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Analysis of synergy degree and its influencing factors in hydropower EPC project management

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Abstract The use of engineering procurement construction (EPC) mode is currently a trend in hydropower engineering construction. The clarification of the internal relationship between hydropower EPC projects and the realization of synergy has great significance in improving management efficiency and implementation effect. In this work, a three-dimensional system and a system model of hydropower EPC project management synergy are constructed. The mechanism and factors that influence the degree of management synergy are analyzed on the basis of management synergy theory. Furthermore, the evaluation index system and the degree of synergy model are established, and grey relational analysis is utilized to identify the key factors that affect the synergy degree. Thus, this study aims to facilitate the hydropower EPC project management synergy, provide a quantitative method for synergy degree evaluation, and propose corresponding promotion strategies. Results show that the order degree of each subsystem presents a steady upward trend. Specifically, the order degree of the subsystem at the trial operation stage is low, which is the major restriction on the further improvement of the synergy degree of EPC project management. The key factors in improving the synergy level of hydropower EPC project management are mainly concentrated in the information and organization synergy subsystems, includ-

ing the construction degree of information platform, the performance of functions, the timeliness of information transfer, and the functions of the information platform.

Keywords hydropower project, EPC mode, synergy degree model, grey relational analysis

1 Introduction

The research on engineering procurement construction (EPC) project management is becoming increasingly mature, but problems on the related management synergism remain. Given the high cost of construction management, the poor communication among organization members, the separation of management links, the separation of management business, and the low management efficiency caused by the lack of synergy in project management, achieving EPC project management synergy and improving the efficiency of project management have become urgent issues that must be addressed.

German physicist Hermann Haken proposed “synergetics”. He believed that subsystems exist in a scientific complex system with orderly and self-organized collective behavior under the control of general laws. Meanwhile, subsystems and their elements transform from being disordered to ordered through internal synergy under the condition of constantly exchanging materials and information with the external environment (Liu, 1989). The synergy degree is orderly in the process of measuring the subsystems and elements of the system in the synergistic mechanism. Previous research on project management synergy mainly focused on aspects, such as organization synergy, process synergy, influencing factors, and synergy model. For instance, Masi et al. (2013), Peña-Mora and Tamaki (2001), Cheng et al. (2003) and Rahman et al. (2014) analyzed the traditional project management mode. They discovered that the synergy of the organizational relationship among project participants indirectly improves the quality of a project and built a synergy evaluation model, thus providing some reference for the optimization

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of the organizational structure (Ahcom, 2002; Cheung et al., 2002; Pavitt and Gibb, 2003). By virtue of the in-depth analysis of the entire process of traditional project management, Chen et al. (2003) proposed new project management modes based on process synergy and concurrent engineering theories separately, offering implications for solving non-synergy in the current process. Furthermore, Mao et al. (2010), Xu and Xu (2012), Yu et al. (2012) and Niu et al. (2014) summarized the characteristics of project management and established the organizational frameworks of different project teams. Ding (2009), Yue and Yu (2011), He and Luo (2014), Jiang and Zhu (2015), Xue et al. (2015), and Li and Fei (2016) used different methods for identifying and evaluating engineering project management synergy from different dimensions and perspectives, selected the sequence parameters, and constructed synergy index systems, all of which are project management synergy. The aforementioned literature covers most of the influencing factors and systematic models of project management synergy, but mainly concentrates on the abstract concepts and mathematical models of large-scale project group management synergy. The research on the application of management synergy in hydropower EPC projects and on systematic pertinence to the concept and quantification of hydropower EPC project synergy management is limited. The research on the synergy model, which is not conducive to maximizing the advantages of EPC project management, is also relatively scarce.

This paper analyzes the importance of engineering construction organization structure in the entire project management process. We construct a three-dimensional (3D) system and a system model of collaboration, and analyzes the synergy mechanism using management synergy theory based on the characteristics of the three dimensions of management organization, process, and business. On this basis, the factors that influence the hydropower EPC project management synergy are identified, and the synergy degree model is designed. The evaluation index system and the synergy degree measurement model are used to identify the key factors that affect the synergy degree through the grey correlation analysis. Finally, corresponding promotion strategies are proposed to provide a quantitative method for evaluating the synergy degree of hydropower EPC project management, and suggestions are given for improving the management efficiency and the implementation effect.

2 Synergetic mechanism of hydropower EPC project management

The level of project management synergy directly affects the control effect of the project and guarantees the improvement in project management efficiency and the achievement of the project objectives. This study investi-

gated the mechanism of hydropower EPC project management synergy by establishing a 3D system of hydropower EPC project management and its model. Consequently, this work serves as a basis for the establishment of a hydropower EPC project management synergy evaluation model.

