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An Approach for Measuring Complexity Degree of International Engineering Projects

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Abstract: With the increasing trend of globalization, countries actively join the international engineering market, increasing the complexity of projects. An appropriate method for assessing project complexity can help project managers recognize the current situation and solve problems. However, existing complexity studies ignored the contribution of human element. The impact of human activities on the complexity of socio-economic systems is concerned in the Harmony Management Theory (HMT), therefore, this study proposed a complexity measurement based on the Harmony Management Theory. Firstly, an evaluation indicator system including three dimensions of organizational, technological, and environmental complexity is proposed through a literature review, Back-Propagation Neural Network-Decision Making Trial and Evaluation Laboratory (BP-DEMATEL) method, and Interval-valued intuitionistic Fuzzy Sets (IIFS) are used to calculate complexity scores. Then, a case study of Yawan high-speed railway project is conducted to verify the effectiveness of the proposed method. The main conclusions are as follows: (1) The complexity measurement based on harmony theory can be carried out from three aspects: Organization, technology, and environment. (2) The overall complexity performance of case project is 0.52, showing a medium level. (3) Technical complexity is the most important factor of the case project. The method proposed in this study can identify the influencing factors of complexity and calculate the comprehensive evaluation value of complexity. Based on the final quantified results, managers can formulate appropriate measures and match the project with appropriate resources so as to improve the performance of International Engineering Projects (IEPs).

Keywords: international engineering projects (IEPs); IEPs complexity (CIEPs); CIEPs measurement; project management; Harmony Management Theory (HMT)

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1. Introduction

The construction industry is one of the pillar industries in most countries [1]. The development of the construction industry involves the implementation of a large number of engineering projects [2]. Engineering projects are always considered to be complex and high-risk, mainly due to the vulnerability to the external environment and the uncertainty associated with the project [3]. There are many theories and methods for engineering project management, but many projects still have difficulties in achieving their goals and even cause project delays and cost increases [4]. A study by Construction Industry Institute (CII) showed that only 5.4% of 975 engineering projects were able to achieve their performance goals in terms of cost and schedule [5]. This means that over 90% of projects struggle to achieve project performance, facing issues of cost overruns and extended timelines. The Complexity of Engineering Projects (CEPs) is considered the most important factor for the difficulty in achieving the performance goals of engineering projects [6]. Complexity is one of the important features in the field of project management, which affects the planning and control of projects, hinders the identification of project objectives, influences the selection of the appropriate organizational form for the project, and even affects the final outcome

of the project [7]. Therefore, the study of project complexity is of great importance for the achievement of engineering project goals.

International architecture is often defined as companies residing in one country working in another country [8]. Globalization has created many opportunities for national organizations to expand their activities from local to other geographical areas [9]. With the increasing trend of economic globalization, the rate of integration in the international engineering market has also increased greatly. According to Engineering News-Record (ENR), the ratio of domestic and foreign revenue of the 250 largest international contractors is maintained at about 6:4, showing that countries are actively joining the international engineering market. With the deepening of the "Belt and Road" policy, China is also increasingly involved in International Engineering Projects (IEPs). Seventy-eight mainland Chinese companies are listed as the Top 250 International Contractors by ENR for 2021, accounting for 25.6% of the total international engineering revenue in the list. The proportion of IEPs in China is increasing under the trend of the global outbreak of epidemic and the downward trend of the international construction market.

Globalization has created complex challenges for management systems [10]. As more and more stakeholders from different countries are involved in IEPs, the projects become more complex [11]. IEPs are more complex than domestic engineering projects by exposing themselves to an external environment full of severe uncertainties [12]. For example, there are fewer skilled workers and less efficient workers abroad, the Chinese-style work speed does not match the pace of work abroad. Stakeholders in various countries always face ineffective communication, disputes due to conflicting interests [13], project delays caused by COVID-2019, incorporation of foreign governments and citizens. Therefore, it is necessary for contractors to study the Complexity of International Engineering Projects (CIEPs), which can help managers cope with the complex environment, improve project performance, and promote project success.

Existing studies on the definitions of project complexity focus on three dimensions, namely, Technical, Organizational, and Environmental complexity (TOE framework). In terms of organizational complexity, Baccarini (1996) first proposed that organizational complexity includes the attributes of variance and interdependence [14]. Variance can usually be measured by the number of organizational hierarchies and organizational units, and the division of tasks. Interdependence is measured according to the degree of interactions between organizations. Bosch et al., (2011) concluded that organizational complexity can be divided into size, resource, project team, trust, and risk [15]. Technical complexity is defined by the difficulty in task execution and was measured by the number of tasks, the number of specialties, and the degree of interaction between different technologies [14]. In terms of environmental complexity, Gao et al., (2018) defined environmental complexity as unpredictable disturbances and problematic contingencies that may occur in the external environment [16].

However, existing complexity studies lack a focus on the complexity of the human element. IEPs is a social and economic activity with human as the main body, so the complexity of human element has a very important influence on the CIEPs. Wu et al., (2007) proposed that it is crucial to reduce the uncertainty of human elements (individual characteristics and group behavior) in order to achieve system coordination and improve project performance in modern engineering projects [17]. Therefore, the complexity of human elements should be considered when measuring the CEPs [18]. If the impact of human element complexity is not considered, the final result of CEPs will be biased. Harmony Management Theory (HMT), which highlights the influence of human element complexity, has demonstrated effectiveness in several fields, such as human resource management, rural construction, large-scale engineering projects, university management, etc. [19]. Therefore, this study measures the CIEPs based on HMT, considering the contribution of human elements.

Various studies have focused on the measurement of CEPs. Delphi, analytic network, and hierarchical analysis are the widely used methods to quantify CEPs. For example, Xia and Chan (2012) used the Delphi method to identify key parameters and measure

project complexity [20]. He et al., (2015) used Fuzzy Analytic Network to measure the complexity of large construction projects in China [21]. Nguyen et al., (2015) used Fuzzy Hierarchical Analysis to determine the parameters and weights of the components of transportation project complexity (socio-political, environmental, organizational, infrastructure, technical, and scope complexity) [22]. However, the traditional evaluation method has two shortcomings: (1) It overly relies on the subjective judgment of experts when determining the indicator weights, which makes the weight set not scientific and reasonable enough, (2) the fuzzy language often does not fully express the preferences of experts when evaluating, which makes the evaluation results not scientifically accurate. However, Back-Propagation Neural Network (BPNN) can train the results of expert scoring and reduce the error between the expected value and the output value, which is a widely used prediction model [23]. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method can evaluate the degree of interaction of complexity indicators. Kim and Nguyen (2021) [24], based on a study of complexity variables of International Development Projects, showed that Delphi and DEMATEL are reliable and accessible methods for capturing the interrelationships between complexity variables. For the ambiguity and uncertainty of the expert language, Interval-valued Intuitionistic Fuzzy Sets can represent the risk level of risk factors, and the uncertainty and ambiguity of expert judgment information can be fully considered using the affiliation function [25].

