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Sustainable Construction Project Management (SCPM) Evaluation—A Case Study of the Guangzhou Metro Line-7, PR China

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Abstract: As a pillar industry of the Chinese national economy, the construction sector needs to improve its level of management to embrace sustainable development. Sustainable construction project management (SCPM) performance evaluation can help to raise the level of management. However, the existing evaluation system that takes into account both the sustainable development and the dimension of traditional project management is meager. In order to address this problem, this study sets out an integrated sustainable performance evaluation method for SCPM, along with a comprehensive analysis of both traditional and future management directions. Through literature review and enterprise data analysis of the relevant factors of finance, schedule, quality, and safety, etc., indicators are filtered and classified. In order to determine the strength of each indicator, a questionnaire is administered to construction professionals within a large construction enterprise (group). From the result of the weight with an improved Group-G1 (iG1) method (finance 0.206, schedule 0.206, quality 0.185, safety 0.134, informatization 0.134, and greenization 0.134), it indicates that finance, schedule and quality management are still top three important dimensions in SCPM. However, amazingly, the greenization and informatization management is as significant as safety management. Finally, based on set pair analysis, the Guangzhou Metro Line 7 project is used as a verifying case, affirming the validity of the sustainable performance evaluation model. The above SCPM evaluation model can not only provide a guideline for construction companies' sustainable management in China, but also serve as reference cases for other countries/regions to carry out relevant research work.

Keywords: sustainable construction project management (SCPM); sustainable performance evaluation; set pair analysis; informatization; greenization; Guangzhou metro; China

1. Introduction

In recent years, with the rapid growth of China's economy and the acceleration of urbanization, the construction industry has developed rapidly [1]. The total output value of China's construction industry in 2017 was 5569 billion yuan, nearly four times higher than a decade ago [2]. Against this background, the construction industry has significant economic, environmental, and social impacts on society [3]. For instance, the construction industry in China contributes 6.7% to the gross domestic product (GDP) and provides more than 5.5 million jobs [2]. However, problems such as low profit, large resource consumption, serious environmental pollution, and poor ability to utilize information technology within the construction industry have raised concerns [4]. Moreover, traditional management fails to adequately address problems that often exist in areas of quality, scheduling, and safety, etc. [5]. China's state-owned construction companies generate a profit margin of 3.5%, compared with 10% for foreign companies [2]. According to the World Business Council for Sustainable Development, the construction industry accounts for about 40% of total national energy consumption, and produces between 45% and 65% of the disposed waste in landfills [6]. At the same time, the informatization level of the construction industry is only higher than that of agriculture, ranking the second to last among all industries [7]. Simply, the high-speed construction industry development pattern of 'high consumption, high pollution, low informatization, and low profit' is a matter requiring urgent attention [8].

Consequently, how best to improve the economy, environment, and social equity, by way of improving the level of management, has become topical within the industry. The quality of management within construction enterprises, which directly impacts the value of projects, and return to stakeholders [9], also impacts the enterprises' sustainable development. Effective performance evaluation of CPM is an important way to improve this management level. Effective performance evaluation of CPM can help managers not only identify existing project problems in a timely manner, but also put forward relevant improvement measures and solutions, ultimately improving the overall performance and management efficiency of construction project managers. However, at present, studies on evaluating the CPM performance have mostly focused on the economic benefits [8], while the environmental problems and information management issues are largely ignored. Furthermore, the majority of construction enterprises in China do not yet have a complete and effective SCPM performance evaluation system [9].

In line with the discussions above, it is, thus, necessary to establish an SCPM performance evaluation system geared to improving both the 'greenization' of projects and 'informatization', ensuring the sustainable development of the construction industry. Therefore, this study seeks to address the following research questions:

1. The existing studies for CPM mostly consider the financial, quality and schedule management. However, these dimensions are insufficient for sustainability evaluation from the social, environmental, and economic perspective.
2. The complexity of processes results in difficulty in establishing a SCPM evaluation system because of the lack of an effective method. No coordination analysis was made in the existing sustainable evaluation systems, and the comprehensive optimal management for SCPM could not be obtained.
3. This is a problem of how to establish a unified dimensional evaluation model for SCPM form integration from the perspective of sustainable development.

