Research on Predicting Economic Indicators of Public-Private Partnership Projects through Case-Based Reasoning

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Abstract—**This study aims to address the issues faced by social capital during the preliminary decision-making stage of tracking and bidding for Public-Private Partnership (PPP) projects, which are characterized by tight schedules, heavy workloads, low efficiency in financial estimation, and varying quality of the results. This study identifies and analyzes the main factors affecting the economic indicators of PPP projects and develops a model to predict these indicators through case-based reasoning. Furthermore, candidate cases that closely resemble the target project are selected from reliable and representative PPP projects previously implemented by the company. Key feature factors closely related to the economic indicators are used to predict the target case's investment net profit margin. The results show that this model is simple and more practical compared to other methods. It is particularly suitable for helping social capital perform financial calculations rapidly and efficiently during the preliminary decision-making stage of PPP projects.**

Index Terms—**Case-based reasoning, Economic indicator prediction, PPP projects, Social capital**

I. INTRODUCTION

Since 2014, local governments in China have launched a large number of Public-Private Partnership (PPP) projects. Although the growth rate of both the number of PPP projects and investment has slowed in recent years, these projects have become more standardized due to strict control at the macro level by the state. State-owned and private enterprises alike have shown strong enthusiasm for participating in PPP projects, with investment decision-making being the top priority for social capital. The screening, research, and evaluation of high-quality PPP projects at the early stage require considerable effort. Despite the large market for PPP projects, there are few decision-making tools based on information technology available to the industry. Most social capital parties face the same challenge: investment financial budgets for PPP projects rely heavily on the calculations and analyses conducted by employees, leading to low efficiency and results that are influenced by the employees' expertise. In the calculation process of PPP projects, many projects are similar in terms of investment composition, operation modes, and business conditions. Therefore, it is unnecessary to spend a lot of time on detailed calculations for similar projects in the early tracking stage. By collecting a few critical conditions, economic indicators can be effectively estimated. Hence, it is essential to develop a scientific and efficient decision-making model for the prediction of economic indicators in PPP projects to improve the decision-making mechanisms of enterprises.

Currently, research on the economic index prediction for PPP projects mainly focuses on aspects such as the franchise period [1]-[4], product prices [5]-[6], return on investment [7]-[8], investment yield [9]-[11], and net present value [12]-[13]. Common methods used include Monte Carlo simulation, game theory, the Capital Asset Pricing Model (CAPM), the Weighted Average Cost of Capital (WACC) model, and system dynamics. For example, Carbonara et al. used the Monte Carlo simulation method to calculate the franchise period of PPP projects [14]. Guo and Zhang integrated game theory with system dynamics to explore the pricing of quasi-operational projects within the PPP model [15]. Xu et al. applied CAPM and WACC models to predict the capital and total return on investment for sewage-related PPP projects [16].

In 1982, Professor Schank [17] from Yale University first introduced the concept of case-based reasoning. Later, Kolodner and Simpson [18] improved the solution process and summarized it as a 4R cycle. Case-based reasoning is a widely used machine learning method [19]-[20], based on human cognitive processes, which solves new problems by drawing on the similarities between previous and new cases [21]-[22]. Research on the application of case-based reasoning in engineering projects has mainly focused on areas such as cost estimation [23]-[26], bidding and procurement [27], built environment [28]-[31], risk management [32]-[34], contract management [35], and safety management [36]. For example, Li et al. (2020) used historical engineering case data to establish a cost estimation model for highway projects based on case-based reasoning techniques, which enabled more accurate estimations even at the investment decision-making stage [37]. Ng (2001) developed an expert prequalification model based on case-based reasoning to assist experts in reviewing the

Manuscript received March 20, 2024; revised December 26, 2024. This work was supported by the Key R&D and Promotion Special (Scientific Problem Tackling) Project of Anyang City (2023C01SF208).

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qualification of bidders[38].

As mentioned above, there is a lack of research on applying case-based reasoning technology to predict the economic indicators of PPP projects. The reasoning process of case-based reasoning aligns with human thinking. By searching for similar historical cases, it leverages prior experience or domain knowledge gained from solved problems to address new ones. The technology is intuitive, highly acceptable, free from rigid rules, and capable of gathering comprehensive case-related information. By combining qualitative and quantitative methods, predictions are made more objective, scientific, and reasonable. This study applies case-based reasoning technology, referencing and drawing from key project information in representative, reliable PPP projects to establish an economic indicator prediction model. This model is used for the preliminary forecasting of economic indicators, improving the efficiency of social capital follow-up in the early stages and aiding enterprises in making better judgments about the quality of PPP projects.

The structure of this study is as follows: Section 1 provides a comprehensive review of the research on the prediction of economic indicators and case-based reasoning techniques for PPP projects. Section 2 identifies the key factors influencing the economic indicators of PPP projects. Section 3 establishes an economic indicator prediction model for PPP projects based on case-based reasoning. Section 4 validates the model and analyzes the results through a case study. Finally, the study is summarized and concluded.

II. Main Influencing Factors of Economic Indicators in PPP Projects

When the conditions of the project change, the economic indicators will also change accordingly. Based on this, this paper identifies the key factors affecting the economic indicators of PPP projects, ensuring systematic, comprehensive, and objective analysis.

A. Project Attributes

Project attributes refer to the types, characteristics, and contents of a project, which help answer the fundamental question of "what project to undertake."

At the beginning of a project, it is essential to determine the project type, as each type requires different social resources. Additionally, different project types operate under distinct models. For example, in non-toll municipal engineering the income for the project company primarily comes from government payments. In contrast, for medical projects, income is generated by charging users for medical equipment or services. This fundamentally determines the return mechanism in a PPP project, which is crucial for calculating economic indicators.

