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Research Article

Systematic Thinking and Evaluation of Construction Quality Management Standardization of Power Engineering in China

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Power engineering is complex, involving many participants, numerous management factors, and different stages. To improve the quality management level of power engineering and realize the standardization of power engineering quality management, power engineering construction quality management standardization (CQMS) is evaluated using the order relation analysis method (G1 method) and the cloud model method. Firstly, based on systematic thinking and practice in China, the CQMS framework is proposed, and the evaluation index system including organizational performance, management behaviour performance, and entity performance related to power engineering construction quality is established. Subsequently, the G1 method is used to determine the weight of each index, and the cloud model method is used to implement the evaluation process. The results are divided into five grades, representing the five grades of construction quality management. Finally, taking a practical multiterminal DC demonstration project in China as an example, the CQMS performance is described and evaluated. The evaluation results directly reflect the level and difference of CQMS and show that this evaluation method can provide a reference for CQMS in power engineering.

1. Introduction

Power facilities contain generating plants, transformer substations, transmission towers, and lines, which are built across all provinces, cities, counties, and villages. They are closely related to daily life and support social and economic development. At the same time, power engineering is complex and variable because of its various management elements, including weather, geology, human behaviour, material quality, and other related factors. Any can occur in design, installation, employing, maintenance, or other processes, and accidents such as electric shock, mechanical breakdown, fire, or even explosions may occur rapidly and lead to catastrophic consequences. Therefore, the function, accuracy, and stability of power facility development and installation are essential, and these requirements can also be collectively referred to as construction quality management standardization (CQMS). CQMS aims to obtain unified and stable performance for construction facilities and can also overcome difficulties related to complexity, randomness, and variety. During the recent decade, the overall construction quality management, which is known as standardization, has become more recognized and favourable in the Chinese construction industry, especially since 2017, when the Ministry of Housing and Urban-Rural Development of China issued a special regulation to generalise the standardization of construction quality management. The application of the CQMS concept in power engineering quality management is an urgent demand of the industry and has strong practical significance.

However, the current power engineering quality management standardization still exists and many problems still need to be solved, such as unclear definitions, the lack of a standard system, imperfect technical specifications, low-quality management personnel, and nonstrict construction process control. This paper investigates the system framework and evaluation method of power engineering CQMS from theoretical research and practical applications. Moreover, the advanced management experience of some enterprises or organizations in China's construction industry is also summarized. Subsequently, the concept and system elements of CQMS are defined, and the corresponding evaluation system is established. Finally, the cloud model and G1 method are used to conduct an empirical analysis of the power engineering CQMS evaluation system, which can reduce the influence of uncertainty and inaccuracy in the evaluation process.

2. Literature Review

Quality management is generally agreed to contain five elements: human behaviour, machine, materials, methods, and environmental factors. To control these factors and obtain satisfactory production, a great amount of research on construction quality management has been conducted, which can be divided into different aspects, including quality management system, factor control, and advanced evaluation methods.

(1) Quality management system. Generally, construction enterprises establish their quality management systems based on ISO 9000 [1]. ISO 9000 provides a set of requirements and processes for standardized quality management practices; however, it is not practical enough in some fields, such as design, internal review, training, and data statistics [2]. Then, the characteristics of the construction industry are considered and information technologies are adopted, which is closely united with the ISO framework during construction design, inspection, and delivery processes [3]. Another widely used quality management framework is the total quality management (TQM) system. Many studies and practices have verified that TQM is conducive to improving overall customer satisfaction, management commitment, skilled employees, and so forth [4]. In the construction industry, TQM has been proven to be one of the most effective methods to solve various typical quality management problems [5–7]. By comparing two classical quality management systems, it was found that the improvement in organization and relationship management is a key way to increase construction quality [8–10]. A good organization strengthens management, while, in turn, good management enhances the organization. Their dynamic combination can mobilize all resources and achieve quality improvement [11]. Therefore, power engineering enterprises must constantly establish and improve their quality management system.

(2) Comprehensive and critical factors of quality management. Based on the summary of the practical experiences of quality management, it is not difficult to discover that the critical factors of quality management contain five elements: human, machine, material, method, and environment [12, 13]. The recognition of these quality management factors and the identification of critical factors are significant for improving quality management systems and promoting quality performance [14]. Some researchers have found that human behaviour and mechanical equipment utilization are more important than other factors, especially for developing countries [15]. This principle is also applicable in the construction industry, where many workers are hired and various types of machines are operated. The normative and safe handling of machines is a basic requirement to prevent the occurrence of safety accidents, injuries, and property losses [16, 17]. For human behaviour related to quality, five critical factors should be considered: the ability of the project manager, the support of top management, the communication of project participants, the skill of labour, and the competence of the client [16, 18, 19].

(3) Advanced evaluation methods. The use of advanced information technology or intelligent technology to assess the existing quality management level can better implement the quality management system and control the key factors. For example, the application of building information modelling (BIM) technology can be combined with positioning technology to quickly find quality defects [20] and can also be used to build a collaborative work platform to enhance the communication and collaboration of quality management team members [21]. The development of artificial intelligence also injects new driving forces into construction quality management. For example, an artificial neural network can be used to establish a simulation model of quality risk and schedule control, and quality management risk assessment can be carried out during the long process of a construction project [22]. The cloud model method can effectively resolve the problems of randomness and fuzziness in construction projects; therefore, it can improve the evaluation results of construction quality, safety, and other aspects [23–25]. As the practice of construction quality management moves forward, the evaluation of quality management and performance has been continually evolving. Analytic hierarchy process (AHP) was widely used in the early stage, which considered the uncertainties of indicators and absorbed expert opinion [26]. Recently, fuzzy mathematics, stability theory, and other improved theories are becoming more popular and can obtain more reliable and intuitionistic evaluation results [27]. For example, to improve the accuracy of expert evaluation results, IBULI-aggregation operators are used to aggregate the evaluation information given by a large group of decision-making experts [28] or an ELECTRE III-based method that incorporates HFLTS possibility distributions is proposed [29].

In some ways, CQMS is realized by integrating these management elements, specifying corresponding management methods, and, finally, forming standardized documents and procedures. However, quality management standardization is a new management concept not only for the construction industry but also in clinical medicine, corporate management, energy management, public management, and so forth. Some research and findings are shown in Table 1. The quality management standardization experience of these different fields is of great significance for clarifying the concept and elements of CQMS. Therefore, in this paper, the concept of CQMS is clearly elaborated, and the complete evaluation indicators of the CQMS evaluation system of power engineering are displayed based on these studies.