Therefore, this study aims to propose a method for measuring the CIEPs. An index system is established based on the HM theory and TOE framework, focusing on the influence of the complexity and uncertainty of human elements. The BP-DEMATEL method and IIFS are used to determine the index weights and evaluation values. The contributions of this study lie in the following aspects. Theoretically, it improves the theoretical system of complexity measurement of IEPs. Practically, it helps decision makers to anticipate the complexity and complications of the project before the project formally starts and make corresponding countermeasures to help the project better achieve its goals. The rest of this paper is organized as follows. Part 2 presents the research methodology. The third part shows the establishment of the proposed method. The fourth part verifies the effectiveness of the proposed method using a case study of Yawan high-speed rail project, followed by the fifth part discussion.

2. Methodology

The overall structure of this paper is shown in Figure 1:

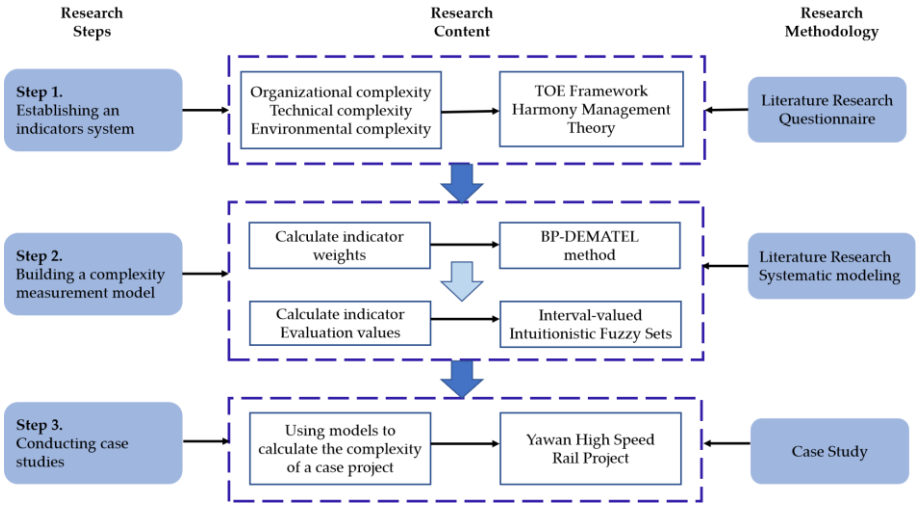


Figure 1. Flow chart of complexity measurement of international engineering projects.

According to Figure 1, the HMT and the TOE framework were used to establish an indicator system first. In line with TOE framework, three dimensions of complexity, technical, organizational, and environmental, are identified to provide a comprehensive

and broad overview of project complexity [15]. Meanwhile, the HMT is widely used in various fields. It focuses on the impact of human activities on projects in the field of engineering project management [26] and improves the management performance of engineering projects by reducing and minimizing the complexity of human elements. Therefore, this study will establish the framework of CIEPs index system combining HM Theory and the TOE framework.

Secondly, the BP-DEMATEL method and IIFS were used to process the data collected by expert scoring in the complexity measurement study. Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a method proposed by the Battelle Institute in 1971 to rank the importance of influences [27]. In the traditional DEMATEL method, the direct correlation matrix is mainly determined by the AHP method, questionnaires, and other methods, which have a common problem of over-reliance on subjective human judgment and difficulty in excluding the bias brought by human factors [28]. This problem can be solved by the BP-DEMATEL method, which has been used by many scholars and proved effective in studying the importance of influencing factors. For example, Hu et al., (2009) used BPNN and DEMATEL to modify the Importance-Performance Analysis model [29], proposing a more rational approach to materiality and performance analysis Wang et al., (2019) combined the fuzzy DEMATEL method with BP neural network prediction to build a reputation bootstrap model and validated the model with better accuracy and efficiency through a case study [30]. Therefore, in this study, BPNN was introduced into the DEMATEL model to determine the direct correlation matrix between the influencing factors.

Intuitionistic Fuzzy Sets (IFS) were proposed by a Bulgarian scholar, Atanassov, in 1983, which is an extension of traditional fuzzy [31]. It takes into account the information of affiliation, non-affiliation, and hesitation at the same time, therefore, it is more flexible and practical than traditional fuzzy sets in dealing with fuzziness and uncertainty [32]. By describing fuzzy concepts, fuzzy information can be expressed more clearly and accurately in a quantified way [33]. In order to solve the uncertainty of real values, IFS was extended to Interval-Valued Intuitionistic Fuzzy Sets (IIFS) [34] by Atanassov (1989) [35]. IIFS have been demonstrated to have great advantages in building more accurate and ideal models and are widely used in decision-making, classification, clustering, image processing, etc. [36,37]. Therefore, this study uses IIFS to deal with the evaluation value of indicators.

3. Indicator System for International Engineering Projects Complexity (CIEPs)

3.1. Overall Framework for CIEPs Indicator Selection

This study integrates Harmony Management Theory and TOE (organizational, technical, and environmental) framework to establish an index system that reflects the CIEPs.

Complexity was initially divided into three dimensions: Technical, Organizational, and Social [38]. Based on this, Bosch et al., (2011) used an inductive approach and proposed a framework for studying complexity in large engineering projects, named TOE (including Technical, Organizational, Environmental) framework [15], which assigns all complexity influences to these three categories. The framework can be reused in different project phases and can be flexibly extended so as to meet the requirements of different industry characteristics. Therefore, this study classifies the influencing factors of complexity into three dimensions of organizational complexity, technical complexity, and environmental complexity, in line with the TOE framework.

The Harmony Theory was proposed by Xi et al., (1989) [39], which not only describes the degree of cooperation of system composition and organizational structure but also emphasizes the activities, feelings, and attitudes within the system members, as well as the relationships among members, and is more suitable for describing human-centered socio-economic activities. Accordingly, a system diagnostic model was further proposed that could calculate the dissonance metric of system elements, subsystems, and the whole system [40]. Based on this, Huang and Xi (2001) proposed the HMT [41], which is the application and development of harmony theory in management. The HMT is oriented to the overall optimization of the system, which not only considers the efficiency of the

organization, but also covers the human factors in the organization. Wu et al., (2017) have discussed the application of HMT in engineering project management and concluded that the study of engineering project management with HMT seems superior to traditional engineering project management and can reduce the uncertainty of human element [17].