PPP projects contracted by governments at different levels vary in terms of the fields involved, investment quotas, technical complexity, and risk exposure. In general, prefecture-level projects involve a broader range of fields, have larger investment quotas, are more technically complex, and carry higher risks compared to county- and district-level projects. Consequently, their impact on economic indicators is more significant.

Investment composition describes the specifics of a project from the perspective of capital demand. In China's PPP projects, most of the participating companies are construction enterprises, which tend to focus more on the project's engineering aspects, particularly the proportion of construction and installation costs. Typically, the fluctuation in construction and installation costs is much smaller than that of land acquisition, relocation, and other costs. Therefore, projects with a higher proportion of construction and installation costs are presumed to have a relatively smaller impact on economic indicators.

The investment cycle captures the time characteristics of different project stages from the perspective of time span. Generally, the longer the investment cycle, the slower the return of social capital, the more unpredictable factors there are, and the lower the economic indicators of the PPP project. Additionally, projects with different investment cycles attract different potential investors. For example, most investors tend to be more interested in PPP projects with a shorter cycle of 10-15 years.

B. Business Attributes

Business attributes encompass a collection of key elements involved in the promotion of project cooperation, addressing the fundamental question of "how to cooperate." The key stakeholders in this context include equity partners, financing partners, and other relevant parties.

The equity ratio represents a fundamental issue faced by all collaborators. In the context of PPP projects, the government representatives must clearly define their equity share in the project company. Different equity ratios reflect varying levels of influence and decision-making power the government holds within the company. When the government holds a higher degree of influence, it may hinder the social capital's ability to manage overall cash flow, particularly in aspects such as profit distribution and capital investment, which can negatively impact economic indicators. Furthermore, it is common for PPP project companies to have multiple social capital shareholders. Under otherwise unchanged conditions, a higher equity ratio signifies a greater financial commitment and, consequently, higher returns on investment. As a result, economic indicators fluctuate in accordance with the equity distribution.

In a PPP project, each participant acquires an equity stake through equity investment, with the ultimate objective of generating returns from the operational profits of the PPP project company [39]. The magnitude of the equity investments made by the participants directly affects the project's economic indicators.

When determining the capital ratio for a PPP project, the proportion of external financing is also established. Bank loans, being one of the primary sources of external financing for most projects, play a significant role. The capital ratio for most PPP projects typically ranges from 20% to 25%. However, for projects requiring special approval, such as rail transportation, the capital ratio needs to be analyzed on a case-by-case basis. Generally, the higher the capital ratio, the greater the amount of equity investment required from the social capital, which leads to a lower internal rate of return. On the other hand, a higher capital ratio results in lower bank loan amounts, leading to reduced interest payments and a higher investment net profit margin.

C. Investment Attributes

The investment attribute refers to the set of factors related to capital investment and recovery throughout the implementation process of a project, addressing the critical question of "how to implement it."

The repayment risk for social capital varies depending on the method of return generation in PPP projects. From the market risk perspective, the risk associated with user payment projects is the highest, followed by feasibility gap subsidy projects, with government payment projects posing the lowest risk. From the perspective of government credit, user payment projects typically do not involve any obligations related to government payments, while government payment projects carry the highest repayment risk, followed by feasibility gap subsidy projects. For "risk-averse" social capital, economic indicators are often calculated by considering only the portion of returns with lower risk when estimating income, while the portion with greater uncertainty is usually disregarded. This represents a conservative approach commonly adopted in measuring economic indicators for PPP projects. Conversely, "risk-seeking" social capital adopts a different approach. Thus, different methods of return generation lead social capital to adopt varying measurement strategies, resulting in significant differences in economic indicators.

When the government investment entity is excluded from profit distribution, an additional dividend ratio is applied to social capital. Under unchanged conditions, the higher the additional dividend ratio, the greater the economic indicators for social capital. In the context of PPP projects, the government typically enhances project quality and increases the willingness of social capital to participate in bidding by ensuring that government investment entities do not share in profit distribution.

There is a positive relationship between post-tax net profit and key economic indicators. An increase in post-tax net profit typically improves economic indicators and is widely regarded as enhancing the economic feasibility of PPP projects. This is because it positively affects multiple economic indicators, increases investor return potential, and makes the project more attractive.

The benchmark income formula refers to the total annual income expected to be generated by the project company when using government payment or feasibility gap subsidies as a revenue model. Common formulas for this calculation include the Caijin No. 21 formula, the equal principal and interest formula, and the equal principal formula. When the benchmark income is constant across years, the economic indicators calculated using the equal principal method are the highest, followed by the equal principal and interest method, while those derived from the Caijin No. 21 formula are the lowest. Furthermore, parameters such as the annual discount rate, reasonable profit rate, annualized rate of return, and capital cost rate in the benchmark income calculation directly affect the project company’s revenue and economic indicators. The higher these parameters, the greater the income and the better the economic indicators. As for metrics like unit price and fee base, they are typically considered only for user-pay projects, in which higher unit prices and fee bases result in better economic indicators. For non-government-backed pure commercial projects, user payments serve as the sole source of income for the project company, making unit price and fee base the key factors determining the revenue. For other PPP projects, whether the revenue comes from user payments, feasibility gap subsidies, or government payments, there is always a benchmark for the project company’s expected annual income, calculated using the benchmark income formula. This benchmark is calculated using the benchmark income formula, and some indicators transmit the impact to the benchmark income formula, such as the annualized rate of return and annual discount rate. The calculation results of the benchmark income formula have a concentrated impact on the internal rate of return generated out of all the investments. The annualized rate of return, annual discount rate, and other parameters, as well as indicators like unit price and fee base, affect the benchmark income formula’s output, which in turn influences the internal rate of return of all investments. Moreover, there is a significant linear correlation between various benchmark income calculation parameters such as annual discount rate and annualized rate of return, along with the indicators such as fee unit price, fee base, and the internal rate of return of all investments. Given the variations in these parameters across different projects, along with the potential lack of user payments or non-standardized benchmark income formulas, the investment attributes of different projects are not directly comparable. Therefore, to enhance comparability across different PPP projects, this paper proposes consolidating the benchmark income formula, annualized rate of return, annual discount rate, charge unit price, charge base, and other factors while retaining only the internal rate of return for all investments.