3. Methodology

Based on a literature review and power engineering practices, this paper aims to establish the framework of CQMS and propose an evaluation index system for power projects. A combination of three methods is adopted: system thinking, cloud modelling, and order relationship analysis (G1). These methods and their applications are shown in Figure 1.

3.1. System Thinking. A system is composed of more than two elements that are organically connected and interact with each other and have specific functions and structures [39]. Decomposition and integration are the basic methods for system analysis. Through this method, a large and complex system can be decomposed into a series of small simple parts, and these parts can be integrated into a system [39, 40]. Based on system thinking, the CQMS evaluation system is decomposed into three subsystems: organization, behaviour, and physical quality. Furthermore, each subsystem is decomposed into specific factors.

3.2. Cloud Model. The cloud model belongs to the category of uncertain artificial intelligence [41] and is a branch of fuzzy mathematics. The traditional fuzzy comprehensive evaluation method takes the membership function as a bridge and transforms the uncertainty into determinism in the form (quantifying fuzziness), which can be analysed and processed by the traditional mathematical method [42]. However, the bridge function of the membership function has been questioned, and its use of an accurate function curve instead of fuzzy concepts has hindered the development of fuzzy theory [43]. In this paper, the evaluation is based on the normal cloud model, and it is used to replace the fuzzy membership function for fuzzy comprehensive evaluation. The normal cloud model is developed based on a normal distribution and fuzzy mathematics; therefore, it is more universal in practice [44]. The cloud numerical characteristics of each risk indicator can be described by the normal cloud theory, and the uncertainty conversion between risk level and evaluation indicator can be reflected by cloud droplets [45]. It realizes the transformation from a qualitative concept to a quantitative description and can vividly describe the evaluation results.

3.3. Order Relationship Analysis (G1 Method). The commonly used methods to determine index weights can be divided into two categories: subjective weights and objective weights. The subjective weighting method refers to the use of decision-making work experience to allocate the weight of indicators [46], such as AHP and Delphi. The objective weight emphasizes the objectivity of index weights, introduces actual data into decision-making, and mines the relationship and influence between indexes [47]. Typical representatives are the entropy method, principal component analysis method, DEA method, and so forth. There are also some experts and scholars that combine both to calculate the weight in practice [48]. Compared with other weight determination methods, the order relationship analysis method (G1 method) has the following significant advantages: (1) the amount of calculation is doubled, and the principle is clear and easy to disseminate; (2) there is no need to construct a judgment matrix, so there is no need to conduct the consistency test of the judgment matrix; (3) when the number of schemes changes, the weight coefficient of schemes still has strong order preservation; and (4) applications do not require a strong mathematical foundation [49, 50].

CQMS index weight decision is a complex problem, which requires a qualitative and quantitative combination. The G1 method lays the foundation for making a convenient and accurate evaluation decision. Based on the above characteristics, this paper selects the G1 method as the main analysis tool. It works by ranking the importance of factors and implementing certain algorithms.

3.4. Case Study. A case study is useful for verifying research results [51]. To verify the practicability of CQMS elements and cloud models, a typical large power engineering project is selected. The evaluation index system is expanded based on this project, and an expert team was specially set up to conduct real inspections on different sections of the project. The evaluation process and results are illustrated and analysed.

4. System Thinking of CQMS

4.1. Conception of CQMS. Standardization refers to the activities of establishing common use or reusable terms and preparing, publishing, and applying documents for practical or potential problems to obtain the best order for a given scope that can promote common benefits [52]. Construction quality management refers to the life-cycle management of personnel, machines, materials, methods, and environmental elements through planning, implementation, inspection, and other means, to ensure that construction quality meets specific standards and requirements set by stakeholders [53–55].

By combining the above two, the definition of CQMS can be as follows: it is the process of unifying and standardizing construction quality management activities by establishing a reasonable framework and compiling specifications, and its purpose is to regulate and control management, operation,

Table 1: Research on quality management standardization in different fields.

Research field	Researcher(s)	Core ideas or critical factors
Life science or clinical medicine	Dati [30]	For commercial specific protein/tumour marker detection laboratories: (1) establish consensus/reference methods; (2) develop the suitable reference material library [30].
	Endrullat et al. [31]	For next-generation DNA sequencing: (1) quality documentation issues (technical notes, accreditation checklists, and guidelines); (2) general standard proposals and quality metrics; (3) standardized data handling, processing, and storage [31].
Enterprise management	Zoga and Pano [32]	In organizational, marketing, and financial terms: (1) external requirements and market pressure; (2) improving the production efficiency; (3) organizing the actual operation; (4) improving the corporate image; (5) transaction facilitation program [32].
	Baltos et al. [33]	Ideas and measures: (1) customer focus; (2) leadership quality-related attitudes; (3) risk management and control management; (4) continual review of systems, policies, processes, and procedures; (5) reassurance of all interested parties along with training initiatives; (6) consideration of feedback information [33].
Energy management	Ates and Durakbasa [34]	Advanced quality approach of energy management: regulations, quality management techniques, benchmarking, FMEA method, voluntary agreements, labelling, and standardization (such as EN 16001 and ISO 50001) [34].
	Wang and Gao [35]	In the safety quality standardization of coal mine: (1) inquiring system; (2) personnel management; (3) training management; (4) evaluation of quality standardization; (5) equipment management; (6) rewards and punishment management; (7) system management [35].
Public administration and services	Kettil [36]	Critical methods of public management: (1) organizational professionalism (should be divided into multiple levels: organization, department, and unit); (2) open standards to reflect unpredictability and flexibility (dynamic adjustment, different stakeholders, etc.) [36].
	Rostgaard [37]	Standardization for home care industry: (1) defining responsibilities; (2) clarifying contract management and accountability; (3) standardization of care assessment; (4) uniform service record file format [37].
	Hsieh et al. [38]	The positive relationship between job standardization and service quality: (1) standardization of management personnel selection; (2) standardization of service quality concepts; (3) specified distinctive performance indicators; (4) standard operating procedures; (5) standardization of the division of customer types and corresponding departments; (6) dynamic quality of service measures [38].

quality process, and construction site environment. CQMS is the actual implementation of the normative quality management mode in the construction industry. In addition to adapting to the characteristics of construction projects, such as long project cycles, numerous participants, and technical complexity, it should also conform to the unique characteristics of construction and the existing management system and consult the advanced management experience of relevant industries and enterprises.