2.1 3D system of hydropower EPC project management synergy

The hydropower EPC project was taken as the research object given the project objectives based on Hall's construct of the 3D structure and the principles of management synergy. From the perspective of the general contractor, the synergy in all dimensions was investigated, and a 3D system of the hydropower EPC project management synergy was established (Fig. 1). This synergy was developed from three dimensions, namely, the organization, process, and business dimensions. The organization dimension is the main body, the business dimension is the object, and the process dimension is the basis of management synergy.

2.2 Hydropower EPC project management synergy system model

Complex systems are usually composed of several subsystems through nonlinear actions, and the cooperation among subsystems promotes the evolution of the system. Grey relational analysis can measure the relative strength of a system that is affected by other factors and can thus facilitate the analysis of the relationship between the system and the influencing factors. On the basis of the study of the 3D system of hydropower EPC project management synergy, the characteristics of synergy in each dimension were analyzed, and the subsystems that affect hydropower EPC project management synergy were summarized as follows: Information, organization, process, business, resource, and institution synergy. The model is shown in Fig. 2.

In Fig. 1, the three dimensions of the hydropower EPC project management synergy system manifest that the spatiotemporal limitations were broken through, and close connections among project design, procurement, construction, and trial operation were realized through informatization, rational resource allocation, and the correct system guidance. Meanwhile, great achievements were made in terms of speed of progress, quality, cost, and safety. In addition to its own operation, each subsystem of the hydropower EPC project management collaborative system model interacts with other subsystems, thereby forming an interactive and mutually supportive whole, which would affect the overall operation of the hydropower EPC project management collaborative system. Two parts, namely, "vertical synergy" and "horizontal synergy", were included.

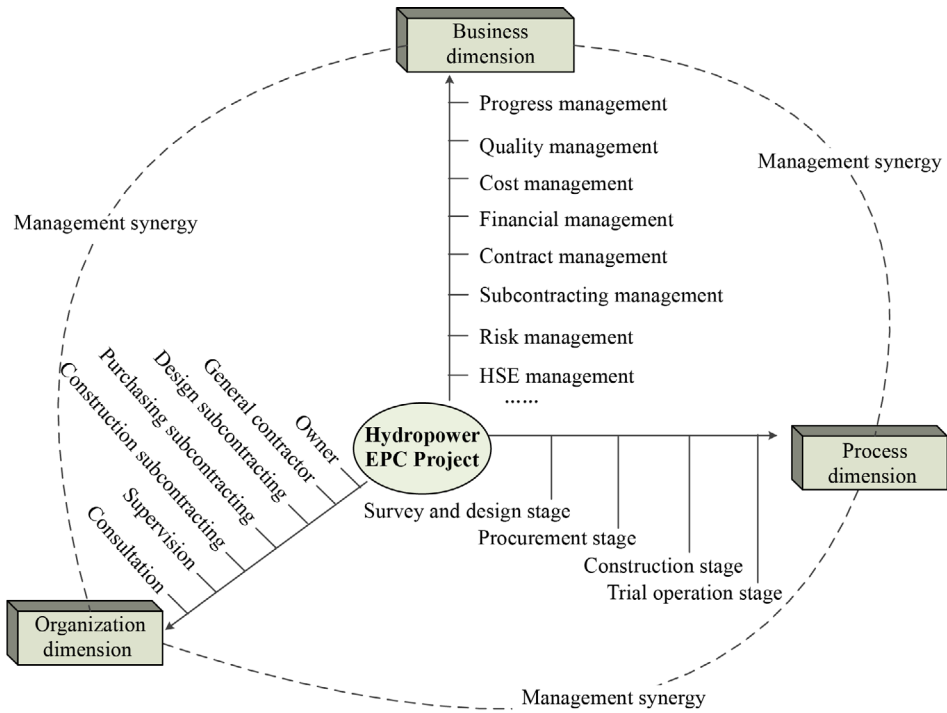


Fig. 1 3D system of hydropower EPC project management synergy.