To answer the above overall questions, the remainder of this research is structured into the following sections. Section 2 focuses on related literature review. The establishment of a sustainable performance index system and a brief introduction for the assessment model are provided in Section 3. Then, Section 4 confirms the weight of the indicators with an iG1 method. In Section 5, a set-pair analysis (SPA) is proposed to assess the sustainable performance in a case study of Guangzhou metro line-7. Finally, the major findings, conclusions, and future areas of research of this study are given.

2. Literature Review

2.1. Traditional CPM Performance

The PMBoK (project management body of knowledge) contains the globally recognized standards and guides for the project management profession [9]. It is the general description of knowledge, skills, and tools required for project management by the Project Management Institute (PMI) [10,11]. It identifies ten knowledge areas for organizing processes: Stakeholder, integration, scope, time, cost, risk, quality, human resources, procurement, and communication [12]. Certain studies have measured performance across some of these knowledge areas or revealed the impact of specific knowledge areas on performance [12]. The performance evaluation of CPM often involves some aspects of the project knowledge area. In terms of CPM, the majority of research studies focus on timely completion [13–16], under budget completion [17–20], safely completed works [21–23], and meeting quality criteria [24–26]. In light of previous studies, those mostly cited indicators will be retained for traditional CPM performance evaluation.

2.2. Sustainable Development

There have been extensive studies conducted on sustainable development over the last decade [27]. These studies have been undertaken in both developed countries and developing countries, indicating that this is a global concern [28]. The concept of sustainable development was first defined in 1987, in the report of the World Commission on Environmental and Development titled “Our Common Future” (the so-called Brundtland Report) [29]. Sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs [29]. In 1997, sustainable development which encompasses the ‘triple bottom line’ of economic, environmental, and social condition into account, was defined as a necessary strategy for China’s construction modernization [30]. It is worth emphasizing that in the Brundtland report itself, there are many direct references to management sciences [29]. The phrase ‘sustainable’ appears in many different contexts, from such narrow, specialist approaches as farm management [31] or coastal zone management [32], to more general areas like economic management [33], international management [34], or even global management [35].

After more than 30 years of development, research on sustainable development in management science is still growing [28]. Many fields have been studied, such as resource consumption [36], garbage disposal [37], and sustainable technology innovation [38]. With such extensive research on the concept of sustainable development in the field of management, greenization has emerged as a widely accepted phenomenon necessary to the implementation of triple bottom-line development of buildings in the construction industry [39]. Many scholars have conducted research in this field. For example, Ding reviewed several widely used building and construction environmental assessment methods across different countries and concluded that current assessment methods did not adequately consider environmental impacts [40]. Whang and Kim developed an assessment of factors for sustainable construction projects in Korea, by concentrating on environmental issues as well as economic and social dimensions [41]. There is a consensus that environmental performance is highly characterized by greenization, such as improved energy, water efficiency, enhanced air quality of construction sites, and reduced environmental pollution [42]. For this reason, greenization is considered an essential ingredient in any CPM performance evaluation index.

2.3. SCPM Performance

Construction projects are increasingly more difficult and complex [43], where construction is a highly project-based industry in which various organizations must couple with each other through project-specific collaborative relationships [44]. In order to optimize, automate, and modernize the traditional processes of this industry, information management has been increasingly valued and is already changing the current systems used in construction projects [45]. The industry has witnessed a growing interest in using the concept of building information modeling (BIM) in conjunction with sustainability principles during the design and construction phases of building projects [46]. BIM also helps reduce miscommunication and errors arising among construction stakeholders [47].

Greenization [48] (the ability to implement ‘green’ construction) places emphasis on environmental issues while the informatization [49] (the ability to manage and utilize accrued construction information) stresses the importance of innovation technologies [43,45,50,51]. Both of them are indispensable and necessary conditions for the sustainable development of the construction industry [42]. However, few studies on performance evaluation take these two points into consideration simultaneously. In this study, SCPM is defined in line with the definition proposed by Silvius [48]. This refers to the comprehensive and harmonized assimilation of social, economic, and environmental principles into effective construction project management systems [52]. The SCPM has been widely investigated in recent years, and the strategic importance of sustainability for construction enterprises has increased [53]. Zheng evaluates the trend of sustainable development in construction industry based on factor-cluster analysis [54]. Banihashemi and Kiani look at the critical success factors affecting the integration of sustainability into project management practices of construction projects in developing countries [55,56]. Pham measures the performance of CPM in the effects of sustainable practices and managers' leadership competencies [57]. However, these studies only consider some factors driving the sustainability of construction companies and lack a specific and feasible sustainable evaluation system.