Based on this, when studying organizational complexity, the influence of human element on organizational complexity should be considered. The dissonance of the system is absolute, and the greater the dissonance, the greater the complexity of the system. Therefore, organizational complexity can be measured by the dissonance of the system according to the system diagnostic model. It should be noted that the human element of technical and environmental complexity has also been considered in organizational complexity. When studying technical and environmental complexity, we only consider the influence of the complexity of physical elements, such as the type of technology and the degree of instability of the external environment (as shown in Figure 2).

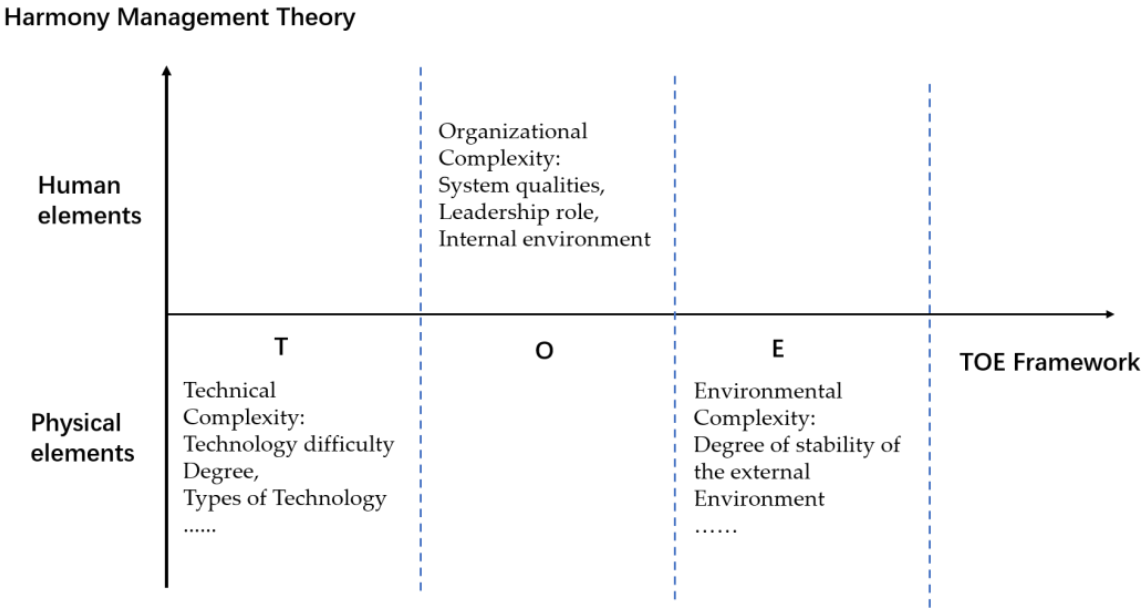


Figure 2. Principle of constructing complexity index system.

3.2. Organizational Complexity

The complexity of a project activity decreases as the experience and skills of workers and project managers increase [42]. Therefore, the impact of human activities on project complexity is significant. This study examines organizational complexity based on HMT. System harmony can be studied in four parts: system composition, organization, internal environment, and external environment. These four components can further be divided into seven subsystems: quality, strength, function, structure, leadership role, internal environment, and external environment [40]. The system diagnostic model proposed by Xi et al., (1989) can calculate the harmony degree of the system elements. A system is often in the following two states, harmonious state, and disharmonious state. The more disharmonious the system, the more complex it is. Therefore, the complexity of the system can be expressed by the discordance quantization of subsystems [43]. In line with this, this study reflects the complexity of human elements by the indicator for measuring the discordance of the system. Discordance of three subsystems related to organizational members can be considered in this study, namely, System Quality (SQ) discordance, which shows the basic quality of the project participator, Leadership Role (LE) discordance reflects how managers deal with the relationship between participator, and Internal Environment (IE) discordance discloses the working atmosphere of the project. The three Indicators and their detailed explanation are shown in Table 1.

Table 1. Indicator System for measuring organizational complexity.

Indicators	Components (Indicator Description)
SQ-System Quality	➢ SQ_1-Political and ideological quality (the construction of party and political work, the responsibility of organization members) ➢ SQ_2-Scientific and cultural quality (average educational level of organization members) ➢ SQ_3-Professional quality (experience level, technical level of organization members) ➢ SQ_4-Physical and mental quality (the ability of organization members to resist stress in case of major accidents or difficulties)
LE-Leadership Role	➢ LE_1-Program (the foresight and planning for future events) ➢ LE_2-Organization (equipped reasonable and efficient material and personnel for the implementation of the project) ➢ LE_3-Command (division of work tasks and employee functions) ➢ LE_4-Coordinate (communication and cooperation among stakeholders) ➢ LE_5-Control (controlled of project implementation plan, correction of errors)
IE-Internal Environment	➢ IE_1-Human relations for projects (the degree of harmony in the relationship between organization members) ➢ IE_2-Work life environment and atmosphere (satisfaction of organization members with their work and living environment) ➢ IE_3-Benefit conditions of the project (satisfaction of organization members with holidays and various subsidy policies) ➢ IE_4-Employee's physical and mental health (physical health and mental health of organization members)

(References [18,43]).

The process of quantifying the disharmony of system elements by Professor Xi is as follows [41]:

(1) Discordance between different elements

$$dh_{ij} = \frac{a'_{ij} - a_{ij}}{a'_{ij}}, \quad (1)$$

where dh_{ij} indicates the disharmony degree between the element a_i and the element a_j. a_i refers to element SQ_1, SQ_2, SQ_3, SQ_4; LE_1, LE_2, LE_3, LE_4, LE_5; IE_1, IE_2, IE_3, IE_4. $a_{ij}{}'$ indicates the optimal match of a_i provided by a_j elements; a_{ij} means that a_j can actually offer the match to a_i.

(2) Discordance of the ideal state and actual state of a certain element

$$dh_{ii} = \frac{a'_{ii} - a_{ii}}{a'_{ii}}, \quad (2)$$

dh_{ii} denotes the discordance of the element a_i itself, $a_{ii}{}'$ is the ideal harmonious state of element a_i, a_{ii} is the actual state of element a_i.

(3) Quantification of the fit between the elements

The optimal match condition is recorded as 1, and the most unfit condition is scored as 0. Then the actual match condition provided by a certain element should be between 0 and 1, and the fuzzy evaluation method is used to evaluate the matching degree.