D. Construction Attributes

In the context of PPP projects in China, construction companies frequently exhibit a strong preference for participating in such projects. A common scenario involves a construction company acting as a shareholder in the project company. Consequently, their financial returns are not solely derived from investment gains but also significantly from general contracting activities. Upon receipt of general contracting payments from the project company, a portion of this revenue is allocated to labor, materials, and machinery companies. Following the deduction of management fees and applicable taxes, the remaining amount constitutes the net profit from general contracting. This profit is typically represented by the net profit margin of general contracting, which characterizes the construction attributes. Higher net profit margins correspond to improved economic indicators for social capital, while lower margins suggest weaker economic performance.

E. List of Key Characteristic Factors

Based on the previous analysis, a list of key characteristic factors that influence the economic indicators of PPP projects has been identified, as shown in Table I. These economic indicators include the internal rate of return (IRR) for investors, the investment net profit margin, among others. The primary economic indicator examined in this context is the investment net profit margin, which serves as a reflection of the project's income level. The same predictive methodology is applicable when analyzing other economic indicators.

TABLE I
CHARACTERISTIC FACTORS AFFECTING ECONOMIC INDICATORS OF PPP PROJECTS

Factor Categories	Factor Attributes	Key Characteristic Factors
Influence Factors	Project Attributes	Project Type
		Level of Government Contracting Authority
		Cooperation Cycle
		Ratio of Construction and Installation Cost
	Business Attributes	Group Equity Ratio
		Total Equity Investment
		Capital Ratio
	Investment Attributes	Revenue Model
		Extra Dividend Ratio
		Net Profit After Tax
		All Investments' Internal Rate of Return
	Construction Attributes	Net Profit Margin of General Contracting
Economic Indicator	Level of Project Benefits	Investment Net Profit Margins

III. ECONOMIC INDICATORS PREDICTION MODEL FOR PPP PROJECTS BASED ON CASE-BASED REASONING

Leveraging the strengths of case-based reasoning and the specific requirements of predicting economic indicators for PPP projects, this paper constructs a predictive model tailored for this purpose. Each of the five steps in the case-based reasoning process is discussed in detail.

A. Case Description and Representation

Case-based reasoning involves identifying historical cases from a case library that resemble the target case, leveraging past solutions, experiences, or domain knowledge to address new problems. The first step in developing the model is to establish a robust case database guided by unified rules and organization. This database should include historical cases sharing the same attributes as the new issues being considered. When selecting case attributes, it is crucial that these attributes serve as effective retrieval cues and possess sufficient representativeness. Additionally, the attribute count must be balanced to maintain the efficiency of the case-based reasoning process.

In this study, we have identified 12 key characteristics that significantly influence the economic indicators of PPP projects, through methods such as data aggregation, literature analysis, principal and secondary factor analyses, combined with expert opinions (see Table I). This selection lays a foundation for effective case retrieval. These characteristics are categorized into subjective and objective factors; for instance, objective factors include project type, the level of contracting authority, and cooperation cycle. Through correlation analysis, we further categorize these characteristics into quantitative and qualitative factors. During the case-based reasoning process, it is necessary to quantify qualitative factors and standardize dimensions, which will facilitate the correlation analysis of characteristic factors and computation of characteristic weights.

B. Case Library Construction

Based on the characteristics of PPP projects, information regarding projects with shared attributes, which are undertaken by the group, is thoroughly examined, organized, and systematically recorded into the case library. The effective application of case-based reasoning technology necessitates structured case representation, typically achieved through methods such as first-order predicate logic, semantic networks, frameworks, and object-oriented approaches. Additionally, the case library must be designed for scalability. Target cases that exhibit high similarity to source cases are stored within the library. As the volume of cases grows, it is essential to merge, delete, replace, or to optimize similar cases to minimize redundancy. This process enhances the efficiency and accuracy of case-based reasoning.

C. Case Retrieval

The goal of case retrieval is to identify cases or case sets from the case library that are aligned with new problems in terms of shared attributes. Common retrieval algorithms in case-based reasoning include inductive indexing, knowledge-guided retrieval, and the K-nearest neighbor (K-NN) method. This study employs a method that integrates preliminary and advanced retrieval processes. Initially, the preliminary search uses the knowledge-guided method to locate PPP project cases within the case library that exhibit the same characteristic features as the source case. Subsequently, the advanced retrieval utilizes the K-nearest neighbor method to pinpoint candidate cases closely resembling the target cases among the source cases. Finally, the economic indicators derived from these candidate cases are employed to forecast the economic indicators of the target cases. Case retrieval serves as the cornerstone of the PPP projects' economic indicator prediction model within the framework of case-based reasoning. The efficiency and accuracy of the case retrieval algorithm are crucial determinants of the predictive performance of the case-based reasoning approach.