Bamgbage suggests that sustainable performance in the construction industry includes social well-being, environmental protection, and financial earnings—-the three main objectives [58]. The SCPM should not only consider the above performance concerns, but also considers the current industry's need to move towards sustainable development.

3. Methodology

In view of the above literature review, this paper aims at establishing a set of sustainable performance evaluation indexes considering social well-being, environmental protection, and financial earnings, along with a set of feasible evaluation methods to ensure that reasonable performance evaluation can be realized within a project. Firstly, the comprehensive evaluation index system of SCPM is constructed. In the index system, the greenization and informatization are not considered in isolation, but their impact on traditional project management performance measures, such as finances and safety, is also reflected. Secondly, the ratings for the evaluation index that is modeled by the iG1, are given in linguistic terms. Given different kinds of professional knowledge and work experience, the evaluators' understanding of the evaluation index and the enterprises may be different. Thus, in aggregating linguistic ratings, the amount of calculation is small so as to reduce errors. Thirdly, the feasibility and practical application of the proposed approach is verified using a case study of the Guangzhou Metro Line 7 (GML7). It also provides a valuable reference for the implementation of the evaluation of SCPM for other construction enterprises.

3.1. Index System of SCPM Performance

3.1.1. The Dimension of the Index System

An important step in establishing a comprehensive performance evaluation system for SCPM is to identify key aspects. It is impossible to analyze all aspects of SCPM. Such an attempt might not only confuse the experts of interactive information but also lead to an inefficient evaluation process. The indicators of this research are mainly established through three channels: Literature review, enterprise database analysis, and the future development trend analysis of the construction industry. The framework of the performance evaluation index system establishment is shown in Figure 1. The first step is the selection of the dimension of the evaluation index system. The traditional dimension of management performance includes financial, safety, schedule, and quality. Others, the frontier dimension includes two aspects, which are informatization and greenization. The second step is classification and filtering the secondary indicator based on literature review and construction enterprise management database.

The "knowledge area" proposed by PMI has been used in traditional CPM performance research studies. Various studies have focused on reducing the integration management [59], construction cost [20,60], and schedule control [61,62]. Demirkesen and Ozorhon contributed to the project management body of knowledge in that it develops a conceptual framework consisting of specific components for integration CPM [63], whereas the dimensions of project management performance are time, cost, quality, safety, and client satisfaction. Tan and Xiong sorted out 50 domestic theses related to performance evaluation in China and finally listed the high-frequency performance indicators which were divided into different hierarchical structures [59]. In their review, the most frequent indicators focus on financial, quality and time management. The performance evaluation indicators of large-scale engineering projects were divided into five categories: Human, material, machine, method, and environment [64]. In this study, we chose the four most representative dimensions, which are finance [65,66], safety [67–69], schedule [70–72], quality [73–75], as the dimensions of the performance index system for SCPM.

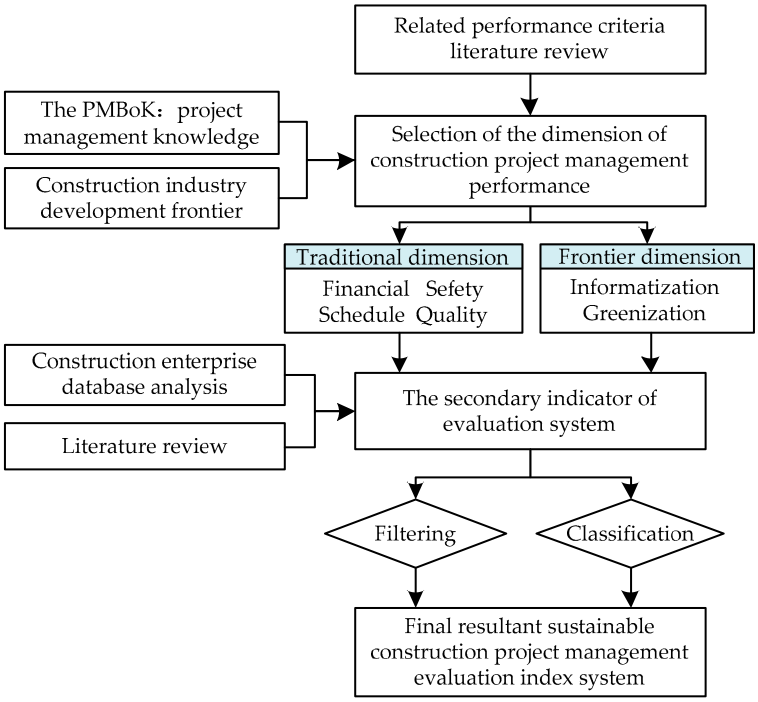

Figure 1. Conceptual framework of performance evaluation index system establishment.