(4) Dissonance of the elements

$$d_{DH}(a_i) = \omega_{i1} \cdot dh_{ij} + \omega_{i2} \cdot dh_{ii}, \tag{3}$$

where ω_{i1} indicates the weighing value of dh_{ij}, and ω_{i2} is the weighing value of elements dh_{ii}, both of which can be obtained by the Analytic Hierarchy Process (AHP).

(5) Dissonance of subsystems

By referring to the three Indicators in this study in Table 1, the system quality discordance is expressed as follows:

$$d_{DH}(SQ) = \sum_{i=1}^{4} d_{DH}(SQ_i) \cdot \omega_i \tag{4}$$

$$d_{DH}(LE) = \sum_{i=1}^{5} d_{DH}(LE_i) \cdot \omega_i, \tag{5}$$

$$d_{DH}(IE) = \sum_{i=1}^{4} d_{DH}(IE_i) \cdot \omega_i, \tag{6}$$

where ω_i denotes the degree of influence of a_i elemental discordance on system quality discordance.

3.3. Technical Complexity

Technical complexity is the core part of project complexity [44]. The technical complexity of international projects is greater than that of domestic projects because of the large differences in technical level, technical standards, and technical experience of managers. Especially the problem of whether the new technology can be better integrated with foreign personnel and environment. According to existing studies, technological complexity mainly includes the difficulty of technologies and variability of technologies, and the degree of interplay between specific activities of tasks and construction [16]. San et al., (2018) pointed out that the diversity of technology types can also increase technical complexity [45]. Therefore, the technical complexity indicators used in this paper are as follows: The diversity of technical types, the difficulty degree of technology, the variability degree of technical specification standards, and the compatibility degree between technology and project requirements.

3.4. Environmental Complexity

Environmental complexity refers to the uncertainty of external environment in the international engineering projects' location [15]. The external environment of international engineering projects is complex since the natural environment, political environment, economic environment, and social stability are all very different from those in China. In line with existing studies, environmental complexity mainly includes unpredictable disturbances and unexpected events that may occur in the external environment [16], such as unstable political, economic, and natural conditions [46]. Therefore, four indicators are selected in this study, namely the stability of the political, economic, and social environment in the project host country, the degree of support for the project from the local government and citizens, the complexity of local policies and regulations, and the possibility of local natural disasters.

3.5. Constructing the Evaluation Index System of International Engineering Complexity

In a summary, this study integrates TOE framework with Harmony Management Theory to construct an index system of international engineering project complexity. The details are shown in Table 2.

Table 2. International engineering complexity index system.

Target Layer	Category	Indicators	References
International Engineering Projects Complexity (CIEPs)	O-Organizational Complexity	O_1-Dissonance of system qualities O_2-Dissonance of leadership role O_3-Dissonance of internal environment	[17,18,43]
	T-Technical complexity	T_1-Diversity of technology types T_2-The difficulty of the technology T_3-The degree of difference between technical specifications and technical standards and domestic T_4-The degree of inappropriateness of various technologies and engineering	[15,16,21]
	E-Environmental Complexity	E_1-Instability of the political, economic, and social environment in the project country E_2-The level of non-support for the project from the local government and people E_3-The extent to which local policies and regulations differ from domestic ones E_4-Likelihood of local natural disasters	[16,21,46]

4. Measurements for CIEPs

4.1. BP-DEMATEL Method to Determine the Index Weights

Authors should discuss the results and how they can be interpreted from the perspective of previous studies and the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

In this study, the Back-Propagation Neural Network-Decision Making Trial and Evaluation Laboratory (BP-DEMATEL) model is used to calculate the performance of the ICEPs. The BP neural network model is applied to derive the direct correlation matrix, and DEMATEL is applied to calculate the weight of indicators. The specific steps are as follows [29,30,47]:

(1) Construction of expert evaluation matrix

Firstly, experts in the discipline of construction management were invited to score the importance of each indicator and the degree of mutual influence between each indicator to form an evaluation matrix,

$$D_m = \begin{bmatrix} d_{11} & \cdots & d_{1,n} \\ \vdots & \ddots & \vdots \\ d_{n,1} & \cdots & d_{n,n} \end{bmatrix} \quad (7)$$

where the score of the main diagonal indicates the strength of the element itself, d_{ii} denotes the intensity of the element itself. Other values indicate the degree of interaction between elements, d_{ij} denotes the degree of influence of element i on element j. D_m denotes the evaluation matrix of the mth expert. n is the number of complexity indicators to be evaluated.

(2) Construction of BP neural network model

In this study, a three-layer BP neural network is constructed, where the input layer is the expert's evaluation of the strength of the element itself, and the output layer is the evaluation of the strength of each complexity-influencing factor influenced by other factors. The number of neurons in the implicit layer is obtained using $m = \log 2\ n$, where m is the number of nodes in the implicit layer, and n is the number of nodes in the input layer.

(3) Training network

The neural network toolbox in MATLAB (R2016b) software is used to implement the training of the above neural network model.

(4) Obtain expert evaluation correction values

Using the trained network model, the average value of the intensity of each complexity influence factor is used as the input layer, and the modified influence degree evaluation value is obtained in the output layer by network operation.

(5) Construction of direct correlation matrix

The direct correlation matrix B between complexity-influencing factors is constructed using the mean of their own strengths and the expert evaluation values trained by the neural network as follows:

$$B = \left(b_{ij}\right)_{n\times n} = \begin{bmatrix} b_{11} & \cdots & b_{1,n} \\ \vdots & \ddots & \vdots \\ b_{n,1} & \cdots & b_{n,n} \end{bmatrix} \tag{8}$$

(6) Normalized direct correlation matrix

The resulting correlation matrix is normalized according to the following equation:

$$X = \left(x_{ij}\right)_{n\times n} = \frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n} b_{ij}} \cdot B \tag{9}$$

(7) Construct the full correlation matrix T

$$T = \left(t_{ij}\right)_{n\times n} = X(I-X)^{-1} \tag{10}$$

where $(I-X)^{-1}$ is the inverse of $I-X$ and I is the unit matrix.

(8) Based on the full correlation matrix, the centrality and causality of each indicator are obtained

In the full correlation matrix, each row corresponding to each indicator sums to e_i, which represents the sum of the indicator influenced by other indicators, and each column corresponding to each indicator sums to f_i, which represents the composite of the indicator influenced by other indicators. Then the centrality of each indicator is,

$$g_i = e_i + f_i (i = 1, 2, ..., n) \tag{11}$$

which indicates the importance of the indicator among the indicators, and the higher its value, the more important the indicator is. The reason degree of each indicator is,

$$h_i = e_i - f_i (i = 1, 2, ..., n), \tag{12}$$

which indicates the degree of net influence of the indicator on the whole index system and its value is greater than 0, which means that the indicator has a greater influence on other indicators, and vice versa, which means that the indicator is influenced by other indicators.