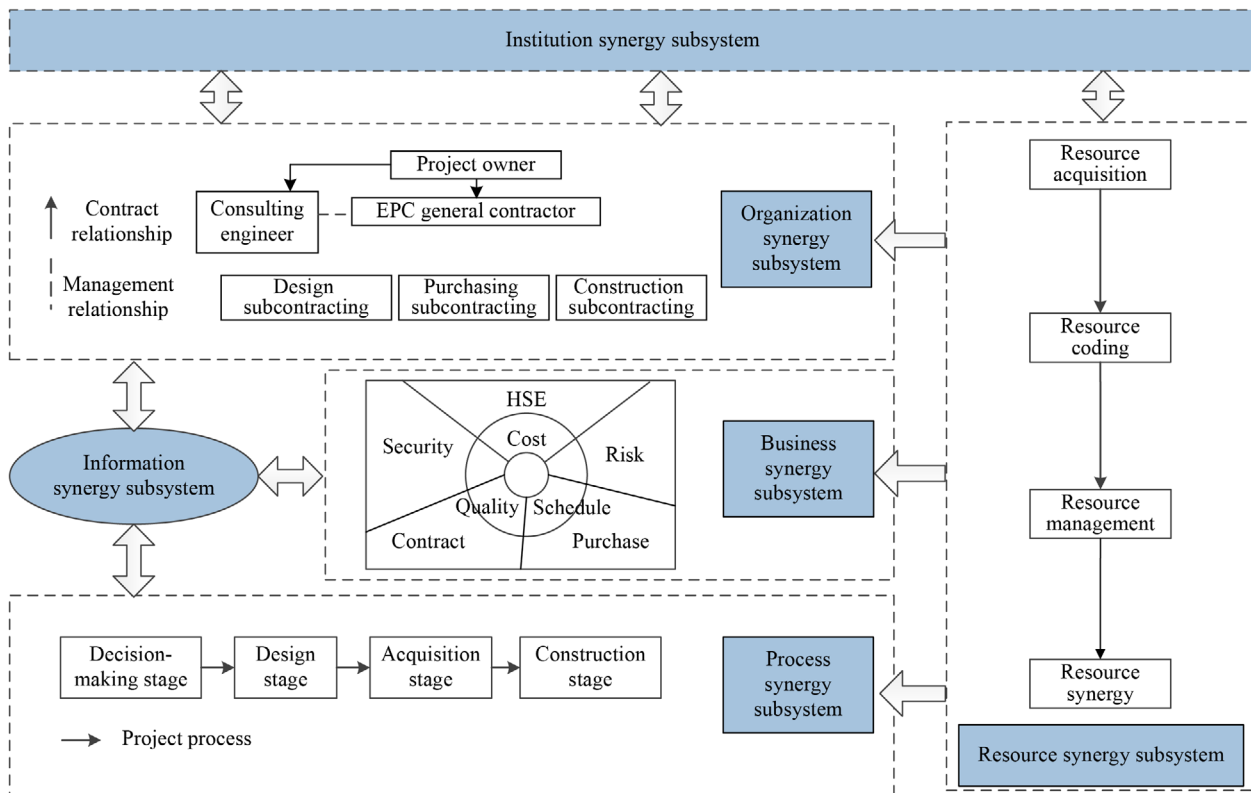


Fig. 2 System model of hydropower EPC project management synergy.

(1) Vertical synergy refers to the synergy within the neutron system of the hydropower EPC project management synergy system model. A project subsystem has many factors, and the degree of synergy within each subsystem determines the entire project's synergy degree and forms its basis.

(2) Horizontal synergy refers to the synergy degree among subsystems in hydropower EPC project management. The higher the synergy degree among subsystems during the operation of the project is, the higher the overall synergy degree of the project will be. The greater the differences are between the hydropower EPC project management synergy subsystems, the more difficult they are to match, thereby decreasing the overall project synergy ability. The key to overall project synergy is to achieve horizontal synergy among the subsystems of the hydropower EPC project by overcoming their differences.

3 Establishment of hydropower EPC project management synergy measurement model

3.1 Index system construction

The 3D synergy system of EPC project management was investigated by analyzing the characteristics of its three dimensions based on a previous research. The model was constructed (Fig. 2). According to the selection principle of order parameters, the scientificity of index selection, and the availability of data computation, the expert consultation method was adopted in this synergetic model to eliminate the alienation and duplication of indicators, and a reasonable number of indicators was determined. Consequently, the evaluation index system for the EPC project management synergy degree of the hydropower project was developed, with 12 order parameters and 38 ordinal parameter components included (Table 1).