In addition to the four dimensions of project management mentioned above, the SCPM performance should take the sustainable development of enterprises into account and encourage the application of cutting-edge technologies to adapt to the future development of the industry. Therefore, based on the traditional view and the perspective of future development, the final sustainable performance index system should consist of the six dimensions: Finance, safety, schedule, quality, informatization, and greenization management.

3.1.2. The Secondary Indicators of the Index System

The database established by this enterprise includes two parts: historical projects and actual needs of the Sichuan Huashi construction enterprise group (Huashi Group), which contains 18 sub-construction companies at home and abroad. The Huashi Group ranks 18th among China's top 60 contractors in ENR, with annual revenue from its main business exceeds 12.7 billion yuan, and stands for the overall development level of the construction industry.

The secondary indicators are filtered and classificated from the Huashi Group management database and literature review. This research looks for the 39 secondary indicators of the six dimensions, Figure 2 shows the final index system for the comprehensive performance evaluation of the SCPM, and then, the secondary indicators are described in the next chapter.

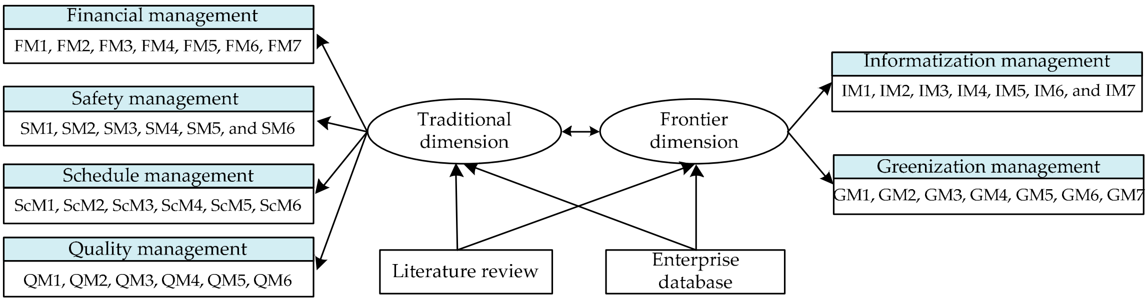

Figure 2. The comprehensive performance index system for the sustainable construction project management (SCPM).

Indicators for Financial Management

A company attaches much significance to financial management, which determines how much benefit the construction enterprise can get from a project. According to the enterprise database, the financial management contains three aspects, which are overall financial position, construction costs and financial management plans of the project. The overall financial situation of the project is measured by FM1 (project profit ratio), FM2 (unit profit) and FM3 (per capita profit). FM4 (project cost-saving), FM5 (success of project claims) and FM6 (project payment default) during the project construction stage are used to measure the funds and cost management ability. Beyond that, FM7 (the financial management plan) is crucial to the success of the project.

Indicators for Safety Management

Project safety management is critical to the success of the project. In the database, safety management contains two aspects, which are safety management results and security awareness. SM1 (safety and security inspections passed rate), SM2 (safety accident occurrence), and SM3 (gracious construction award) are used to measure the safety management performance. In addition, construction enterprises should raise their security awareness in terms of SM4 (safety education training), SM5 (hazard identification) and SM6 (safety construction facilities).

Indicators for Schedule Management

According to the database, in previous historical projects, the project managers mainly controlled the project schedule from three aspects: Whether the project was completed on time, whether the sub-contract project duration was reached, and whether the schedule plan was practical and rational. The ScM1 (time saving rate: The difference between the planned and the actual schedule) and the ScM2 (unit-project competed rate) are used to measure the completion of the schedule. The sub-contracts schedule conditions are measured by ScM3 (completion rate of labor sub-contracts) and ScM4 (specialized sub-contracts). In the schedule management system, managers need to input the ScM5 (image progress plan record), and ScM6 (realistic schedule planning) determines the outcome to a large extent.