(9) The centrality is normalized, i.e., the weight profile of each complexity influencing factor is obtained

4.2. Determination of Index Evaluation Value Based on Interval Intuitionistic Fuzzy Set

In this study, Interval Intuitionistic Fuzzy Set theory is used to represent the evaluation value of the indicators by experts. The specific steps of the method are as follows [48,49].

(1) Expert Evaluation

A questionnaire was used to collect experts' evaluations of each complexity influencing factor, and the results were tallied.

(2) Build interval intuitionistic fuzzy sets

The evaluation results are processed and expressed in the form of an interval intuitionistic fuzzy set:

$$\widetilde{A} = \left\{ \left\langle x, \left[\mu_A^L(x), \mu_A^U(x) \right], \left[v_A^L(x), v_A^U(x), \right] \right\rangle \middle| x \in X \right\}, \tag{13}$$

where X is a non-empty set, $\left[\mu_A^L(x), \mu_A^U(x)\right]$ and $\left[v_A^L(x), v_A^U(x)\right]$ are the affiliation interval and non-affiliation interval of element x belonging to X, respectively. $\mu_A^L(x)$ and $v_A^L(x)$ are the lower bounds of affiliation and non-affiliation, respectively. $\mu_A^U(x)$ and $v_A^U(x)$ are the upper bounds of affiliation and non-affiliation, respectively and $0 \le \mu_A^L(x) \le \mu_A^U(x) \le 1$, $0 \le v_A^L(x) \le v_A^U(x) \le 1$, $\mu_A^U(x) + v_A^U(x) \le 1$. The degree of hesitation is denoted $\pi_A(x) = [\pi_A^L(x), \pi_A^U(x)]$, where $\pi_A^L(x) = 1 - \mu_A^U(x) - v_A^U(x)$ denotes the lower limit of hesitation and $\pi_A^U(x) = 1 - \mu_A^L(x) - v_A^L(x)$ denotes the upper limit of hesitation.

(3) Find the weight of each expert to give the evaluation value of the index

The mean value of each evaluation indicator m_{ij} is calculated first. The evaluation values given by n experts E_i ($i = 1, 2, 3, \ldots, n$) about the indicator C_j ($j = 1, 2, 3, \ldots, n$) are as follows:

$$r_{ij} = \left\langle \left[\mu_{ij}^L(x), \mu_{ij}^U(x) \right], \left[v_{ij}^L(x), v_{ij}^U(x) \right] \right\rangle \tag{14}$$

Then the mean value of the evaluation value is defined as follows:

$$m_{ij} = \left\langle \left[\mu_{ij}^{L\prime}, \mu_{ij}^{U\prime} \right], \left[v_{ij}^{L\prime}, v_{ij}^{U\prime} \right] \right\rangle \tag{15}$$

where,

$$\mu_{ij}^{L\prime} = \frac{1}{n} \sum_{i=1}^{n} \mu_{ij}^L$$

$$\mu_{ij}^{U\prime} = \frac{1}{n} \sum_{i=1}^{n} \mu_{ij}^U$$

$$v_{ij}^{L\prime} = \frac{1}{n} \sum_{i=1}^{n} v_{ij}^L$$

$$v_{ij}^{U\prime} = \frac{1}{n} \sum_{i=1}^{n} v_{ij}^U$$

The similarity between the mean value of each rating m_{ij} and the rating r_{ij} is then calculated as follows:

$$s(r_{ij}, m_{ij}) = 1 - \frac{d(r_{ij}, m_{ij})}{\sum_{i=1}^{n} d(r_{ij}, m_{ij})} \tag{16}$$

where, two interval intuitionistic fuzzy sets are as follows:

$$\widetilde{A_1} = \left\{ \left\langle x_1, \left[\mu_A^L(x_1), \mu_A^U(x_1) \right], \left[v_A^L(x_1), v_A^U(x_1) \right] \right\rangle \middle| x_1 \in X \right\} \tag{17}$$

$$\widetilde{A_2} = \left\{ \left\langle x_2, \left[\mu_A^L(x_2), \mu_A^U(x_2) \right], \left[v_A^L(x_2), v_A^U(x_2) \right] \right\rangle \middle| x_2 \in X \right\} \tag{18}$$

Then the distance between them both is defined as follows:

$$d\left(A_1 \middle| \widetilde{A_2} \right) = \frac{1}{4} \begin{pmatrix} \left| \mu_A^L(x_1) - \mu_A^L(x_2) \right| + \left| \mu_A^U(x_1) - \mu_A^U(x_2) \right| + \\ \left| v_A^L(x_1) - v_A^L(x_2) \right| + \left| v_A^U(x_1) - v_A^U(x_2) \right| + \\ \left| \pi_A^L(x_1) - \pi_A^L(x_2) \right| + \left| \pi_A^U(x_1) - \pi_A^U(x_2) \right| \end{pmatrix} \tag{19}$$

The weight of the evaluation information r_{ij} given by the evaluation expert E_i on the indicator C_j can be expressed as follows:

$$W_{ij} = \frac{s(r_{ij}, m_{ij})}{\sum_{i=1}^{n} s(r_{ij}, m_{ij})} \tag{20}$$

(4) To derive the comprehensive evaluation value of expert evaluation information

The evaluation values of all experts are assembled, and the final comprehensive evaluation matrix, which assembles the evaluation information of all experts, is obtained.

$$R_0 = (r_{ij})_{n\times 1}, \tag{21}$$

where $r_j = \sum_{i=1}^{n} \omega_{ij} r_{ij}$.

(5) The final evaluation value is derived

The final evaluation value of each tier can be obtained by performing a weighted average calculation based on the comprehensive evaluation value of the indicators evaluated by experts and the weights of each indicator that has the BP-DEMATEL algorithm alone. The weighted average operator can be expressed as follows:

$$\widetilde{A}_0 = \left\langle \left[1 - \prod_{i=1}^{n} \left(1 - \mu_A^L(x_i)\right)^{\omega_i}, 1 - \prod_{i=1}^{n} \left(1 - \mu_A^U(x_i)\right)^{\omega_i} \right], \left[\prod_{i=1}^{n} v_A^L(x_i)^{\omega_i}, \prod_{i=1}^{n} v_A^U(x_i)^{\omega_i} \right] \right\rangle \tag{22}$$

$W = (\omega_1, \omega_2, \ldots, \omega_n)$ are the weights of each vector, $0 \le \omega_i \le 1$, and $\sum_{i=1}^{n} \omega_i = 1$.