3.2 Measurement model of hydropower EPC project management synergy degree

3.2.1 Ordering degree model of subsystems

Order refers to the manifestation of the interrelated formation of subsystems in the evolution process of a system and is mainly divided into two states: Orderly and disorderly. Orderliness represents a system's ordering degree. Generally, examining the orderliness degree of a system is the basic step of determining the system synergy degree. In this study, six interacting systems, namely, information synergy (S₁), organization synergy (S₂), process synergy (S₃), business synergy (S₄), resource synergy (S₅), and institution synergy (S₆), were designed as the subsystems of the hydropower EPC project management synergy system. The order parameters $x_i = (x_{i1}, x_{i2}, \dots, x_{ij})$, $\beta_{ij} \leq x_{ij} \leq \alpha_{ij}$, where $i = 1, 2, \dots, n$; j is the

number of ordinal parameter components, $j \in [1, k]$; and α_{ij} and β_{ij} are the order parameters' upper and lower limits of critical points in the system, respectively. Because of the different properties of order parameters, the direction of action of order degree of subsystem S_i is different. Suppose that $x_{ij} = (x_{i1}, x_{i2}, \dots, x_{ih})$ ($1 < h < k$) are positive indicators, the larger the value of x_{ij} is, the greater the orderliness of subsystem S_i is. Suppose that $x_{ij} = (x_{i(h+1)}, x_{i(h+2)}, \dots, x_{ik})$ are negative indicators, the larger the value of x_{ij} is, the lower the orderliness of subsystem S_i is. The order degree of order parameter component x_{ij} is $\mu_i(x_{ij})$. The greater the order degree $\mu_i(x_{ij})$ is, the greater the contribution of the order parameter component is to the subsystem.

$$\mu_i(x_{ij}) = \begin{cases} \frac{x_{ij} - \beta_{ij}}{\alpha_{ij} - \beta_{ij}}, & j \in [1, h] \\ \frac{\alpha_{ij} - x_{ij}}{\alpha_{ij} - \beta_{ij}}, & j \in [h + 1, k] \end{cases} \quad (1)$$

The order degree of the subsystems in the hydropower EPC project management collaborative system could be expressed by integrating the order parameters' order degree. Generally, the linear weighting or geometric averaging method is used to calculate the order degree. However, these two methods have their own drawbacks. To improve the calculation accuracy, the two methods were combined to calculate the order degree of the subsystems:

$$\mu_i(x_i) = \frac{\sum_{i=1}^n \omega_i \mu_i(x_{ij}) + \sqrt[n]{\prod_{i=1}^n \mu_i(x_{ij})}}{2}, \quad \omega_i \geq 0, \sum_{i=1}^n \omega_i = 1, \quad (2)$$

where ω_i is the weight of the order parameters, $\sum_{i=1}^n \omega_i \mu_i(x_{ij})$ is the order degree of the subsystems calculated by the linear weighting method, whereas $\sqrt[n]{\prod_{i=1}^n \mu_i(x_{ij})}$ is that calculated by the geometric averaging method.

3.2.2 System orderliness model

In the hydropower EPC project management collaborative system, the initial time is t_0 , the order degree of the subsystems is $\mu_i^0(x_i)$ ($i = 1, 2, \dots, 6$), and the order degree of the subsystems at system evolution time t_1 is $\mu_i^1(x_i)$ ($i = 1, 2, \dots, 6$). The hydropower EPC project management synergy system mainly involves four stages of implementation, namely, design, procurement, construction, and trial operation. The design stage was set at initial time t_0 , the procurement stage was set at t_1 , the construction stage was at t_2 , and the trial operation stage was at t_3 . The degree of management synergy (DMS) of the hydropower EPC project management synergy system in the time period is calculated as follows:

Table 1 Evaluation index system

Subsystem	Order parameter	Ordinal parameter component
Information synergy S_1	Information transfer A_1	Timeliness of information transfer B_{11}
		Accuracy of information transfer B_{12}
		Degree of information transfer B_{13}
	Information platform A_2	Construction degree of information platform B_{21}
		Functions of information platform B_{22}
		Benefits of information platform B_{23}
Organization synergy S_2	Organization architecture A_3	Adaptability of information platform B_{24}
		Organization management level B_{31}
		Organization management span B_{32}
	Organization synergy A_4	Departmental settings B_{33}
		Performance of functions B_{41}
		Inter-organization synergy B_{42}
Process synergy S_3	Process management A_5	Organization standardization degree B_{43}
		Leadership attention B_{44}
	Process control A_6	Process interconnection B_{51}
		Process reengineering B_{52}
Business synergy S_4	Target setting A_7	Process risk control effectiveness B_{61}
		Process safety control effectiveness B_{62}
		Uniformity of business objectives B_{71}
	Business level A_8	Definiteness of objectives at each stage B_{72}
		Synergy of objectives B_{73}
		Quality of target management process B_{74}
Resource synergy S_5	External resources A_9	Progress control level B_{81}
		Cost control level B_{82}
		Quality control level B_{83}
	Internal resources A_{10}	Political resources B_{91}
		Economic resources B_{92}
		Legal resources B_{93}
Institution synergy S_6	Institution development A_{11}	Natural resources B_{94}
		Resource demand definition B_{101}
		Normativity of resource approval process B_{102}
	Institution effect A_{12}	Rationality of resource allocation B_{103}
		Logistics smoothness B_{104}
		Degree of perfection of the system B_{111}
		Clearness of metrics B_{112}
		Adaptability of institutions and organizations B_{121}
		Institutional incentive effect B_{122}
		Institutional deterrence strength B_{123}