Indicators for Quality Management

Management situation of project quality is mainly evaluated from three aspects: The quality acceptance rate, the quality self-inspection situation, and the quality plan. Quality acceptance rate is divided into three categories: QM1 (the outcome), QM2 (sub-engineering), and QM3 (construction unit) qualification rate. The quality self-examination of the project is measured by QM4 (worker self-examination passed rate). Moreover, QM5 (quality accident occurrence) and QM6 (quality planning) are used as the evaluation indicators of the quality plan.

Indicators for Informatization Management

Because informatization is an important means to improve the management level, project managers should enhance the level of informatization from two aspects: The technology and the management. There are four indicators to measure the level of information technology which are the IM1 (information modelling), IM2 (information management), IM3 (software and hardware configuration), and IM4 (training of personnel of building information management). Furthermore, the management of informatization also should consider the IM5 (information platform), IM6 (dynamic tracking management) and IM7 (enterprise database establishment).

Indicators for Greenization Management

Greenization is the future direction of the construction industry, and the greenization management of construction projects is mainly from the view of green construction. The managers should consider three aspects: The greenness of the construction site, the greenness of the construction materials, the disposal of construction waste. The GM1 (satisfaction degree of residents around), GM2 (green site award) and GM3 (green inspection passed rate) are the key indicators to measure the greenness of the construction site. The greenness of the materials was measured by GM4 (green material usage) and GM5 (resource-saving situation). Otherwise, GM6 (the disposal of construction waste which contains noise, flying dust, effluent, and garbage) is also a big problem for project managers. Furthermore, GM7 (green construction plan) is an important guarantee.

However, the importance of each indicator may vary from one project to another. It is necessary to develop a methodology to quantify the importance of SCPM performance indicators. Therefore, this research proposes a new approach that combines an SPA and a combination weighting of iG1 to establish a performance evaluation of the SCPM performance model. Based on a questionnaire survey, this approach evaluates the extent to which the project participation sides value each performance indicator. Then the quantified extents are converted into an importance matrix through iG1. The proposed method is detailed in the next chapter.

3.2. Assessment Model

3.2.1. The iG1 Weight Method

Compared with the analytical hierarchical process (AHP), iG1 weight method has the following three advantages: (1) It is applicable to a situation where the judgment matrix is an inconsistent matrix. (2) Multiple experts have the rank of importance of different indicators. (3) The amount of calculation is small so as to reduce errors. In order to reduce the interference of subjective factors in application, it is usual to invite multiple experts to judge the indices by importance at the same time. In addition, the problem of expert group judgment is that the judgment matrix is usually inconsistent, and different opinions are more likely to arise when determining the relative importance ratio of indicators. Therefore, this research offers some improvements to the iG1 weight method. Finally, the rank of these factors by the individual degree of their influence on construction management converts the component values, and then the ratio of the score standard deviation of adjacent indicators determines the importance degree of the indicators, making the importance weight of the indicators more scientific and reasonable.

Firstly, the ranking of multiple experts is conducted in the second comprehensive ranking, the ranking of indicators is converted into scores R_{ij} (the first important score is m, the second important score is $m-1$, etc.), and then the score of each expert is summarized to obtain the comprehensive scores R_i^* of indicators.

$$R_i^* = \frac{1}{n}\sum_{j=1}^{n} R_{ij} (j = 1, 2, 3, \ldots, n) \quad (1)$$

Secondly, according to the score R_i^*, the higher the score, the higher the ranking, and vice versa. If two indicators score the same, the ranking is determined by calculating the standard deviation of different scores. The comprehensive ranking of indicators is R_k.

$$\sigma_i = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(R_{ij} - R_i^*\right)^2} \quad (2)$$

If the ranking is based on the standard deviation of the score, the higher the score, the lower the ranking, and vice versa. If the scores of the two indicators are the same, the ranking is the same.

After the comprehensive ranking is determined, the ratio of x_{i-1} to x_i degree of importance is determined by the standard deviation of the indicator score.

$$x_i^* = \frac{1}{n}\left(x_{i,1} + x_{i,2} + \ldots + x_{i,j}\right) \quad (3)$$

$$s_i = \sqrt{\frac{1}{n}\left[\left(x_{i,1} - x_i^*\right)^2 + \ldots + \left(x_{i,j} - x_i^*\right)^2\right]} \quad (4)$$

$$r_i = \begin{cases} s_{i-1}/s_i, s_{i-1} \geq s_i \\ 1, s_{i-1} < s_i \end{cases} \quad (5)$$

$$\omega_m^* = \left(1 + \sum_{k=2}^{n}\prod_{i=k}^{n} r_i\right)^{-1} \xrightarrow{\text{recursion}} \omega_{m-1}^* = r_i\omega_m^* \quad (6)$$

where x_{ij} represents the score of the jth expert to the ith indicator in their dimension, s_i represents the standard deviation of the ith indicator, and x_i^* is the average score of all experts. The final combined weight is $w_m^*, w_{m-1}^*, \ldots, w_1^*$.