4.2. Practice of CQMS in China. Three leading enterprises (China State Construction, China Vanke, and Country Garden) and one public administration organization (Construction Industry Association of Henan Province) are selected as typical units, and, to a large extent, their collective construction quality management experience represents the best practice in China's construction industry. As shown in Table 2, their practices have more similarities than differences, which shows that good experiences can be refined and learned by other organizations. These experiences are summarized as follows:

(1) CQMS should be promoted under the guidance and requirements of special regulations, specifications, manuals, or handbooks.

(2) CQMS can be executed in macro or microlayers. If an enterprise or organization is large, CQMS can be applied in the layers of enterprise, areas, projects, or sections. Although the details and requirements may vary, the principles and processes are the same.

(3) CQMS are normally conducted through several aspects and contain a series of factors. Although the four organizations show different concentrations, they all consider those essential elements, such as organization, technology, and physical performance.

(4) CQMS can be evaluated and divided into different levels. The number and names of the levels may have differences, but the evaluation result can reflect the overall performance of CQMS and provide incentives for construction participants.

4.3. Decomposition of CQMS Elements. Systematic analysis refers to an analysis and research method that regards a comprehensive item or problem as an organic whole containing many specific factors. By using decomposition, integration, correlation analysis, and other methods, the hierarchical structure and interrelation of the CQMS factors can be obtained, which can provide decision support for construction quality management practices. According to the principles of systematic thinking, CQMS should cover

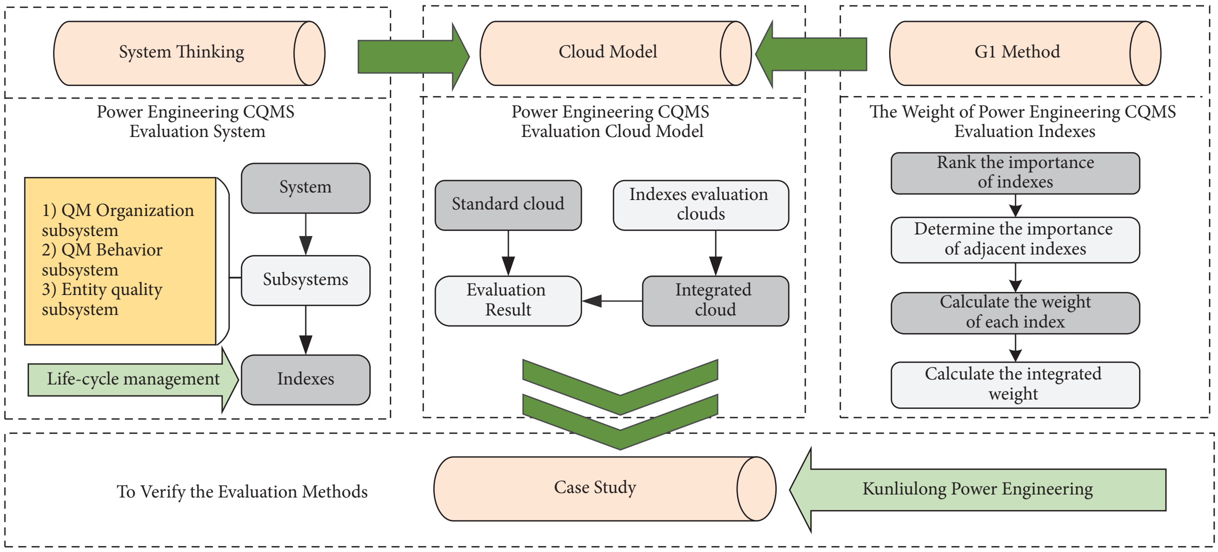

Figure 1: Research methodology.

Table 2: Comparison of quality management and evaluation practices in the construction industry.

Organization	Regulation	Evaluation layer	Evaluation aspects and major factors	Levels of evaluation result
China State Construction	China State Construction Quality Management Assessment and Evaluation Handbook (2020)	Project, enterprise	(1) Institutions; (2) Organizations, personnel, and qualifications; (3) Technology; (4) Process; (5) Quality performance.	Four levels (according to the total score): A: ≥95; B: 85–94; C: 70–84; D: ≤69.
China Vanke	China Vanke Group Assessment Management Manual (2019)	Section, project, area, enterprise	(1) Risk inspection (quality and safety, specified actions, process, etc.); (2) Measured indicators (concrete, masonry, decoration, doors and windows, etc.); (3) Special inspection.	Three levels: Yellow card (one serious safety or quality defect); Red card (2 serious defects or 2 yellow cards in total); Unlicensed (no serious defects).
Country Garden	Country Garden Quality Management Inspection and Grading Method (2015)	Project, area, enterprise	(1) Physical quality (foundation, structure, decoration, etc.); (2) Quality behaviour (drawings review, construction management, etc.); (3) Regional control (supply chain, risk alarming, etc.); (4) Supervision (supervision documents, records, etc.).	Three levels (according to the total score): A: top 5 of the total score; B: in the middle place of the total score; C: bottom 3 of the total score.
Construction Industry Association of Henan Province	Quality Control Standardization for Construction Projects (2018)	Project	(1) Process; (2) Technology; (3) Building structure; (4) Decoration and roofing; (5) Mechanical and electrical installation.	Three levels (according to the total score): Good: ≥85; Qualified: 75–84; Unqualified: ≤74.

different subjects, implementation stages, and management elements. Based on the layers of "system–subsystem–elements," three subsystems and corresponding evaluation elements are involved:

(1) Quality management organization subsystem refers to the leadership mechanism and management staff responsible for quality management affairs, including qualification, departments, staff, and quality performance.

(2) Quality management behaviour subsystem contains the duty performance and actions of quality departments and staff. Quality behaviours include construction plan preparation, technical disclosure, construction record, material quality control, mechanical equipment management, design change control, construction supervision, and record.

(3) Physical quality subsystem refers to the real quality performance of engineering structures and accessorial equipment, including foundations, beams, plates, and columns.

Based on the above framework, specific and detailed evaluation indicators can be identified for real construction projects. These indicators should be accorded with the technical characteristics and management requirements of each project. Since the standardized quality management system should have liquidity and each project has its specialty, the evaluation indicators may not be the same with another project. Therefore, a real power engineering project is adopted to illustrate the evaluation process.