(6) Score function can be expressed as follows: $\left[\mu_A^L(x), \mu_A^U(x)\right]$, $\left[v_A^L(x), v_A^U(x)\right]$

$$S(x) = \frac{v_A^L(x) + v_A^U(x) - \mu_A^L(x) - \mu_A^U(x)}{2} + \frac{\mu_A^L(x) + \mu_A^U(x) + 2\left(\mu_A^L(x)\cdot\mu_A^U(x) - v_A^L(x)\cdot v_A^U(x)\right)}{v_A^L(x) + v_A^U(x) + \mu_A^L(x) + \mu_A^U(x)} \tag{23}$$

5. Case Study

5.1. Project Overview and Data Collection

The Yawan high-speed railway project, which is 150 km long from Bandung to Jakarta, with an altitude difference of about 700 m, is selected as a sample case in this study. The project involves China, Indonesia, Japan, and other countries. The implementation of the project faces a complex internal and external environment, which is characterized by large engineering volume, long construction period, complex geographical environment, huge investment, and political significance. The difficulties faced by Yawan high-speed railway are mainly in three aspects: Organization, technology, and environment. In terms of organization, the project participants come from different countries, and most of the employees come from the local area, so the quality of personnel and work habits are very different, making organization and coordination difficult. In terms of technology, different countries have different technical standards and specifications, and there are many different types of technology. In terms of environment, the political, economic, social, legal, and natural conditions of each country differ greatly from those of China, and there are many uncertainties.

The main purpose of this study is to propose a measurement method for the complexity of international engineering projects for project managers to refer to. The case study is mainly aimed at verifying the feasibility of the method and model. Once the measurement method is verified to be feasible, future research can use this method specifically to conduct comparative research and analysis on multiple countries and cases. However, in this study, there will be no comparative study of multiple cases. Based on the overview of Yawan high-speed railway project, this study takes the project as an example. In-depth interviews with five experts and scholars in the field of engineering management have been conducted, Delphi method is used to get the scores.

5.2. BP-DEMATEL Model Construction of International Engineering Complexity Influencing Factors

The degree of interaction between the indicators was determined by a five-point scale: Very large = 4, large = 3, medium = 2, low = 1, and none = 0. The expert's evaluation value of the element's own strength is used as the input layer, and the output layer is the evaluation value of the strength of each complexity-influencing factor influenced by other factors, and the input and output are brought into the neural network toolbox in MATLAB software, where the number of neurons in the implicit layer is 2. The network model is shown in Figure 3, and the expert's scoring results are trained according to this model.

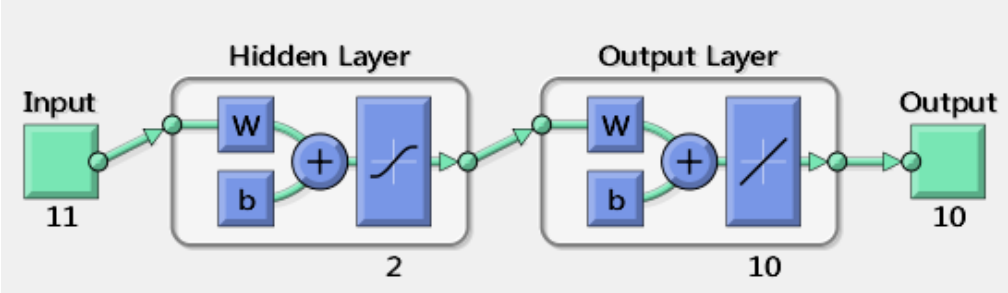


Figure 3. BP neural network model diagram.

Then, the experts' evaluation values for each index were averaged as the input of the prediction model, and the final learned experts' evaluation values were obtained, as shown in Table 3.

Table 3. Expert evaluation values after training of BP neural network.

Indicators	O_1	O_2	O_3	T_1	T_2	T_3	T_4	E_1	E_2	E_3	E_4
O_1	2.98	4.54	3.25	3.98	3.60	1.78	1.23	−0.04	2.86	1.10	0.06
O_2	2.78	2.75	4.03	−1.28	−0.04	4.83	1.28	2.35	3.54	1.08	1.22
O_3	2.22	2.00	2.76	2.02	3.13	0.93	1.43	1.96	1.12	2.32	−0.65
T_1	3.60	2.00	1.89	2.60	2.19	2.57	4.43	0.45	1.30	2.93	2.48
T_2	2.86	1.69	2.83	3.59	3.20	2.07	0.47	1.25	3.31	3.03	−2.43
T_3	4.26	2.75	2.12	2.17	2.30	3.00	3.11	1.89	9.14	1.91	1.76
T_4	1.95	3.09	2.96	3.42	3.72	4.20	2.80	1.81	2.51	1.82	0.07
E_1	2.95	1.89	2.36	3.44	0.39	4.47	2.55	1.80	4.61	2.99	−1.07
E_2	2.00	3.45	2.90	3.32	2.92	2.60	1.89	2.19	3.00	3.10	1.55
E_3	0.60	2.98	1.40	4.17	1.17	1.85	0.70	1.62	3.58	1.60	1.35
E_4	0.74	1.36	1.19	1.64	1.23	1.66	1.59	1.89	0.78	0.96	1.20

This evaluation value is taken as the direct correlation matrix and brought into Equation (7) to normalize the direct correlation matrix. Then, the normalized matrix is brought into Equation (8) to obtain the comprehensive impact matrix, as shown in Table 4.

According to the comprehensive influence matrix, the final influenced, influential, centrality, and cause degrees of each secondary indicator are obtained, as shown in Table 5.

Define the degree of being influenced C as the sum of the elements in each column of the comprehensive influence matrix, and the degree of influence D as the sum of the elements in each row. D + C is defined as the centrality of the index, and the higher the value, the higher the importance of the index. D − C is the cause of the index, and the index can be divided into two categories of cause-and-effect factors according to its positive or negative value [29]. Therefore, among the 11 indicators, there are 4 causal factors, namely, T3 (the degree of difference between technical specifications and technical standards and domestic), T4 (the degree of inappropriateness of various technologies and engineering), E1 (instability of the political, economic, and social environment in the project country), E4 (likelihood of local natural disasters). The remaining seven are result-based factors, which will be influenced by the aforementioned cause-based factors.

Table 4. Combined impact matrix of influencing factors.