1) Determination of Characteristic Factor Weights in Cases

Similarity is categorized into local similarity (similarity among characteristic factors) and comprehensive similarity (similarity among cases). The comprehensive similarity between cases is calculated as the sum of the products of the local similarities of characteristic factors and their corresponding weights.

$$SIM\left(T,S_i\right)=\sum_{j=1}^{n}\omega_j SIM\left(T_j,S_{ij}\right), \tag{1}$$

where i denotes the number of source cases, j denotes the number of characteristic factors, ω_j denotes the weight value associated with the j-th characteristic factor, $SIM(T_j,S_{ij})$ denotes the similarity between characteristic factors, and $SIM(T,S_i)$ denotes the similarity between cases.

The computation of local similarity varies depending on the attributes of the characteristic factors. To facilitate the determination of weights for each characteristic factor, the qualitative characteristics among the 12 factors are quantified through an attribute classification methodology, as detailed in Table II.

In the case retrieval process, data mining methods and SPSS software are applied to remove noisy data, standardize the data using Z-scores, and perform dimensionality reduction on the preliminary case dataset. This enhances retrieval efficiency and ensures that the retrieved candidate cases are more similar to the target case for better matching [40].

The weights of characteristic factors in a case can be calculated using the Analytic Hierarchy Process and the Correlation Coefficient Matrix method. After data cleaning, the dataset of the source cases undergoes correlation analysis through SPSS software to construct a correlation coefficient matrix of the characteristic factors. This allows the identification of the correlation coefficients between the key characteristic factors influencing economic indicators and the indicators themselves, from which the weight of each characteristic factor is calculated.

Following the construction of the correlation coefficient matrix using SPSS, the correlation coefficients between the key characteristic factors and the economic indicators are analyzed. Characteristic factors with small correlation coefficients are excluded, and only those with higher correlation coefficients are retained, thereby improving the efficiency of case retrieval.

2) Calculation of Case Similarity

Two methods are commonly used to calculate case similarity. The first method involves calculating the local similarity of characteristic factors along with their subjective and objective weights. Subsequently, the combined subjective and objective weights are computed to determine the comprehensive similarity. The second method uses the weighted Euclidean distance. Euclidean distance is the straight-line distance between two points in multidimensional space and quantifies the magnitude of differences between measurement results. In this paper, the weighted Euclidean distance method is employed to calculate the similarity between cases. The similarity *SIM* (*T*, *S*) between cases ranges from 0 to 1. The greater the distance between the source and target cases, the lower their similarity, and vice versa.

The distance between the target case a_i and the completed PPP project case b_j in the database is denoted as $S(a_i,b_j)$, and the calculation using the Euclidean distance method is expressed as follows:

$$S\left(a_i,b_j\right)=\sqrt{\sum_{k=1}^{p}\left(\omega_k\left(v_{jk}-v_{ik}\right)\right)^2}, \tag{2}$$

where p is the number of comparison attributes, k is the number of characteristic factors, ω_k denotes the weight of characteristic factors, v_{jk} refers to the attribute value of the k-th characteristic factor of the j-th source case, and v_{ik} represents the attribute value of the k-th characteristic factor of the i-th target case.

Then, the maximum distance between the source case and the target case is denoted as D_{max}. The distance between the j-th source case and the target case is denoted as D_m (m=1,2,3, ..., j), and these distances are ranked in ascending order as D_1, D_2, D_3, ..., D_j. The similarity calculation formula between the source case and the target case is expressed as follows:

$$SIM\left(a_i,b_j\right)=1-\frac{D_j}{D_{\max}}. \tag{3}$$

The value of $SIM\ (a_i,b_j)$ lies within the interval [0, 1]. A higher value indicates a greater similarity between cases. During the case retrieval process, source cases with higher similarity rankings are selected as candidate cases to predict the economic indicators of the target cases. Conversely, a lower value indicates less similarity between the cases.

If, after ranking the calculated similarities in descending order, the maximum similarity remains below the preset threshold, adjustments should be made to the selection of characteristic factors, the correlation coefficients of these factors, and the weight values of these characteristic factors within the source cases. After making these adjustments, case retrieval is repeated until a source case meets the criteria to be selected as a candidate. Specifically, this means that the similarity between the source case and the candidate case exceeds the preset threshold.

D. Reuse of Case

Case reuse is the process of obtaining a solution to the problem to be solved by utilizing the solution set of candidate cases. The calculated similarity between cases is ranked in descending order, and the economic indicators of the candidate cases that exceed the threshold in terms of similarity are predicted using exponential smoothing as the economic indicator forecast for the target case. Although case-based reasoning is not typically associated with time series analysis prediction, the exponential smoothing method can still be applied to calculate the prediction for the target case. It is expressed as follows:

$$\begin{aligned}E&=\overline{E}+SIM\left(T,S_1\right)\left(E_1-\overline{E}\right)\\&+SIM\left(T,S_2\right)\left[1-SIM\left(T,S_1\right)\right]\left(E_2-\overline{E}\right)+\cdots\\&+SIM\left(T,S_k\right)\left[1-SIM\left(T,S_1\right)\right]\left[1-SIM\left(T,S_2\right)\right]\\&\cdots\left[1-SIM\left(T,S_{k-1}\right)\right]\left(E_k-\overline{E}\right),\end{aligned} \tag{4}$$

where $\overline{E}$ represents the arithmetic average of the economic indicators of the candidate case, E_k represents the economic indicators of the k-th candidate case, and $SIM(T,S_k)$ represents the similarity between the k-th candidate case and the target case.