$$DMS = \theta \sum_{i=1}^6 \omega_i |\mu_i^1(x_i) - \mu_i^0(x_i)|,$$

$$\theta = \frac{\min_i [\mu_i^1(x_i) - \mu_i^0(x_i) \neq 0]}{|\min_i [\mu_i^1(x_i) - \mu_i^0(x_i) \neq 0]|} \quad (3)$$

3.3 Grey relational analysis

Grey relational analysis can measure the relative strength of a system that is affected by other factors. Thus, this method was adopted to facilitate the analysis of the relationship between the system and the influencing factors. The analysis steps are presented as follows:

Step 1: Use the improved 1–3 scale (–1, 0, 1) analytic hierarchy process to calculate the objective weight of each index.

Step 2: Measure the correlation coefficient $\xi_i(k)$ between the synergy degree at each stage and the order parameter component according to the grey correlation formula $\xi_i(k) = (\Delta_{\min} + \rho \times \Delta_{\max}) / (\Delta_i(k) + \rho \times \Delta_{\max})$, where Δ_{\min} is the minimum difference, Δ_{\max} is the maximum difference, $\Delta_i(k)$ is the absolute difference, and ρ is the resolution coefficient. $\rho = 0.5$ was taken in this study.

Step 3: Calculate the correlation degree between the synergy degree of each subsystem and the secondary index according to the formula $R = \frac{1}{m} \times \omega_j \times \xi_i$ (Table 2), where ω_j is the weight of the ordinal parameter components, m is the number of stages, and ξ_i is the correlation coefficient of the evaluation object. Here, only the top six order parameter components are listed to embody their keys.

4 Empirical analysis

4.1 Data source

Taking the EPC project of a pumped storage power station (hereinafter referred to as Project A) as an example, the synergy degree of the project was evaluated on the basis of

the synergy evaluation model of hydropower EPC project management, the feasibility of the model was verified, and a reference was provided for the construction of a hydropower EPC project. The development and construction of Project A involves many stakeholders. The project is operated in the close joint venture mode. That is, if one party causes contractor losses, then the other party bears joint and several liabilities. The ultimate profits and losses are shared by the joint parties according to their proportion of shares. The engineering design and equipment procurement of Project A are in the charge of a survey and design institute, and the allocation of main project construction and resource management are in the charge of large-scale construction engineering bureaus B and C.

Quantitative indicators for sequence parameters and their components are difficult to adopt. Therefore, we invited experts to complete Questionnaire 1 to evaluate the synergy of different project stages using a 10-point semi-quantitative evaluation method (1 = worst value, 10 = best value (ideal value)). The majority of the experts invited were relevant participants of Project A to ensure the objectivity of scoring. Furthermore, they are chosen from different positions and departments, thereby ensuring the reliability of data sources. Then, we collected the questionnaires and analyzed them statistically. A total of 98 questionnaires were distributed, and 95 of them were received. The average score of each index was used as the original data for the synergy of indicators at each stage.

4.2 Sub-systematic orderliness measurement

An improved 1–3 scale (–1, 0, 1) analytic hierarchy process was used to measure weight. The optimal transfer matrix was calculated by constructing the judgment matrix. Then, the quasi-optimal consistent matrix was calculated with its consistency. Finally, the subsystem, the order parameter, and the secondary index weight were determined.

Given the different dimensions of the original data, we first eliminated the influence of dimension difference by dimensionless treatment. On the basis of our field research on Project A, 50 experienced experts in hydropower engineering construction management with senior profes-

Table 2 Ranking of synergy degree and correlation degree of ordinal parameter components at each stage

Order	1	2	3	4	5	6
Design stage	B ₂₁	B ₁₁	B ₂₂	B ₄₁	B ₂₃	B ₂₄
	0.2500	0.2332	0.2290	0.2278	0.2256	0.2256
Procurement stage	B ₂₁	B ₁₁	B ₂₂	B ₃₂	B ₂₄	B ₄₁
	0.2500	0.2461	0.2378	0.2349	0.2346	0.2320
Construction stage	B ₄₂	B ₂₁	B ₄₁	B ₃₂	B ₄₃	B ₃₃
	0.2515	0.2500	0.2482	0.2470	0.2447	0.2441
Trial operation stage	B ₁₁	B ₂₁	B ₂₃	B ₂₂	B ₄₁	B ₄₃
	0.2500	0.2445	0.2395	0.2387	0.2368	0.2360

sional titles were invited to answer Questionnaire 2. Consequently, we obtained the subsystem weight, $W = [0.106, 0.174, 0.287, 0.263, 0.106, 0.064]^T$. The order degree of each order parameter was calculated separately according to the secondary index weight and Eq. (1). Then, the order degree and weight of the order parameter were substituted into Eq. (2) to obtain the order degree of all subsystems and draw a line chart to show their trends at each stage clearly (Table 3 and Fig. 3).