3.2.2. The SPA Evaluation Model

To reflect the realistic circumstance in a construction project, only the hierarchy of sustainable performance is not adequate to evaluate the project management comprehensively. To accommodate this, the set pair analysis model is introduced to calculate the nearness degree of sustainable performance by using the association degree function. It is not only able to judge the tightness of the relationship between the appraised object and the various hierarchies, but also to find out the transformation trends of adjacent hierarchies, thus, the accuracy of the evaluation results has been improved.

The SPA method, proposed by Zhao in 1989 [76], is a systematic methodology considering both certainties and uncertainties as an integrated certain-uncertain system and depicting the certainty and uncertainty systematically from three aspects: Identity, discrepancy, and contrary. Set pair refers to a couple that consists of two interrelated sets. The basic idea of SPA is to analyze the features of a set pair and set up a connection degree formula of these two sets including identity degree, discrepancy degree and contrary degree under certain circumstances. Based on the connection degree formula, a series of SPA-based researches have been conducted [77,78]. In the process of performance assessment for SCPM, the dimension can be considered as set A, and the evaluation elements of performance assessment can be considered as set B. And the evaluation elements of performance assessment can be considered as set B. Then two sets constitute a set pair $\mu = (A, B)$. Connection degree $\mu_{(A-B)}$ is used to analyze the mathematics property of set pair $\mu_{(A-B)} = a + bi + cj$. This is the three-member connection degree, the fundamental formula of SPA. Because there are usually more than three levels in practice, b_i is usually extended as: $b_i = b_1 i_1 + b_2 i_2 + \ldots + b_{r-2} i_{r-2}$. Then the connection could be expressed as:

$$\mu_{(A-B)} = a + b_1 i_1 + b_2 i_2 + \ldots + b_{r-2} i_{r-2} + cj.$$

where a, b and c are the identical degree, discrepancy degree and contrary, respectively. $b_1, b_2, \ldots, b_{r-2}$ are the partial quantities of discrepant coefficient and $a + b_1 + b_2 + \ldots + b_{r-2} + c = 1$, $i \in [-1, 1]$, $j = -1$, $i_1, i_2, \ldots, i_{r-2}$ are the uncertainly coefficient of discrepancy degree, j is the coefficient of contrary degree, $r = 1, 2, \ldots, r$ and r is the number of members in A or B.

Where $t = 1, 2, \ldots, m$, and m is the number of indicators, at-coefficient that the tth member in A are in the same level with and the member in set B, $b_{t,1}, b_{t,2}, \ldots, b_{t,r-2}$-coefficient that the partial quantities of discrepant coefficient and $b_{t,i}$ denotes the two members from A and B, respectively, have a distance of i levels, $i_1, i_2, \ldots, i_{r-2}$-the discrepant marking coefficient, c_t is the coefficient means that the two members have the farthest distance of levels, and $a + b_1 + b_2 + \ldots + b_{r-2} + c = 1$. The formulas to calculate the identity–discrepant–contrary coefficients are as below (set four-elemental connection degree for example).

1. When the evaluation indicator is in grade I,

$$\mu_{I1} = \begin{cases} 1 & X_t \geq S_{1t} \\ 1 + \frac{2(X_t - S_{1t})}{S_{1t} - S_{2t}} & S_{2t} \leq X_t < S_{1t} \\ -1 & X_t < S_{2t} \end{cases} \tag{7}$$

2. When the evaluation indicator is in grade II,

$$\mu_{I2} = \begin{cases} 1 & S_{2t} \leq X_t < S_{1t} \\ 1 + \frac{2(X_t - S_{1t})}{S_{1t} - S_{0t}} & X_t > S_{1t} \\ 1 + \frac{2(X_t - S_{2t})}{S_{2t} - S_{3t}} & S_{3t} \leq X_t < S_{2t} \\ -1 & X_t < S_{3t} \end{cases} \tag{8}$$

Similarly, the connection degree calculation equation can obtain, when the evaluation indicator is in grade III, IV.