E. Case Adjustment and Refinement

When predicting the economic indicators for new projects, it is crucial to refine and adjust the predicted indicators derived from reasoning, following case retrieval and case reuse. The results of qualitative analysis are then integrated to produce more realistic economic indicators. Common methods for case adjustment include model guidance, derivative replay, re-instantiation, and parameter adjustment. During the reasoning process, a deviation may arise between the predicted and actual values. In such cases, the predicted values should be refined based on prior experience, expert knowledge, the influence of key factors on the economic indicators, collected intelligence, risk tolerance, and the construction of the engineering supply chain. This process aims to bring the predicted values as close as possible to the actual values.

F. Case Storage and Learning

When the economic indicators obtained through case reasoning are practical and the relative error compared to the actual indicators of the target case is minimal, the target case is treated as a new case and stored in the database. In future situations with similar issues, this new case can serve as a source case to help to resolve the problem. Through incremental learning, the database improves the accuracy of economic indicator predictions based on case reasoning, while continuously incorporating more cases into the database.

IV. Case Study on the Prediction of Economic Indicators in PPP Projects

In recent years, Z Group has actively engaged in the implementation of PPP projects. Initially, 42 cases were compiled in which Z Group had successfully secured bids and directly participated in project execution. Following a meticulous review and verification process of the case-related information, 12 projects were removed due to having been excluded from the PPP database or discontinued by Z Group for various reasons. Consequently, 30 project cases were retained for detailed research and analysis.

A. Reliability and Representativeness of Data on PPP Cases

To ensure the credibility of the research outcomes, it is essential that the case data not only possess reliability but also demonstrate a high degree of representativeness.

1) Evaluating the Reliability of PPP Project Data

The 30 PPP projects examined in this study have been incorporated into the PPP Central Project Management Database. Within this repository, each project has successfully undergone comprehensive value-for-money evaluations and financial affordability analyses. Concurrently, local governments are subjected to multiple layers of rigorous scrutiny and auditing during the submission process to the PPP center. Consequently, it can be inferred that projects in this database carry official endorsement, adhere to procedural legitimacy, comply with the standards of government-enterprise cooperation, and provide reliable project data.

Moreover, these projects have also passed the stringent investment evaluation and decision-making process dictated by the Z Group. Initially, regional companies perform the first round of project detail verification and submit a feasibility report to upper management for review. Subsequently, this report is forwarded to the Z Group's Investment Evaluation and Decision-making Committee for further assessment. Throughout this multistage process, project details are meticulously verified to ensure information accuracy and validity. Hence, the case data selected for this study are thoroughly vetted and deemed reliable.

2) Evaluating the Representativeness of Selected PPP Project Data

The selected pool of 30 PPP projects in this study encompasses a wide range of pertinent information. The selected projects exhibit a distribution of types, levels of government contracting authority, and revenue model that align closely with those documented in the national PPP project management database. Municipal engineering, transport infrastructure, and government infrastructure projects respectively account for 30%, 23%, and 20% of the sample. Additionally, sectors such as affordable housing projects, healthcare projects, urban comprehensive development, and educational projects collectively account for 27% of these projects. Moreover, the projects exhibit diverse and essential metrics including cooperation cycle, total equity investment, and capital ratio, effectively encompassing the typical ranges for standard PPP projects. For instance, the cooperation cycle spans from 10 to 33 years, and total equity investments range from 232 million yuan for smaller projects to 19.4 billion yuan for larger ones. Thus, the selected PPP project data in this study are highly representative.

B. Case Description

A knowledge-guided preliminary search was conducted to select 30 reliable and representative PPP projects from a curated repository. Building on these findings, the selected cases were comprehensively analyzed based on 12 previously identified key characteristics. Additionally, a case-based reasoning model was integrated to predict the economic indicators of PPP projects, ensuring a systematic and thorough approach to case description.

C. Case Retrieval

The boxplot function in SPSS was used to analyze the net profit margins of 30 selected PPP projects, identifying two outliers (Fig. 1). Specifically, the net profit margins for the 21st and 27th cases were found to deviate significantly from the normal range. After removing these outliers, the boxplots grouped by project type showed that all values fell within the expected range (Fig. 2). Consequently, the dataset's dimensions were reduced from 30×12 to 28×12.

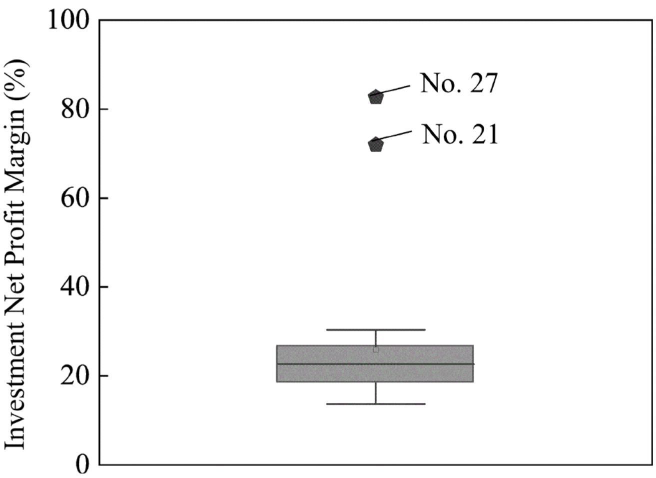

Fig. 1. Box Plot of the Investment Net Profit Margin

Secondly, due to differences in the units of characteristic factors and economic indicators, it is necessary to standardize the quantitative data to ensure comparability and facilitate correlation analysis between these variables and indicators. The dataset was standardized using the Z-Score function in SPSS software. The standardized dataset is presented in Table III.