5. Empirical Analysis

5.1. Overview of the Case Project and Evaluation. Guangdong-Guangxi Ultra High Vacuum (UHV) Multiterminal DC Demonstration Project (abbreviated as Kunliulong DC Project) is an important trans-province power transmission project in South China. It was the first ±800 kV UHV multiterminal hybrid DC power transmission "highway" all over the world during its construction period. When the project enters its production stage, it is expected to have the capability of transmitting, annually, 33 billion kWh of electricity. Moreover, the electricity transmitted is renewable energy, which is equivalent to reducing 9.5 million tons of coal consumption and 25 million tons of carbon dioxide annually. This project may effectively promote energy conservation, emission reduction, and air pollution prevention, and it is a strong driving force for South China to develop a green economy. The basic project information is shown in Table 3.

The Kunliulong DC Project has a large volume and various tasks, including three converter stations, grounding electrodes, overhead lines, and 19 transmission line sections. The construction technologies and processes are complex and difficult due to the following reasons:

(1) Large work quantity: the total volume of filling works for the three converter stations is 4.3 million square meters.

(2) Complexity of equipment installation: the VSC-HVDC carries ultrahigh voltage and high flow rate, and equipment installation requirements are rigorous.

(3) Difficulties in field construction. Some sections stride across rivers and others are located on mountains, resulting in a maximum height difference of 18 meters between the tower legs and a vertical height difference of more than 300 meters between the peak and foot of the foundation. Some different sceneries of this project are shown in Figure 2.

Since the quality management of the Kunliulong DC Project is challenging, the application and evaluation of CQMS are of great necessity. In April 2020, a nine-membered expert group was set up by China Southern Power Grid Energy Development Research Institute and it inspected all 19 sections of this project. The main inspection indicators covered the following aspects: project organizations, quality institution, quality management system, quality management process, local physical quality, safety management, health management, environment management, schedule management, document management, and so forth. Inspection methods included observing the management systems, checking construction records and documents, interviewing the department and staff, inspecting construction sites, inquiring the project teams, and on-site measuring.

5.2. Establishment of Evaluation Index System. To establish the evaluation index system for the CQMS of the Kunliulong DC Project, the characteristics and requirements of this project are considered. Firstly, according to the CQMS framework, the CQMS evaluation index system of power engineering consists of three main parts (organization subsystem, behaviour subsystem, and physical quality subsystem). Since the quality management method is traditional and mature, it is not considered a special part of this evaluation. Then, specific indicators are determined by reference materials, practical experience, and the Delphi process, as shown in Figure 3.

(1) Organization: in organization management, the three most important aspects are organization design, organization operation, and organization adjustment [56–58]. Correspondingly, the indicators set in the system are the following: quality management staff, responsibility allocation, and duty performance. In contrast, because of the long lines and numerous subcontractors, construction subcontracting management is added to the index system.

(2) Quality behaviour: to enable a more systematic evaluation, quality management behaviours are divided according to different stakeholders of the project: designers, contractors, suppliers, and supervisors. In addition, in accordance with the principles that have the most direct impact or are most relevant to CQMS, the indicators are set as

Table 3: Basic information of Kunliulong DC Project.

Total length	1,452 *km*
Total investment	$3.75 billion
Annual transmission capability	33 billion kWh
Technological highlights	(1) Ultrahigh voltage (UHV): first hybrid UHVDC and voltage source converter based UHV direct current (VSC-UHVDC) transmission project in the world. (2) Large capacity: largest VSC-UHVDC transmission project (up to 5000 MW) in the world. (3) Overhead lines: first transmission project using VSC-UHVDC overhead line with self-clearing capability in the world. (4) Hybrid DC: hybrid DC technology is used for the first time in the world, with conventional DC at the conveying end and VSC DC at the two receiving ends. (5) Multiterminal: largest multiterminal DC transmission project in the world.

(a) (b) (c) (d)

Figure 2: The Kunliulong DC Project construction site. (a) The ±800 kV converter station. (b) The Guangdong section crosses the Beijing river transmission line. (c) Construction site of VSCUHVDC converter valve. (d) Inspection site of casing through wall for VSC-HVDC.

follows: design delivery and design change control [59]; construction plan, specification and implementation, and quality record; material quality control and mechanical equipment quality control [60]; supervision scheme and record; and inspection and acceptance.

(3) Physical quality: considering the fact that the special structure and quality requirements of power engineering are different from ordinary buildings, the physical quality of power engineering facilities includes foundation, tower, wiring, accessories, and grounding device. Specifically, the standardization of engineering awards is also included.

5.3. Evaluation Process Based on G1 Method and Cloud Model. The evaluation results are obtained through the calculation of indicator weight, indicator score, and total score. Then, the CQMS performance and related levels are identified by comparing an integrated cloud with standard clouds. The evaluation is conducted in the following steps.

5.3.1. Indicator Weight Calculation Based on G1 Method. In this inspection and evaluation, firstly, the relative importance degree of each indicator was ranked by the nine-membered expert group; then, the weight of each indicator was calculated through the following steps:

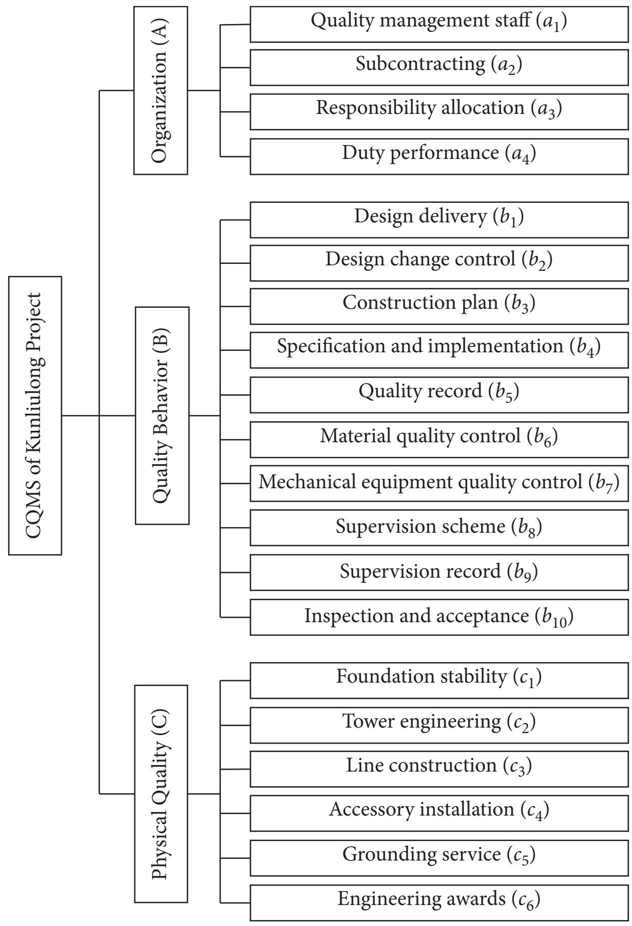

FIGURE 3: Evaluation index system of the Kunliulong DC Project CQMS.