Indicators	O_1	O_2	O_3	T_1	T_2	T_3	T_4	E_1	E_2	E_3	E_4
O_1	0.19	0.33	0.29	0.30	0.27	0.25	0.18	0.12	0.32	0.20	0.05
O_2	0.26	0.19	0.30	0.15	0.16	0.32	0.17	0.18	0.35	0.18	0.08
O_3	0.21	0.21	0.15	0.21	0.21	0.18	0.15	0.14	0.22	0.20	0.01
T_1	0.30	0.27	0.26	0.21	0.24	0.28	0.28	0.14	0.30	0.25	0.12
T_2	0.25	0.23	0.25	0.28	0.15	0.23	0.15	0.14	0.32	0.24	-0.03
T_3	0.38	0.37	0.34	0.34	0.30	0.28	0.29	0.22	0.60	0.29	0.12
T_4	0.28	0.32	0.31	0.32	0.30	0.35	0.17	0.19	0.37	0.25	0.05
E_1	0.31	0.30	0.30	0.33	0.21	0.36	0.25	0.14	0.43	0.28	0.03
E_2	0.27	0.33	0.30	0.32	0.27	0.30	0.22	0.20	0.28	0.28	0.10
E_3	0.19	0.26	0.21	0.29	0.18	0.23	0.16	0.15	0.32	0.15	0.09
E_4	0.14	0.16	0.15	0.17	0.13	0.17	0.14	0.13	0.18	0.13	0.03

Table 5. Degree of being influenced, impact, centrality, and reason for influencing factors.

Indicators	O_1	O_2	O_3	T_1	T_2	T_3	T_4	E_1	E_2	E_3	E_4
Influenced degree D	2.78	2.96	2.86	2.92	2.42	2.97	2.15	1.75	3.70	2.45	0.64
Impact degree C	2.49	2.33	1.90	2.65	2.21	3.54	2.93	2.94	2.87	2.22	1.52
Centering degree D + C	5.27	5.29	4.76	5.57	4.63	6.51	5.08	4.69	6.57	4.67	2.17
Reason degree D − C	−0.29	−0.64	−0.97	−0.26	−0.20	0.56	0.78	1.19	−0.83	−0.22	0.88

The value obtained after normalization of centrality is the weight value of each indicators and the weight value of the primary index is obtained by adding the corresponding secondary index weight values, as shown in Table 6.

Table 6. Weights of complexity indicators.

Indicators	O_1	O_2	O_3	T_1	T_2	T_3	T_4	E_1	E_2	E_3	E_4
Weights	0.10	0.10	0.09	0.10	0.08	0.12	0.09	0.08	0.12	0.08	0.04
Category Weights	O (organizational complexity) 0.28			T (technical complexity) 0.39				E (environmental complexity) 0.33			

According to the final results, it can be seen that the weights of the category, organizational complexity, technical complexity, and environmental complexity, are 0.28, 0.39, and 0.33, respectively, with the greatest weight of technical complexity, which means that technical complexity has the most important influence on the overall project complexity. Among the indicators, O_1 (dissonance of system qualities), O_2 (dissonance of leadership role), and O_3 (dissonance of internal environment) are 0.10, 0.10, and 0.09, respectively, O3 have the smaller values, so the influence of O_3 on organizational complexity is less important. T_1 (diversity of technology types), T_2 (the difficulty of the technology), T_3 (the degree of difference between technical specifications and technical standards and domestic), and T_4 (the degree of inappropriateness of various technologies and engineering)have weights of 0.10, 0.08, 0.12, and 0.09, respectively, in which T_3 has the largest weight value, which means that this indicator has the most important influence on technical complexity. E_1 (instability of the political, economic, and social environment in the project country), E_2 (the level of non-support for the project from the local government and people), E_3 (the extent to which local policies and regulations differ from domestic ones), E_4 (likelihood of local natural disasters) have weights of 0.08, 0.12, 0.08, and 0.04, respectively, where E_2 has the largest weight value, which means that this indicator has the most important influence on environmental complexity.

5.3. Application of Interval Intuitionistic Fuzzy Sets

To obtain the evaluation values of these eleven complexity indicators for the Yawan Express Rail Link project, a questionnaire was administered to the members of the evaluation team, and the results of their survey were expressed in the form of interval intuition fuzzy numbers, as shown in Table 7.

Table 7. Results of experts' evaluation of each secondary indicator.

Indicators	Rate the Value
O_1	⟨[0.23, 0.39], [0.40, 0.55]⟩
O_2	⟨[0.24, 0.43], [0.38, 0.54]⟩
O_3	⟨[0.30, 0.41], [0.42, 0.52]⟩
T_1	⟨[0.45, 0.57], [0.17, 0.34]⟩
T_2	⟨[0.39, 0.53], [0.23, 0.43]⟩
T_3	⟨[0.43, 0.56], [0.24, 0.44]⟩
T_4	⟨[0.42, 0.57], [0.17, 0.41]⟩
E_1	⟨[0.26, 0.42], [0.44, 0.57]⟩
E_2	⟨[0.20, 0.34], [0.50, 0.62]⟩
E_3	⟨[0.54, 0.64], [0.18, 0.29]⟩
E_4	⟨[0.41, 0.61], [0.24, 0.36]⟩

Based on the values of the weights of indicators (Table 6) and Equation (22), the interval intuitionistic fuzzy numbers of the category can be obtained as in Table 8.

Table 8. Evaluation results of first-level indicators.

Category	Rate the Value
Organizational complexity	⟨[0.26, 0.41], [0.40, 0.54]⟩
Technical complexity	⟨[0.42, 0.56], [0.20, 0.41]⟩
Environmental Complexity	⟨[0.34, 0.49], [0.38, 0.51]⟩

According to the weights of the category and Formula (22), the interval intuitionistic fuzzy number of the complexity of Yawan high-speed railway project is ⟨[0.36, 0.50], [0.32, 0.48]⟩.

According to Formula (23), the real value of the complexity of Yawan high-speed railway project can be calculated as 0.52. The scores of indicators can also be calculated according to the interval intuition fuzzy number and Formula (19), as shown in Table 9.

Table 9. Score of each complexity indicator.

Indicators	**O_1**	**O_2**	**O_3**	**T_1**	**T_2**	**T_3**	**T_4**	**E_1**	**E_2**	**E_3**	**E_4**
Score	0.39	0.42	0.43	0.67	0.59	0.60	0.64	0.40	0.32	0.72	0.62
Category Score	Organizational complexity 0.41			Technical complexity 0.62				Environmental Complexity 0.48			

According to the final results, it can be seen that the overall evaluation result of the complexity of the Yawan Express Rail Project is 0.52, indicating that the complexity of Yawan is not too high.

In terms of indicators, the evaluation value of the technical complexity index is 0.62. The evaluation index value of environmental complexity is 0.48. The evaluation result of organizational complexity is 0.41.