Next, SPSS software was used to perform a correlation analysis on the standardized dataset, resulting in a correlation coefficient matrix between the variables and the investment net profit margin of economic indicators (Table IV). If the absolute value of a correlation coefficient is less than 0.3, it indicates a weak correlation between the variable and the investment net profit margin. Weakly correlated variables are excluded, reducing the number of key variables from 12 to 6. After dimensionality reduction, the dataset's dimensions are reduced from 28×12 to 28×6.

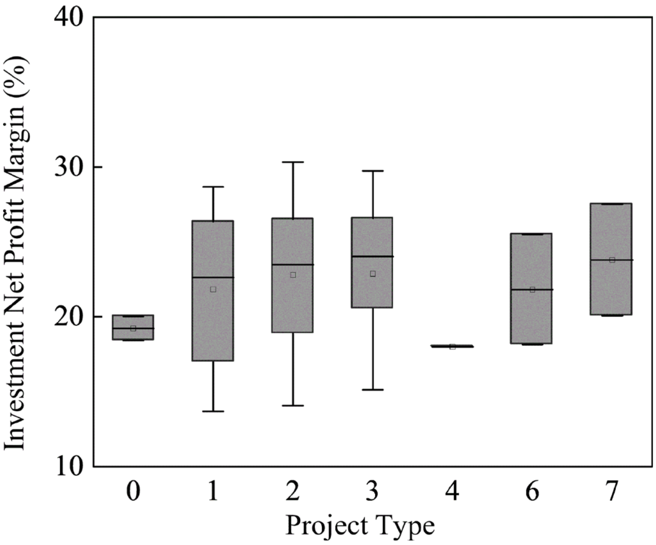

Fig. 2. Box Plot of the Investment Net Profit Margin Categorized by Project Type

Finally, the weight of 6 key characteristic factors is calculated separately (Table V). With the 30th case as the target case, the distance between the source case and the target case is measured using the Euclidean distance method (2) and (3) to determine the similarity between the cases (Table VI).

TABLE V
WEIGHT VALUE OF KEY CHARACTERISTIC FACTORS

Key Characteristic Factor	Correlation Coefficient with Investment Net Profit Margin	Absolute Value of Correlation Coefficient	Weight Value
Level of Government Contracting Authority	0.312	0.312	0.127
Revenue Model	0.444	0.444	0.181
Group Equity Ratio	-0.486	0.486	0.198
Total Equity Investment	-0.381	0.381	0.155
Net Profit After Tax	-0.353	0.353	0.144
Net Profit Margin of General Contracting	0.476	0.476	0.194

D. Case Reuse

In this study, a threshold of 0.75 was established, and the cases with the highest similarity rankings were identified through the case retrieval results. These cases were 14, 11, 9, 2, 10, 24, and 15, with respective similarity scores of 0.909, 0.870, 0.845, 0.830, 0.824, 0.823, and 0.776. These seven cases were selected as reference cases for predicting the economic indicators of the target case. Exponential smoothing (4) was applied, yielding a predicted investment net profit margin of 20.44%. In comparison, the actual investment net profit margin for the 30th case was 18.87%. The relative error between the predicted and actual values was calculated as 8.30%, which falls within the acceptable margin of error.

E. Case Revision and Adjustment

The predicted values serve only as preliminary economic indicators. To refine these predictions, it is essential to integrate both subjective and objective considerations, including internal dynamics and external influences on economic indicators. The final economic indicators are derived through a combination of quantitative and qualitative analysis, informed by insights from similar projects and practical engineering experience.

TABLE VI
SIMILARITY BETWEEN SOURCE AND TARGET CASES

Case Number	Distance Between Target and Source Case	Case Similarity
1	0.330	0.720
2	0.201	0.830
3	0.484	0.589
4	0.518	0.560
5	0.366	0.689
6	1.178	/
7	0.496	0.579
8	0.528	0.552
9	0.182	0.845
10	0.207	0.824
11	0.154	0.870
12	0.506	0.570
13	0.703	0.404
14	0.108	0.909
15	0.264	0.776
16	0.361	0.693
17	0.542	0.540
18	0.424	0.640
19	0.511	0.566
20	0.738	0.374
22	0.297	0.748
23	0.539	0.543
24	0.209	0.823
25	0.315	0.733
26	0.296	0.749
28	0.461	0.608
29	0.486	0.587

F. Case Storage and Learning

Given the notable accuracy of the prediction results, the 7 selected candidate cases can be incorporated into the case repository to guide future predictions of economic indicators in similar PPP projects. The results above are derived from analyzing case 30 as the target case. When each of the 28 cases is individually treated as the target case, the same methodology is applied to predict the investment net profit margin (Table VII). Excluding one case due to the absence of candidate cases, the average error between the predicted and actual values across the remaining 27 target cases is -0.07%. These findings further validate the effectiveness of the case-based reasoning model in predicting the economic indicators of PPP projects.

V. CONCLUSION

This study addresses the inefficiency and inconsistent quality of investment assessments among private sector participants in current PPP projects. To tackle these issues, we propose a case-based reasoning model for predicting economic indicators in PPP projects. The validity and practicality of the model have been demonstrated through real-world case studies. Compared to other advanced methodologies, the proposed case-based reasoning model presents several key advantages: it is straightforward, adaptable, and capable of accommodating diverse real-world scenarios, thereby supporting rapid and informed decision-making. Moreover, its incremental learning mechanism allows the model to evolve and refine itself as new data becomes available, ensuring improved alignment with actual project conditions over time. Nevertheless, certain limitations must be acknowledged. First, the model's predictive accuracy may be constrained by an insufficient sample size. Second, the subjective nature of feature selection and weight assignment could introduce potential biases. Future research should focus on addressing these limitations to enhance the robustness and reliability of the model.

