$M = I + T \tag{6}$$

$$k_{ij} = \begin{cases} 1 & m_{ij} \geq \lambda \\ 0 & m_{ij} < \lambda \end{cases} \quad (i = 1,2, \dots n; j = 1,2, \dots n) \tag{7}$$

where k_{ij}=1 indicates a direct relationship and k_{ij}=0 indicates no direct relationship.

(2) The achievability matrix is shown, where the achievable set K, the prior set Q, and the common set L of each factor are identified and divided into levels according to the principle of priority of results to draw a hierarchical diagram of the influencing factors in **Fig. 2**.

4 Results

4.1 Key Factors Analysis

Centrality and causality together determine the importance of the factor in the overall system. Using centrality as the horizontal coordinate and causality as the vertical coordinate, the cause-effect diagram shown in Fig 1 is drawn. X8 and X9 have high centrality rankings, but they are result factors that are easily influenced by other factors, so they are not included in the key influencing factors. X2, the pipeline information integrity factor, has a medium centrality ranking but a high causality ranking. This indicates that it has a stronger driving force, so it is included in the key influencing factors. Therefore, the key influencing factors of underground pipeline renovation in old districts are Policies and regulations support (X1), Pipeline data integrity (X2), Difficulty of government financing (X4), and Scale of transformation (X7).

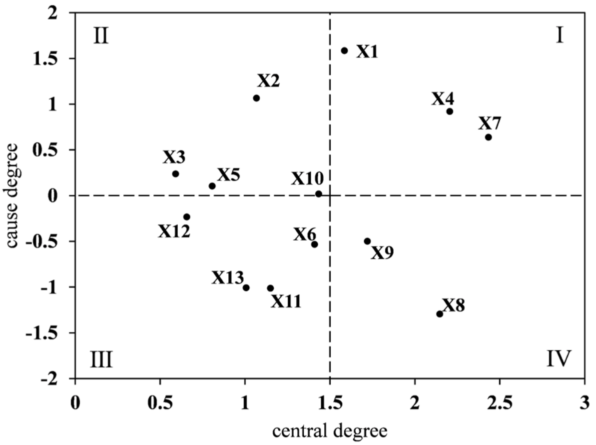

Fig. 1. Cause and Effect Diagram of Pipeline Change Influencers

Cause Degree is an essential index to distinguish the cause and result factors in the system. If the value of the Cause Degree is positive, it belongs to the Cause Factor, indicating that the factor has a strong influence on other factors. If the value of the Cause Degree is negative, it belongs to the Result Factor, indicating that the factor is strongly influenced by other factors. From **Fig 1.** Cause and Effect Diagram of Pipeline Change Influencers, we can see that Policies and regulations support (X1) and pipeline data integrity (X2) as a strong cause factor, while Comprehensive design difficulty (X8) and engineering quality management (X11) a strong results factors.

4.2 Factor Hierarchy Analysis

L1 is the surface-level influencing factor in Fig. 2. Resident cooperation and engineering quality management directly affect the smooth construction process of the project.

Operations management is the evaluation of the subsequent development after the completion of the pipeline reconstruction in the neighborhood.

The mid-level factors are L2 and L3, which are mainly the driving force for pipeline rehabilitation, but also the actual problems to be faced in rehabilitation. In addition to the direct effect on the underground pipeline rehabilitation process, they will also indirectly affect the underground pipeline rehabilitation by influencing the surface-level factors. Community awareness and construction impact areas will affect the cooperation of residents in L1. Fund disbursement, comprehensive design difficulty, and construction technical requirements will have a certain impact on the safety management of project quality in the construction process. In the design process, not only need to take into account the cost, duration, and other constraints but also consider the construction and the degree of impact on residents traveling, construction technology must take into account the gas, electricity, and other high-risk pipeline protection measures. Therefore, the difficulty of comprehensive design and construction technology requirements is the pipeline renovation process of the center of the higher degree of influence factors.

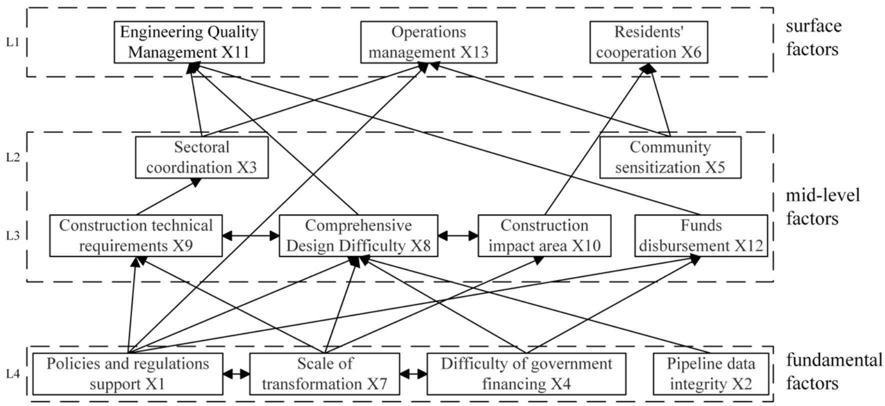

Fig. 2. Hierarchical diagram showing the factors influencing rehabilitating

The fundamental factors are also the main influence and cause factors of the underground pipeline transformation of the old district. Most of the old district renovation construction relies on government financial support, so the government is the most fundamental influencing factor but also the government is the most significant impetus to promote the old district renovation mode. In the planning stage, the old-quarter pipeline reconstruction scale and the completeness of pipeline data determine the work path and workload in the design and construction stage, which is the basic problem of pipeline reconstruction.

5 Conclusion

Under the guidance of national policies, the transformation of underground pipelines in old neighborhoods is being steadily promoted. There are several completed transformations of the old district have been put into normal use. However, no practical solution has been found to the difficulties and disputes in the transformation process. How to effectively ensure the smooth implementation of pipeline renovation projects still needs further research. This paper puts forward the following suggestions based on the results of the model analysis.

(1) Increase policy support by setting up green approval channels and special subsidies to promote pipeline renovation in old districts. Policies, regulations, and standards are the most fundamental factors affecting the transformation. The government should provide proper guidance, and improve the policy system. For example, the Government can set up special functional bodies and establish green approval channels, which can not only delineate the responsibilities of the various parties involved but also speed up the implementation of various tasks.[6]. Municipalities should promote the establishment of special subsidies, and monitor existing funds well. Active pursuit of national grants for renovation work in old neighborhoods, which can alleviate some of the financial pressure on pipeline rehabilitation.

(2) Innovate diversified financing models and encourage social capital ownership to promote market-oriented reforms. The financing of the project is an effective factor in the pipeline renovation work. An innovative financing model is partly funded by residents and social capital in addition to government funding. Existing projects have proved that it is feasible to adopt the PPP mode for the transformation of old districts and that the social capital, in cooperation with the government can recover its investment through property management at a later stage. The government can provide certain priority and loan modes for enterprises participating in the community transformation work, to ensure the integrity of the whole process of the capital chain[7].

(3) Establish an information management platform for underground pipelines in old districts to optimize the management and sharing of pipeline information. Pipeline data is the basis of pipeline reform design and construction, which plays a key role in determining the smoothness of the design and construction phase. Adopt GIS technology to build a pipeline information management platform. Integrate multi-disciplinary pipeline data and solve the problem of missing information on underground pipelines in old cities through unified detection. This facilitates the exchange of information between departments, which brings great convenience to subsequent pipeline operations and reduces the impact of incomplete pipeline information on pipeline renovation work in old neighborhoods.

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