5.4. Analysis of Evaluation Results

5.4.1. Measures for Managing Organizational Complexity

As shown in Table 9, the final score of organizational complexity is 0.41, which is the lowest score among the three complexity indicators of organization, technology, and environment, and it can be seen that the evaluation of organizational complexity in Yawan high-speed railway project is small. Specifically, among the organizational complexity, the scores of O_1, O_2, O_3 are 0.39, 0.42, and 0.43, respectively, and the highest score among the three indicators is O_3, which shows that this indicator is one of the most important aspects of organizational complexity. Yan (2019) et al., also pointed out that in order to increase the company's business opportunities and improve competitiveness, it is recommended that project teams spend more time and resources to establish harmonious relationships [50], which illustrates the importance of internal project environment harmony for the whole project team.

From Table 1, it can be seen that the internal environment of the project mainly includes four aspects: Human relations for projects, Work life environment and atmosphere, Benefit conditions of the project, Employee's physical and mental health. Therefore, the specific measures to reduce the internal environment disharmony are as follows: (1) Strengthening the training of language communication between workers from different countries, improving the efficiency of communication while enhancing the closeness between project members, forming good interpersonal relationships, (2) optimizing the infrastructure construction on the project to provide a good living and working environment for project members [51], (3) setting up incentive mechanisms and improving the welfare and subsidy mechanisms for workers to motivate them to work, (4) setting up psychological consultation rooms and conduct psychological assessments for workers at the right time to help laborers adapt to the foreign environment and avoid low work efficiency due to incompatibility with local life [52]

5.4.2. Management Measures for Technical Complexity

As shown in Table 9, the final score of technical complexity is 0.62, which is the highest score among the three complexity indicators of organization, technology and environment, which shows that technical complexity is the most important in the complexity of international engineering projects. Lan also mentioned in the dynamic study of project complexity that more attention should be paid to technical complexity in the process of complexity management [53]. Therefore, technical complexity should be studied and managed in more depth from several aspects, and the specific measures are as follows: (1) continuous assessment and training of technicians to help them better adapt to the difficult technical means, (2) unify the different quality standards, (i.e., technical specifications and standards), and to train the corresponding technicians and laborers in each country to avoid conflicts in the construction process due to different technical standards [54].

Specifically, among the technical complexity, the scores of T_1, T_2, T_3, and T4 are 0.67, 0.59, 0.60, and 0.64, respectively, among which T_1 has the highest score. Therefore, more attention should be paid to managing technical diversity. The specific measures are: (1) Before the construction phase begins, the types of technology and the tasks of the construction phase are subdivided and as detailed as possible, (2) in the construction process, the technology and equipment are efficiently used, and the whole process of construction can be understood through the integrated means of BIM technology so that the technology used in each stage of the project is uploaded into the database and matched with the subsequent stages of the project [55].

5.4.3. Management Measures for Environmental Complexity

As can be seen from Table 9, the final score of environmental complexity is 0.48, which is the middle score among the three complexity level indicators of organization, technology, and environment. Specifically, among the environmental complexity, E3 has the highest score among the four indicators. Amirtash et al., (2021) also pointed out that complex

international engineering projects are closely related to the differences in regulations and standards among countries, which also supports the conclusion proposed in this study's conclusion [56].

In order to deal with the problem of large differences between policies and regulations of project countries and domestic countries in international engineering projects, the following measures are proposed: (1) Compare the policies and regulations of project countries and domestic countries before project implementation, and formulate corresponding countermeasures for the parts with large differences, (2) request assistance from local lawyers or legal advisors during project implementation, (3) for the parts with large differences between domestic and foreign policies and regulations, contact local government or legal departments in advance to coordinate the differences.

6. Conclusions

With the increasing trend of economic globalization and the development of 'One Belt One Road' policy proposed by the Chinese government, more and more Chinese contractors are going out to undertake international engineering projects. In order to help Chinese contractors understand and manage the complexity of international engineering projects, this paper proposes a model for measuring the complexity of international projects. Based on TOE framework and harmonious management theory, this study proposes a model for measuring the complexity of international projects, uses BP-DEMATEL and interval intuitionistic fuzzy set to establish the complexity measurement model, and uses Yawan high-speed railway project as a case to verify the complexity measurement model in this paper, and finally proposes measures to deal with complexity.

The main findings of this study are as follows:

(1) For measuring the complexity of international engineering projects, three aspects of technical, organizational, and environmental complexity are needed. Meanwhile, in order to consider the influence of uncertainty of human elements on the complexity of international engineering projects, it is necessary to divide the influencing factors of complexity into human elements and physical elements based on the harmony theory.

(2) Among the technical, organizational, and environmental complexity of Yawan high-speed rail project, technical complexity scored the highest, and T1 (diversity of technology types) is the most important aspect. Environmental complexity was in the middle, with E3 (the extent to which local policies and regulations differ from domestic ones) being the most important indicator. Organizational complexity has the lowest score, with O3 (dissonance of internal environment) being the most important indicator.

(3) Combined with our findings, this study makes the following recommendations: (i) Strengthen the management of technology in stages and tasks and improve the efficiency of the use of technological tools, (ii) pay attention to the degree of differences in domestic and foreign policies and regulations, and when disputes occur, strengthen ex ante and ex post controls and summaries, (iii) improve the work and living standards of project labor and staff, strengthen interpersonal communication, communication, and cooperation, and focus on project staff's psychological condition.

The main contribution of this study is that it improves the theoretical system for measuring complexity in international engineering projects. Previous research has mainly focused on qualitative research, such as the definition of complexity, and many scholars have called for quantitative research on complexity. This study combines the theory of harmony management with the TOE framework, which makes up for the lack of previous studies on the difficulty of achieving engineering goals due to human complexity in engineering projects.

The practical significance of this study is that the proposed model can be used to assess the complexity of international engineering projects, help managers understand the project complexity in advance, and develop corresponding countermeasures. As in the case study, we used this method to obtain the quantified complexity value of the case and further refined the complexity evaluation value of the indicators. Based on this, project managers

can list the indicators with higher complexity performance as important indicators for management. The specific influencing factors of complexity in international engineering projects can be more clearly understood by using the proposed method so that appropriate resources can be matched for different projects. Complexity changes dynamically during the whole process of an engineering project, so the method proposed in this study can be repeatedly used in different stages of the project according to the needs of managers. The indicator system set in this study is flexible and can be extended as needed.

The limitation of this study lies in the subjectivity of the selection of indicators. Future research can first analyze and discuss the indicators affecting complexity and clarify the interrelationship between indicators through dimensionality reduction so that the established indicator system can express the complexity of international engineering projects more objectively and accurately. Secondly, this study only selected the Yawan high-speed railway project in China as an example. Future research can focus on the cases of international engineering projects in multiple countries and compare and analyze them.

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