Step 1: judge the relative importance degrees of indicators at each layer. The indicators are denoted as $U = \{u_1, u_2, \ldots, u_n\}$ (where n represents the number of indicators). The most important factor in U is determined by the expert group through collective discussion and is denoted as u_1. The next most important factor is selected from the remaining indicators and is denoted as u_2. The above processes are repeated and the order of importance of all indicators is obtained and denoted as $U' = \{u_1', u_2', \ldots, u_n'\}$.

Step 2: compare and determine the ratio of importance degree of adjacent indicators at each layer. The importance of adjacent indicators in U' is determined through group discussion according to the criteria listed in Table 4. As shown in formula (1), r_k represents the ratio of the importance degree of u_{k-1}, to u_k', ω_{k-1} is the weight of indicator u_{k-1}', and ω_k is the weight of indicator u_k'.

$$r_k = \frac{\omega_{k-1}}{\omega_k}, \quad k = 2, 3, \ldots, n. \tag{1}$$

Step 3: calculate the weight of indicators at every level. After all values of r_k ($k = 2, 3, \ldots, n$) are given by the expert group, the weight of indicator n is calculated by using formula (2). Then, after the weight of indicator n is determined, the weights of other indicators can be obtained by using formula (3).

$$\omega_n = \left(1 + \sum_{k=2}^{n} \prod_{i=k}^{n} r\right)_i^{-1}, k = 2, 3, \ldots, n, \tag{2}$$

$$\omega_{k-1} = r_k \omega_k, \quad k = 2, 3, \ldots, n. \tag{3}$$

Step 4: calculate the integrated weights of indicators at each layer. W_a represents the weights of the first layer, including ω_A, ω_B, and ω_C. W_b means the weights of the second layer, including ω_{a1}, ω_{a2}, …, ω_{c5}, and ω_{c6}. W' represents the integrated weights of all indicators, and it can be calculated by using the following formula:

$$W' = W_a^T \times W_b. \tag{4}$$

The weight calculation of indicators $c_1 - c_6$ which are included in physical quality standardization © is taken as an example. First, these indicators are denoted as $U = \{c_1, c_2, c_3, c_4, c_5, c_6\}$ and they are ranked in order of importance as $c_2 \geq c_1 \geq c_3 \geq c_6 \geq c_5 \geq c_4$. Then, c_2, c_3, c_1, c_6,

Table 4: Criteria for judging the importance of indicators.

r_k	Significance meaning
1.0	The indicator u_{k-1}' is just as important as u_k'
1.2	The indicator u_{k-1}' is slightly more important than u_k'
1.4	The indicator u_{k-1}' is more important than u_k'
1.6	The indicator u_{k-1}' is intensely more important than u_k'
1.8	The indicator u_{k-1}' is extremely more important than u_k'

c_5 and c_4 are denoted as c_1', c_2', c_3', c_4', c_5' and c_6', so $U_P' = \{u_1', u_2', u_3', u_4', u_5', u_6'\}$. In this calculation, the results of importance comparison are judged by the 9-expert group as follows: $r_2 = 1.2$, $r_3 = 1.4$, $r_4 = 1.2$, $r_5 = 1.4$, and $r_6 = 1.0$. Next, by using formulas (1) and (2), it can be obtained that $\omega_{c6}' = 0.0975$, $\omega_{c5}' = 0.0975$, $\omega_{c4}' = 0.1365$, $\omega_{c3}' = 0.1638$, $\omega_{c2}' = 0.2293$, and $\omega_{c1}' = 0.2752$. This means that the weights of C_1, C_2, C_3, C_4, C_5, and C_6 are 0.2293, 0.2752, 0.1638, 0.0975, 0.0975, and 0.1365, respectively. Repeating these steps, finally, the integrated weight of each indicator can be obtained by using formula (4), as shown in Table 5.

5.3.2. Level Classification and Standard Cloud Computing. According to the comprehensive assessment score, the evaluation results are divided into five certain levels, named as 3A, 2A, A, B, and C. The criteria for these levels are based on the characteristics of power project management, enterprises' quality strategies, and quality objectives of contractors. Level classification shows that the quality management performance of one enterprise or project is outstanding, excellent, good, okay, or passing. It is obvious that the evaluation result can provide an incentive for related participants of power project quality management, as shown in Table 6.

The rating levels are set as "3A," "2A," "A," "B," and "C," and each rating interval is denoted as $[A_{\min}, A_{\max}]$. The formulas for calculating the expectation value, entropy standard, and hyperentropy of the standard cloud model are shown in the following formula:

$$\begin{cases} E_x = \frac{1}{2} \times (A_{\min} + A_{\max}) \\ E_n = \frac{1}{6} \times (A_{\max} - A_{\min}) \\ H_e = b \end{cases} \tag{5}$$

The hyperentropy ($H_e = b$) should be adjusted according to project characteristics. The standard cloud eigenvalues of the five levels are shown in Table 7. According to these eigenvalues, the standard cloud map of CQMS can be drawn by using MATLAB R2017 software, as shown in Figure 4.

5.3.3. Indicator Clouds and Integrated Cloud Computing. In the following section, section 8 of the Kunliulong DC Project is taken as an example for the calculation of indicator clouds and integrated cloud. After checking the actual situation of section 8, a total of 14 management defects were discovered: (1) 9 defects belonging to the aspect of safety, health, and environment management; (2) 1 defect of construction technical management; (3) 1 defect of project process control; (4) 2 defects of physical quality; and (5) 1 integrated defect. The nine experts gave their scores to the 20 indicators according to their understandings, which had differences and led to their different scores, as shown in Table 8.