4.3 Systematic synergy measurement

According to the calculated order degree of each subsystem, the weight of each subsystem, and Eq. (3), the design stage of Project A was taken as the base period (initial time was t_0), and the synergy degree of the project at each stage was then calculated and a line chart was drawn to present the trend of the synergy degree of the system at each stage clearly (Fig. 4).

Table 3 Order degree of subsystems

Subsystem	Design stage	Procurement stage	Construction stage	Trial operation stage
Information synergy S_1	0.4767	0.5056	0.5526	0.4676
Organization synergy S_2	0.5319	0.5477	0.5368	0.5027
Process synergy S_3	0.6267	0.6449	0.6643	0.6115
Business synergy S_4	0.6099	0.6585	0.6728	0.5863
Resource synergy S_5	0.6552	0.6631	0.6693	0.6217
Institution synergy S_6	0.5367	0.5927	0.6453	0.5480

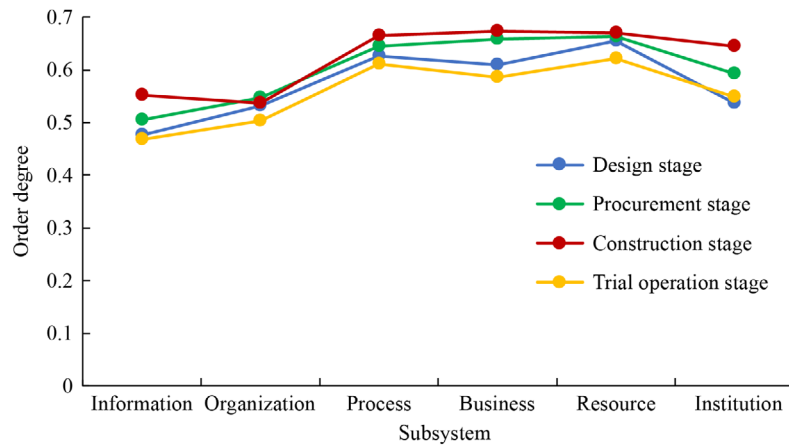


Fig. 3 Order degree of subsystems.

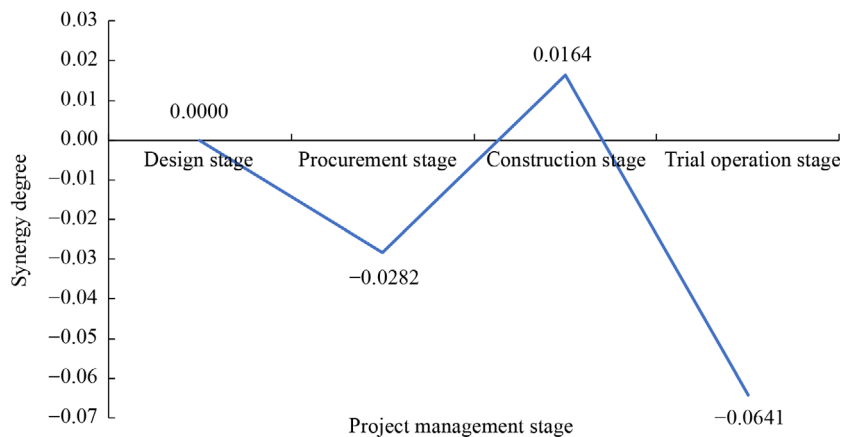


Fig. 4 System synergy degree at different stages.

4.4 Synergy measurement analysis

Based on previous studies (Xu et al., 2017; Jin and Zheng, 2018) and the characteristics of a hydropower EPC project, the synergy degree of the hydropower EPC project management synergy system was divided into six levels from high disharmony to high synergy. The criteria were defined in Table 4.