TABLE II
QUANTIFICATION OF THREE QUALITATIVE FACTORS INFLUENCING ECONOMIC INDICATORS

QUALITATIVE CHARACTERISTIC FACTORS	QUANTIZATION STANDARDS							
	0	1	2	3	4	5	6	7
PROJECT TYPE	AFFORDABLE HOUSING PROJECT	GOVERNMENT INFRASTRUCTURE	TRANSPORT INFRASTRUCTURE	MUNICIPAL ENGINEERING	EDUCATIONAL ENGINEERING	URBAN COMPREHENSIVE DEVELOPMENT	HEALTHCARE PROJECT	OTHER
LEVEL OF GOVERNMENT CONTRACTING AUTHORITY	PREFECTURE LEVEL	COUNTY AND DISTRICT LEVEL	TOWNSHIP LEVEL					
REVENUE MODEL	USER PAYMENT	GOVERNMENT PAYMENT	FEASIBILITY GAP SUBSIDY					

TABLE III
KEY CHARACTERISTIC FACTORS FOLLOWING DATA NOISE PROCESSING AND STANDARDIZATION

Case Number	Project Type	Level of Government Contracting Authority	Revenue Model	Cooperation Cycle	Ratio of Construction and Installation cost	Group Equity Ratio	Total Equity Investment	Capital Ratio	Extra Dividend Ratio	Post-tax Net Profit	All Investments' Internal Rate of Return	Net Profit Margin of General Contracting	Investment net profit margin
1	0	1	0	0.0000	1.2178	0.1780	-0.3673	0.8462	0.9900	-0.5990	-1.2482	0.1456	-0.7894
2	1	1	1	-0.8095	-0.8028	0.1780	0.3407	-0.4812	-0.5084	0.4407	-1.9398	-1.2025	-1.7793
3	1	2	2	-0.1619	0.8810	-0.7086	-0.0308	-0.1493	2.4883	0.0922	-0.7331	0.4599	0.8722
4	2	1	2	-0.8095	-0.2135	1.0646	-0.0822	-0.4812	-0.5084	-0.1610	-0.5713	1.2300	-0.2202
5	3	2	1	-0.8095	1.2178	0.6213	-0.1014	-0.1493	-0.5084	-0.1020	2.8868	0.5211	0.3846
6	2	0	1	-0.8095	-0.2977	1.0646	4.9207	-0.4812	-0.5084	4.3824	0.3999	0.9943	-1.7018
7	3	1	1	-0.8095	0.2075	0.9759	0.4562	-0.4812	-0.5084	0.8044	0.7384	1.0222	0.3846
8	2	1	1	-0.1619	-1.0554	0.9759	-0.1081	-0.4812	-0.5084	-0.0620	0.2822	1.4623	0.7613
9	4	1	1	0.8095	1.2178	1.0646	-0.4275	-0.4812	-0.5084	-0.6771	-0.3064	-0.3870	-0.8752
10	3	1	1	-0.8095	0.4601	0.1780	0.1615	-0.1493	-0.5084	0.6273	0.6648	-1.2025	-0.9547
11	3	1	1	-0.8095	0.5443	0.1780	0.0114	-0.1493	-0.5084	0.2293	0.1498	-1.2025	-1.4779
12	7	1	2	0.8095	-0.2977	-1.5953	0.1419	-0.4148	-0.5084	0.5378	0.6795	-1.2025	-0.4441
13	1	1	1	-0.8095	1.2178	-2.4819	-0.4506	-0.1493	-0.5084	-0.6447	-0.5713	0.5438	1.3577
14	3	1	1	0.4857	-0.3819	0.1780	-0.2273	-0.0830	0.9900	-0.1382	-0.2181	-1.2025	-0.2599
15	2	1	1	1.4572	0.4601	-0.7086	-0.4697	-0.4812	-0.5084	-0.6371	0.0468	-1.2025	0.9057
16	0	2	2	-0.8095	-0.7187	1.0646	-0.3856	0.7135	-0.5084	-0.6066	0.4441	0.1945	-0.4525
17	3	2	2	0.8095	-1.4764	-0.7086	-0.4244	-0.1493	2.4883	-0.5857	-0.4094	0.9506	1.5817
18	3	1	2	3.0762	-0.1293	0.1780	-0.1101	-0.1493	-0.5084	-0.0449	-1.0274	0.6695	0.9162
19	1	1	2	-0.8095	1.2178	-0.7086	-0.4025	-0.1493	-0.5084	-0.6085	-1.0863	0.8528	0.0288
20	2	0	2	-0.8095	-2.3183	-1.9676	-0.3038	4.8285	-0.5084	-0.3343	1.0768	1.2719	1.7030
22	1	2	1	-0.8095	1.2178	0.6213	-0.4014	-0.1493	-0.5084	-0.6009	1.2240	0.1788	0.1565
23	6	1	2	-0.8095	0.2075	1.0646	-0.3977	-0.1493	-0.5084	-0.5724	0.9444	1.3715	0.6922
24	3	0	1	0.4857	-1.4764	0.1780	0.0235	0.1825	0.9900	0.3341	-1.5278	-1.2025	-0.3437
25	6	1	2	-0.1619	1.2178	1.0646	-0.4568	-0.1493	-0.5084	-0.7133	0.3411	0.0356	-0.8480
26	1	0	1	1.4572	-1.3922	-0.7086	-0.2599	-0.3484	-0.5084	-0.2677	-1.1746	-1.2025	-1.0887
28	3	1	2	0.3238	-0.1293	-0.7086	-0.4570	-0.4812	2.4883	-0.6638	0.2086	0.5071	1.0669
29	7	2	2	1.4572	-0.8028	-1.1519	0.1998	-0.0830	-0.5084	1.1015	0.4441	-1.2025	1.1171
30	2	1	1	-0.1619	0.2075	0.6213	-0.3915	-0.1493	0.2408	-0.5305	0.2822	-1.2025	-0.6931