Step 1: the scoring results of the experts are denoted as $Z_{pq} = (z_{p1}, z_{p2}, \ldots, z_{p20})$ $(p = 1, 2, \ldots, 9)$, representing the nine experts, and $q = 1, 2, \ldots, 20$, representing the 20 indicators from a_1 to c_6. Then, the cloud eigenvalues of indicators can be calculated by using the one-dimensional reverse normal cloud generator model, as shown by formulas (6) to (9). Through this step, the conversion from quantitative to qualitative expression of scoring results can be realized. The cloud eigenvalues of indicator n are denoted as $Cu_n\,(Ex_n, En_n, He_n)\,(n = 1, 2, \ldots, 20)$, and the specific values are shown in Table 9.

$$E_{Xn} = \frac{1}{m}\sum_{p=1}^{m} z_{pq}, \tag{6}$$

$$E_{Nn} = \sqrt{\frac{\pi}{2}}\,\frac{1}{m}\sum_{p=1}^{m} \left| z_{pq} - E_{Xn} \right|, \tag{7}$$

$$H_{En} = \sqrt{|S_n^2 - E_{Nn}^2|}, \tag{8}$$

$$S_n^2 = \frac{1}{m-1}\sum_{p=1}^{m} \left(z_{pq} - E_{Xn}\right)^2. \tag{9}$$

Step2: eigenvalues of the integrated evaluation cloud ($C_U = (E_X, E_N, H_E)$) can be obtained by using the formula group (10), after the indicator weights and eigenvalues of the evaluation clouds are obtained.

$$\begin{cases} Ex = \sum_{n=1}^{20} (E_{Xn} \times \omega_n) \\ E_N = \sqrt{\sum_{n=1}^{20} (E_{Nn}^2 \times \omega_n)}, \\ H_E = \sum_{n=1}^{20} (H_{En} \times \omega_n) \end{cases} \tag{10}$$

By using the data in Table 9, the integrated cloud eigenvalues of section 8 were calculated as $C_U = (89.3527, 1.4667, 0.5179)$. The integrated cloud map is shown in Figure 5. From the simulation results, the integrated cloud map of section 8 is between "2A" and "A" and is more inclined to "2A."

5.4. Comparison of the Evaluation Results of Four Typical Sections. The CQMS performance of the total 19 sections of the Kunliulong DC Project was scored by the

Table 5: Construction quality management standardized evaluation indicator weights and integrated weights.

Layer	Weight of layer (ω)	Indicator	Weight of indicator (ω)	Integrated weight (ω')
Organization (A)	0.2451	Quality management staff (a_1)	0.2555	0.0626
		Subcontracting (a_2)	0.1825	0.0447
		Responsibility allocation (a_3)	0.3066	0.0751
		Duty performance (a_4)	0.2555	0.0626
Quality behaviour (B)	0.3431	Design delivery (b_1)	0.0658	0.0226
		Design change control (b_2)	0.0658	0.0226
		Construction plan (b_3)	0.1590	0.0546
		Specification and implementation (b_4)	0.1590	0.0546
		Quality record (b_5)	0.0548	0.0188
		Material quality control (b_6)	0.0947	0.0325
		Mechanical equipment quality control (b_7)	0.0947	0.0325
		Supervision scheme (b_8)	0.0789	0.0271
		Supervision record (b_9)	0.1136	0.0390
		Inspection and acceptance (b_{10})	0.1136	0.0390
Physical quality (C)	0.4118	Foundation stability (c_1)	0.2293	0.0944
		Tower engineering (c_2)	0.2752	0.1133
		Line construction (c_3)	0.1638	0.0675
		Accessory installation (c_4)	0.0975	0.0402
		Grounding device (c_5)	0.0975	0.0402
		Engineering awards (c_6)	0.1365	0.0562

Table 6: Evaluation results, comprehensive score, and performance level of CQMS.

Evaluation result	Comprehensive score (Z)	Quality performance level
3A	$Z \geq 95$	Outstanding
2A	$90 \leq Z < 95$	Excellent
A	$80 \leq Z < 90$	Good
B	$70 \leq Z < 80$	Okay
C	$60 \leq Z < 70$	Passing

Table 7: Standard cloud eigenvalues of CQMS evaluation.

Level	Rating interval	Standard cloud eigenvalues
3A	[95, 100]	(97.5000, 0.8333, 0.50)
2A	[90, 95)	(92.5000, 0.8333, 0.50)
A	[80, 90)	(85.0000, 1.6667, 0.50)
B	[70, 80)	(75.0000, 1.6667, 0.50)
C	[60, 70)	(65.0000, 1.6667, 0.50)

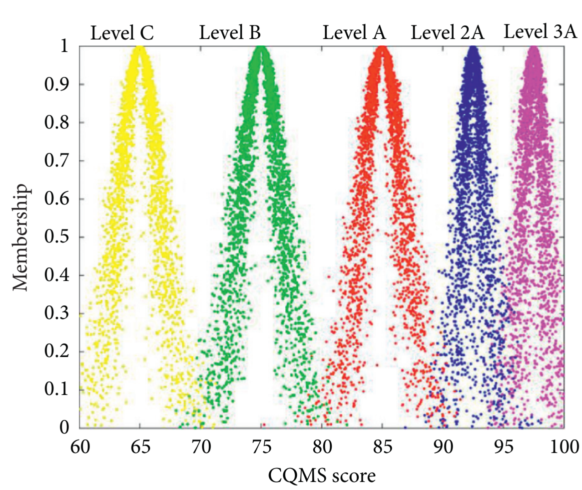

Figure 4: Standard cloud map of CQMS evaluation.

Table 8: Indicator scoring results of section 8.

Indicator	Score								
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9
a_1	92	90	91	92	93	92	90	89	91
a_2	76	78	75	75	76	76	75	74	75
a_3	97	96	95	93	94	95	93	95	96
a_4	89	88	87	87	88	89	90	89	88
b_1	93	90	92	90	89	88	91	90	90
b_2	96	94	93	93	97	96	95	97	93
b_3	81	80	81	83	80	82	80	76	79
b_4	86	83	85	84	85	80	82	83	83
b_5	93	90	89	94	91	92	90	89	91
b_6	96	95	94	93	93	95	93	94	93
b_7	83	81	82	85	85	82	85	81	83
b_8	91	90	89	88	90	89	87	88	89
b_9	87	85	80	83	85	84	85	86	85
b_{10}	91	90	91	90	90	89	93	89	90
c_1	96	94	93	92	95	93	95	94	95
c_2	87	85	87	88	86	83	82	86	87
c_3	93	90	93	95	94	90	91	92	93
c_4	93	90	89	92	93	93	93	95	95
c_5	94	94	93	96	95	96	95	94	93
c_6	95	94	96	96	96	97	97	98	96

Table 9: Indicator weights and cloud eigenvalues of section 8.