Table 3 and Fig. 3 indicate that the order degree of each subsystem is within [0.4, 0.7] and tends to be stable at each stage, with only small fluctuations. Among them, the procurement and construction stages have higher synergy degrees, whereas the trial operation stage has the lowest. For each subsystem, the process, business, and resource synergies have higher synergy degrees, while information, organization, and institution synergies have lower synergy degrees, indicating that the former play key roles in the synergy of Project A. The low synergy degrees of the latter three subsystems are analyzed as follows:

(1) The low synergy degree of the information synergy subsystem is due to the weak awareness of the importance of informatization among field managers. They rely heavily on the experience of conventional construction management, and the promotion of the informatization concept in the frontline of construction is hampered. The project lacks in information department and platform, hindering the timely and accurate dissemination of information.

(2) The low synergy degree of the organization synergy subsystem is due to the imperfect organization of the project. The unclear and overlapping responsibilities of the functional departments of the EPC general contracting project department lead to the poor performance of personnel functions. Four security committees were set up according to the requirements of the owner, resulting in unclear division of labor in terms of safety management at all stages. In addition, the management fails to meet the integration requirements.

(3) The low synergy degree of institution synergy subsystem is due to fewer projects adopting EPC mode in hydropower industry. Consequently, the EPC contract norms, EPC rules, and regulations in the entire industry are inadequate, and the risk sharing and benefit distribution mechanisms require further improvement. Furthermore, the system of the project department of Project A is imperfect, thereby leading to difficulties in project transformation from the traditional mode to the EPC mode.

Figure 4 demonstrates that the synergy degrees of Project A at the procurement and trial operation stage are within (-0.2, 0], which belong to the low disharmony level, whereas the overall synergy at the construction stage

is 0.0164, which belongs to the low synergy level. In view of the development status of each stage, the overall synergy degree at the design stage is low, which then decreases at the procurement stage and increases at the construction stage. The variations in the overall synergy degree at each stage are analyzed as follows:

(1) The low degree of overall synergy at the design stage is mainly caused by the many uncertainties at this stage, the unclear objectives and resources at all levels, and the initial state of cooperation among departments.

(2) The overall synergy increases at the construction stage mainly because the project development attracts the attention of leaders at all levels with the increase in the construction cycle of the project. After the full exchange and adjustment among the participants, all aspects of the project gradually improved.

(3) At the trial operation stage, the overall synergy declines rapidly because the general contractor and the owner docked, the owner conducted and the general contractor guided, and then the focus of the work shifted, thus resulting in the rapid decline of the synergy.

4.5 Analysis of key factors

The above analysis reveals some differences in the synergy at the design, procurement, construction, and trial operation stages of Project A. The grey relation analysis was subsequently employed to calculate the correlation between the synergy degree at each stage and the component of each order parameter.

First, Table 2 shows that the construction degree of information platform (B₂₁) has the closest relationship with the synergy degree at the design, procurement, construction, and trial operation stages, and its association degree with the system is slightly higher than those of the other order parameters. This shows that improving the construction degree of information platform and maximizing the performing efficiency of various departments can improve the efficiency of information platform construction. Therefore, the hydropower EPC project management synergy degree exerts the most significant effect. Second, the top six factors influencing the synergy level of hydropower EPC project management are mainly concentrated in the information synergy (S₁) and organization synergy (S₂) subsystems. At the design stage, the main factors include the construction degree of information platform (B₂₁), the timeliness of information transfer (B₁₁), the functions of information platform (B₂₂), the performance of functions (B₄₁), and the information level. The procurement stage involves the benefits of information platform (B₂₃), the adaptability of information platform (B₂₄), the construction

Table 4 Evaluation criteria for synergy degree

Rank range	[-1, -0.6]	(-0.6, -0.2]	(-0.2, 0]	(0, 0.2]	(0.2, 0.6]	(0.6, 1]
Synergy level	High disharmony	Moderate disharmony	Low disharmony	Low synergy	Moderate synergy	High synergy

degree of information platform (B₂₁), the timeliness of information transfer (B₁₁), the functions of information platform (B₂₂), the organization management span (B₃₂), and the performance of functions (B₄₁). Meanwhile, the main factors at the construction stage are inter-organization synergy (B₄₂), the construction degree of information platform (B₂₁), the performance of functions (B₄₁), the organization management span (B₃₂), the organization standardization degree (B₄₃), and the departmental settings (B₃₃). Finally, those at the trial operation stage are the timeliness of information transfer (B₁₁), the construction degree of information platform (B₂₁), the benefits of information platform (B₂₃), the functions of information platform (B₂₂), the performance of functions (B₄₁), and the organization standardization degree (B₄₃). Obviously, the common influencing factors at each stage are the construction degree of information platform (B₂₁) and the performance of functions (B₄₁).