TABLE IV
CORRELATION COEFFICIENT MATRIX BETWEEN KEY CHARACTERISTIC FACTORS AND INVESTMENT NET PROFIT MARGIN

	Project Type	Level of Government Contracting Authority	Revenue Model	Cooperation Cycle	Ratio of Construction and Installation Cost	Group Equity Ratio	Total Equity Investment	Capital Ratio	Extra Dividend Ratio	Post-tax Net Profit	All Investments' Internal Rate of Return	Net Profit Margin of General Contracting	Investment Net Profit Margin
Project Type	1	0.053	0.399*	0.286	-0.037	-0.014	-0.010	-0.156	-0.131	0.121	0.344	-0.169	0.103
Level of Government Contracting Authority	0.053	1	0.239	-0.040	0.356	0.072	-0.339	-0.254	0.213	-0.295	0.312	0.076	0.312
Revenue Model	0.399*	0.239	1	0.137	-0.247	-0.215	-0.153	0.153	0.124	-0.128	0.102	0.326	0.444*
Cooperation Cycle	0.286	-0.040	0.137	1	-0.226	-0.225	-0.167	-0.173	0.157	-0.099	-0.316	-0.316	0.220
Ratio of Construction and Installation Cost	-0.037	0.356	-0.247	-0.226	1	0.203	-0.116	-0.406*	-0.110	-0.191	0.158	0.024	-0.162
Group Equity Ratio	-0.014	0.072	-0.215	-0.225	0.203	1	0.216	-0.349	-0.189	0.144	0.151	0.150	-0.486**
Total Equity Investment	-0.010	-0.339	-0.153	-0.167	-0.116	0.216	1	-0.132	-0.144	0.958**	0.068	0.123	-0.381*
Capital Ratio	-0.156	-0.254	0.153	-0.173	-0.406*	-0.349	-0.132	1	-0.038	-0.142	0.164	0.216	0.299
Extra Dividend Ratio	-0.131	0.213	0.124	0.157	-0.110	-0.189	-0.144	-0.038	1	-0.166	-0.262	0.054	0.294
Net Profit After Tax	0.121	-0.295	-0.128	-0.099	-0.191	0.144	0.958**	-0.142	-0.166	1	0.080	-0.009	-0.353
All Investments' Internal Rate of Return	0.344	0.312	0.102	-0.316	0.158	0.151	0.068	0.164	-0.262	0.080	1	0.217	0.229
Net Profit Margin of General Contracting	-0.169	0.076	0.326	-0.316	0.024	0.150	0.123	0.216	0.054	-0.009	0.217	1	0.476*
Investment Net Profit Margin	0.103	0.312	0.444*	0.220	-0.162	-0.486**	-0.381*	0.299	0.294	-0.353	0.229	0.476*	1

Note: "*" denotes significant correlation at the 0.05 level(two-tailed), "**" denotes significant correlation at the 0.01 level(two-tailed).

TABLE VII
PREDICTION RESULTS OF ECONOMIC INDICATORS FOR 28 TARGET CASES

Target Case	Investment Net Profit Margin for the Target Case (%)	Candidate Cases (Descending Similarity)	Arithmetic Average of Investment Net Profit Margin for the Candidate Case (%)	Predicted Investment Net Profit Margin (%)	Prediction Error (%)
1	18.41	22/5/9	21.65	22.91	24.44
2	13.68	10/11/14/24/30	18.62	17.54	28.21
3	26.35	17/28/19/18	26.48	29.31	11.23
4	21.13	23/8/18/7/16/25	23.34	25.52	20.76
5	24.02	22/16/8/7/18/9/1	22.25	22.75	-5.28
6	14.05	——	——	——	——
7	24.02	8	25.82	25.82	7.49
8	25.82	7/4/23/5	23.67	23.65	-8.39
9	18.00	30/22/25/16/14/5/1/11	19.81	19.40	7.78
10	17.62	2/11/14/24/30	17.83	13.75	-21.98
11	15.12	2/10/14/24/30/15/26	19.31	13.91	-8.02
12	20.06	29	27.52	27.52	37.19
13	28.67	20	30.32	30.32	5.76
14	20.94	11/30/2/10/24/15/26/9	18.42	15.31	-26.90
15	26.51	26/14/11/30/2/24/10	17.68	17.34	-34.60
16	20.02	25/22/5/9/4/18/23	22.32	18.68	-6.67
17	27.74	19/3/28/18	25.63	22.77	-23.45
18	26.56	19/28/4/3/23/5/25/17/16	23.83	23.08	-13.11
19	22.32	28/17/3/18	27.48	27.40	22.77
20	30.32	13/19	25.50	28.32	-6.59
22	22.93	5/9/16/1/25/18	20.86	23.48	2.38
23	25.49	4/8/18/25/16	22.33	21.46	-15.81
24	20.54	11/10/2/14/26/30	17.20	15.37	-25.15
25	18.13	16/9/22/18/4/23/5	22.59	19.90	9.75
26	16.98	15/24/14/11/2/10/30	19.04	25.78	51.83
28	27.28	19/17/3/18	26.24	22.72	-16.71
29	27.52	12	20.06	20.06	-27.11
30	18.87	14/11/9/2/10/24/15	18.92	20.44	8.30

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