Indicator	Indicator weight	Cloud eigenvalues of each indicator
a_1	0.0626	(92.1111, 1.2688, 0.0346)
a_2	0.0447	(75.5556, 1.0522, 0.4131)
a_3	0.0751	(94.8889, 1.2997, 0.4146)
a_4	0.0626	(88.3333, 1.0212, 0.2070)
b_1	0.0226	(90.3333, 1.3926, 1.6002)
b_2	0.0226	(94.8889, 1.8258, 1.5455)
b_3	0.0546	(80.2222, 1.7020, 1.0235)
b_4	0.0546	(83.4444, 1.7330, 1.8848)
b_5	0.0188	(91.0000, 1.6710, 0.4558)
b_6	0.0325	(93.9444, 1.1914, 0.1292)
b_7	0.0325	(83.0000, 1.6711, 0.1972)
b_8	0.0271	(89.0000, 1.1141, 0.5087)
b_9	0.0390	(84.4444, 1.7639, 0.9573)
b_{10}	0.0390	(90.3333, 1.1141, 0.5087)
c_1	0.0944	(94.1111, 1.2688, 0.0354)
c_2	0.1133	(85.6667, 1.9496, 0.4462)
c_3	0.0675	(92.3333, 1.7639, 0.3337)
c_4	0.0402	(92.5556, 1.2997, 0.2976)
c_5	0.0402	(94.4444, 1.1759, 0.3239)
c_6	0.0562	(96.1111, 1.0212, 0.5641)

nine-membered expert group, by repeating the above steps of scoring, cloud eigenvalue calculation, and level classification. The inspection results and integrated cloud eigenvalues of typical sections (sections 1, 5, 8, and 16) are shown in Table 10. Accordingly, their integrated cloud maps are shown in Figure 6.

The evaluation results of CQMS performance of typical sections of Kunliulong DC Project are as follows:

(1) The integrated cloud map of section 1 is between "2A" and "3A" and is closer to "3A," which means the CQMS performance of section 1 achieved an "outstanding" level

(2) The integrated cloud map of section 5 is between "C" and "B" and is closer to the "C" level which means the CQMS performance of section 5 just meets the "passing" level

(3) The integrated cloud map of section 8 is between "A" and "2A" and is closer to "2A" which means the CQMS performance of section 8 is close to an "excellent" level

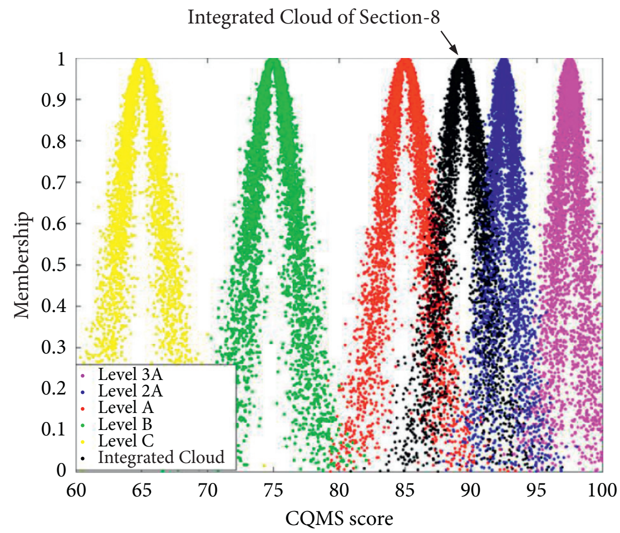

Figure 5: CQMS evaluation integrated cloud map of section 8.

Table 10: CQMS inspection results and integrated cloud eigenvalues of typical sections.

Line	Expert group inspection results		Composite score	Integrated cloud eigenvalues
	Management aspect	Number of defects		
Section 1	Safety, health, and environmental management	3	95.76	$C_U = (95.7624, 1.4521, 0.4687)$
	Technical management	3		
	Information management	1		
	Design management	1		
	Overall planning	1		
	Quality organization or behaviour	1		
Section 5	Safety, health, and environmental management	5	66.39	$C_U = (66.3950, 1.4528, 0.5405)$
	Subcontracting	2		
	Construction preparation	1		
	Process control	1		
	Disclosure and implementation	1		
	Financial control	1		
	Quality organization or behaviour	9		
Section 8	Safety, health, and environmental management	9	89.35	$C_U = (89.3527, 1.4667, 0.5179)$
	Technical management	1		
	Process control	1		
	Physical quality	2		
	Information management	1		
Section 16	Safety, health, and environmental management	10	73.45	$C_U = (73.4472, 1.5051, 0.3906)$
	Quality organization or behaviour	5		
	Information management	4		

(4) The integrated cloud map of section 16 is between "C" and "B" and tends to be consistent with "B," which means the CQMS performance of section 16 is at the "okay" level

It can be proven from the above results that the evaluation results based on the cloud model are well consistent with the real situation of quality management as inspected by the expert group. The evaluation based on the cloud model method considers the randomness and fuzziness in the evaluation process. In addition, the cloud map transforms qualitative language to a quantitative value and is intuitionistic. The evaluation results of different sections showed an objective gap, which is convenient for managers to grasp the overall situation of project quality management. It can also help managers carry out special improvements for the sections in relatively unsatisfying situations.