4.6 Strategies for improving synergy degree of hydropower EPC project management

The above analyses reveal that the overall synergy degree of Project A is low, with the highest being only 0.0164, which is basically consistent with the current situation of project synergy. As the synergy process of EPC project management is from disorder to order, each subsystem

needs to communicate, adjust, and finally change in terms of the process of integration of all parties to achieve the “1 + 1 > 2” effect. Although the current subsystems of Project A can meet the requirements to a certain extent, the process of integration of all parties still has many contradictions, and various problems continue to arise due to the obvious deficiencies of some subsystems adopting the EPC mode. In addition, the complexity of the project escalated the conflicts, indicating that each subsystem of Project A requires further improvement. In this section, based on the synergy results of Project A, the strategies for improving the synergy of the subsystems and the management efficiency of the subsequent construction of Project A are proposed as described in Table 5.

5 Conclusions

This study established a synergy degree model and measured the order and synergy degrees of each subsystem at the design, procurement, construction, and trial operation stages. The key influencing factors of hydropower EPC project management synergy were analyzed accordingly using the grey correlational model. The conclusions are presented as follows:

- (1) In terms of the orderliness of subsystems, the

Table 5 Promotion strategies of each synergy subsystem

Synergy subsystem	Promotion strategies
Information synergy	<ol style="list-style-type: none"> ① Develop standard systems (data exchange, information classification and coding, information delivery, and data application standards) ② Improve an engineering data center (data acquisition, exchange, conversion, storage, and management) ③ Develop a project management platform (integrated presentation layer, user layer, decision-making layer, application layer, and docking with external system)
Organization synergy	<ol style="list-style-type: none"> ① Improve the organizational structure (clarify the responsibilities of each functional department and give full play to their role) ② Solve organizational conflicts (analyze the root causes and influencing factors of organizational conflicts and propose methods for solving the conflicts) ③ Leaders must participate and pay attention (leaders should strengthen their awareness at the overall planning stage to ensure the implementation of the project in the entire construction life cycle)
Process synergy	<ol style="list-style-type: none"> ① Clarify the information on process handover (define the boundary of each process and the information type, content, and handover method of each process integration) ② Optimize workflow (design a workflow to meet the needs of project management and project implementation)
Business synergy	<ol style="list-style-type: none"> ① Set clear business objectives (decompose the project structure and unify the business objectives according to the multi-level characteristics of the project) ② Establish a collaborative work mechanism (establish a business collaborative work mechanism and integrate resources under the guidance of management collaborative thought) ③ Establish a project management system (standardize project management and realize the specialization, standardization, and refinement of the management system)
Resource synergy	<ol style="list-style-type: none"> ① Supervise external resources (strengthen the supervision of all parties, coordinate the relationship between internal and external resources, and make full use of external resources) ② Formulate systems to regulate the use of internal resources (plan as a whole before the start of the project, and make regulations on possible conflicts over systematic resources based on previous experience)
Institution synergy	<ol style="list-style-type: none"> ① Formulate EPC rules and regulations (EPC project development, EPC model transformation, coordinated development, and so on) ② Develop a risk sharing mechanism (understand the subject, object, and method of risk sharing and improve the contract terms) ③ Develop benefit sharing mechanism (design a relatively fair way of income distribution) ④ Formulate a reward and punishment system (provide reward and inflict punishment according to the contract and relevant systems to promote the goal of coordinating all participants in the project)

hydropower EPC project management system was divided into six subsystems. The orderliness is within the range of [0.4, 0.7], tending to remain stable at all four stages, with only small fluctuations. The synergy degree is low in the information, organization, and institution synergy subsystems.

(2) With regard to the system synergy degree, a synergy degree model of hydropower EPC project management was constructed, and the synergy degree at each stage was calculated and categorized according to the six synergy levels defined. Taking hydropower Project A as an example, the analysis results show that for each process with the design stage as the base period, the synergy degrees at the procurement and trial operation stages are within $(-0.2, 0]$, which belong to the low disharmony level, whereas that at the construction stage is 0.0164, which belongs to the low synergy level. In the future, the evaluation criteria for synergy degree at each stage should be formulated according to the actual situation so that the measurement of synergy degree will have a more practical impact on the project.

(3) For the key factors, the construction degree of the information platform and the level of hydropower EPC project management collaboration have the highest grey correlation degree, revealing that the increase in the construction degree of information platform has the most significant effect on improving the synergy level of hydropower EPC project management. Moreover, the top six order parameter components that affect the synergy level of EPC project management are concentrated in the information and organization synergy subsystems. This finding clearly demonstrates that these two subsystems are the main driving forces for improving the synergy level of hydropower EPC project management. Therefore, in future construction projects, the order degree of these two subsystems should be improved continuously, and efforts should be made to improve those of the four other subsystems.

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