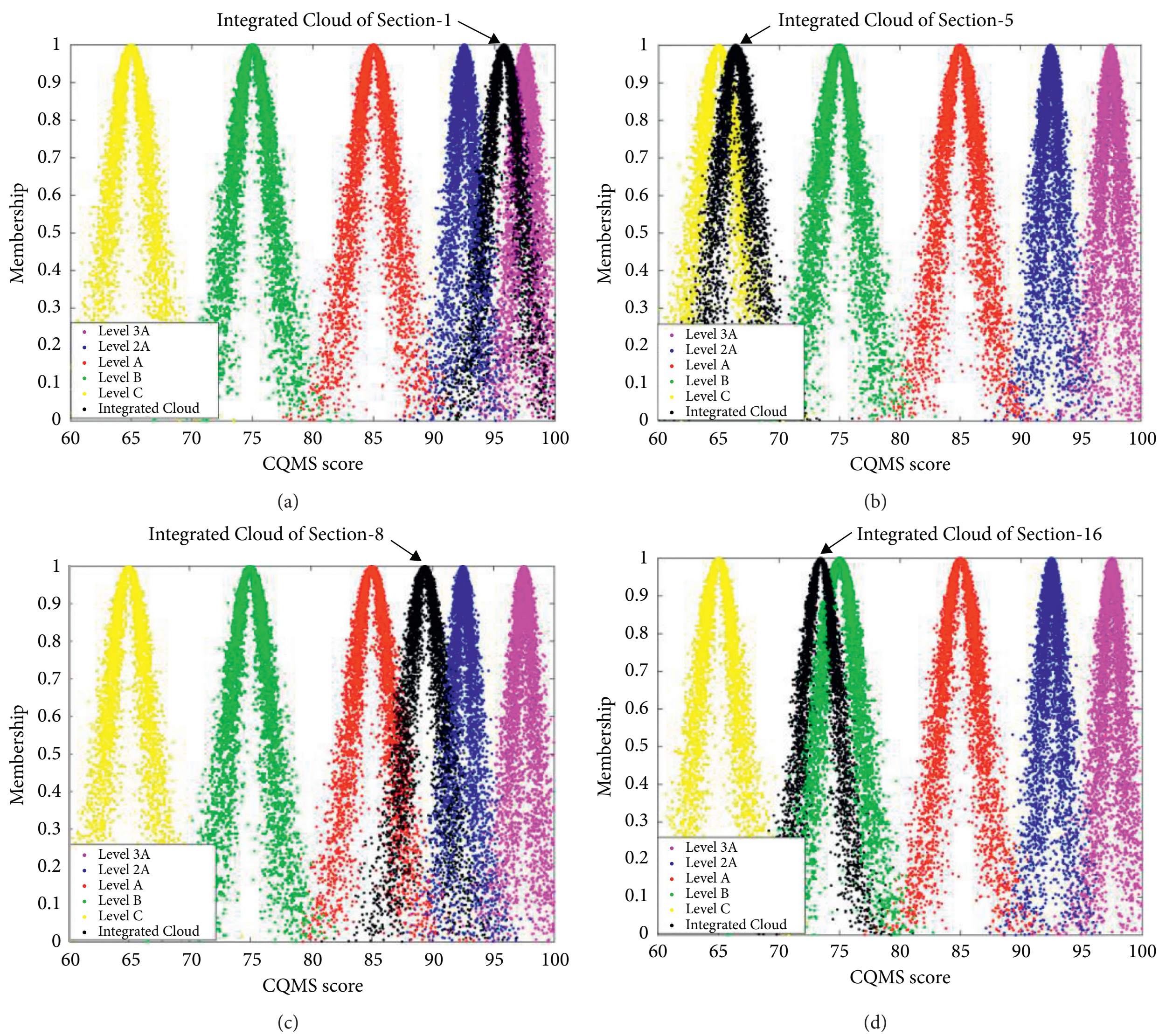

FIGURE 6: Comparison of CQMS evaluation integrated cloud maps of sections 1, 5, 8 and 16. (a) Line of section 1. (b) Line of section 5. (c) Line of section 8. (d) Line of section 16.

6. Conclusions

This paper discusses the conception of CQMS, establishes the model of CQMS evaluation index system based on the best practices in China, and conducts a case study about CQMS inspection and evaluation. The main conclusions and contributions of this research are as follows:

(1) Construction quality management is a systemic issue, including multiple stages, participants, and elements. Quality management has passed through a long developmental process period and proposed some classic and effective management systems such as ISO 9000 and TQM. Leading enterprises or professional consultant organizations have accumulated an abundance of useful experience in quality management. These experiences should be collected, refined, structured, and disseminated to the industry, so that they can be a valuable reference for other organizations or projects. Standardization is such a tool to generalise and popularize good experience and best practices from individual organizations to a field or whole industry. Moreover, CQMS refers to a deep combination of construction quality management and standardization.

(2) Standardization is especially applicable for construction quality management under a systematic thinking way. After identifying and decomposing the participants, stages, objectives, requirements, and processes of construction quality management, the CQMS framework was established clearly and comprehensively. Three major aspects, organization, quality behaviour, and physical quality, are involved and further decomposed into detailed management factors. Consistently, an evaluation index system for CQMS can be established, but this system is not strictly stationary; instead, it needs to be adjusted

according to a project's characteristics and client requirements. Moreover, this evaluation can achieve better results if it is conducted under the support of special regulations or procedures.

(3) The appropriate selection of evaluation methods is essential for obtaining convincing and intuitionistic information, and a typical case study can provide strong verification for the established CQMS evaluation model. Based on the data collected from the Kunliulong DC Project by a specifically chosen nine-membered expert group, the total evaluation process was illustrated. The G1 method is used to obtain the indicator weights, and the cloud model is adopted to calculate the cloud eigenvalues of each indicator and the integrated cloud eigenvalues of the whole index system. From a total of 19 sections, 4 sections (sections 1, 5, 8, and 16) were selected as representative sections. Especially in section 8, all evaluation steps were described.

(4) The evaluation results of the four representative sections were compared, showing that the CQMS performances of sections 1, 5, 8, and 16 are, respectively, close to "3A," "C," "2A," and "B" level, and they can be expressed as "outstanding," "passing," "excellent," and "okay." These results are distinguished and intuitionistic, which can help managers know instantly the situation regarding construction quality management of different sections and improve those weak points. Lastly, it verified that the index system and evaluation method of CQMS had good practicability.

This paper is an application of CQMS in the power engineering field and provided some new ideas for managers or decision-makers to standardize the quality management and inspection of power project sites for future consideration. As some researchers' view, the authors also agree that CQMS is a fluid system problem. This means that the evaluation indicators of CQMS in this paper only cover the main elements of power engineering quality management. With the continuous practice of on-site CQMS, more evaluation factors should be evaluated. In addition, although the G1 method is easy to operate and relies, to a certain extent, on the subjective opinions of experts, it still may reduce the credibility of the evaluation results, and the weight of each indicator may be obtained through better methods. These deficiencies may be remedied in future studies.

Data Availability

All data, models, and code generated or used in this study are available from the corresponding author upon request.

Disclosure

Any opinions, findings, and conclusions expressed in this material are those of the authors and do not necessarily reflect the foundations' views.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this study.

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