3. When the evaluation indicator is in grade IV,

$$\mu_{I4} = \begin{cases} 1 & S_{4t} \leq X_t < S_{3t} \\ 1 + \frac{2(X_t - S_{1t})}{S_{1t} - S_{2t}} & S_{3t} \leq X_t < S_{2t} \\ -1 & X_t > S_{2t} \end{cases} \tag{9}$$

S_{1t}, S_{2t}, S_{3t}, S_{4t} and are the corresponding thresholds of evaluation degree I, II, III, IV respectively.

From the third chapter, the weight of key performance indicators is $W = (\omega_1, \omega_2, \ldots, \omega_n)^T$, Therefore the connection degree of $\mu_{(A-B)}$ is defined as:$\mu_{(A-B)} = \sum_{t=1}^{m} (\omega_t - \mu_{It})$.

When $\mu_{(A-B)} = \max\{\mu_{st}\}$, the t indicator belongs to the level i, the association degree for the t indicator to the level i is μ, which must be greater than the association degree to other levels. Combined with the characteristics of the project and the key points of construction, it can make the corresponding recommendations for SCPM performance.

3.3. Determination of the Weights

As discussed in the previous section, the SCPM performance index system has been identified. The next step is to score these indicators against certain dimensions. As the weight for these indicators can be complex, iG1 is then applied to reduce the impact of subjective elements and to analyze the final weight of the sustainability dimension in the entire system.

4. Data Collection

4.1. Survey Population

As a systematic technique of data collection, the questionnaire survey method has been widely used to collect professional opinions on the issues influencing the adoption of various innovations in construction management research. This study identified and selected respondents to the questionnaire that were especially knowledgeable or experienced within the construction industry. The participants were developers, constructors, designers, surveyors, and others who were involved and knowledgeable in SCPM. These people altogether constituted the sustainable building development team. An internet survey was carried out to rank the SCPM performance indicators. Out of the 64 questionnaires received, nine were rejected because of incomplete responses. Again, some were not properly filled. In this study, the remaining 55, through the questionnaire consistency check (Cronbach alpha $\alpha = 0.823 > 0.7$), were used for analysis.

The survey questionnaire consisted of two parts, part 1 aimed at determining the basic information about interviewees and part 2 aimed at their views on ranking the performance indicators of SCPM.

The certified 55 questionnaires indicated the academic background of the respondents as follows: 72% were degree holders, 36% were postgraduates. Thus, it is evident that the respondents had either university or polytechnic education. On the unit of analysis, the response rates showed that developers constituted 20% of the respondents, constructors 45.5%, surveyors and valuers 16.4%, designers 12.7%, and others 5.4%. Regarding years of professional experience, 38.2% have one to three years, 18.2% have four to six years, 14.5% have seven to nine years, and 29.1% have 10 years or above of experience. As to the frequency of performance evaluation, the annual part makes up a share of 20%, the quarterly part accounts for 60.0%, the monthly part 9.1 %, and the part of only once 10.9%. As for project performance evaluation, about 32.7% of the informants deem it very important, 60% think it is important and 5.5% consider it general important while 1.8% feel it is unimportant.

4.2. Survey Questionnaire

The scoring system which is commonly used in assessments of performance management usually includes the following two procedures: Setting up scoring dimension and basing the scoring on those dimensions. The largest characteristic is that the questionnaire focuses on the importance degree of multiple indicators in their respective criteria instead of the rank of a single indicator. For example, the order of importance of the indicators in informatization management by the *i*th. It can be expressed as $IM_j = \left\{IM_{1j}, IM_{2j}, \ldots, IM_{ij}\right\}$.

4.3. Data Analysis

All total scores for the comprehensive SCPM performance indicators which get from questionnaire results, were imported into iG1 weight method to calculate the subordinate weighting. Figure 3 shows the importance of indicators for six dimensions.

From the results of the weight shown in Figure 3 (finance 0.206, schedule 0.206, quality 0.185, safety 0.134, informatization 0.134, and greenization 0.134), there is not much difference among the six sustainable dimensions. The results of the survey further verify that in addition to the traditional goals of finance, quality, schedule, and safety, greenization and informatization have become the current focus. The informatization and greenization management dimensions have the same weight as safety management, all of which are 0.134. It shows that the professionals have come to realize the importance of informatization and greenization in SCPM.

In the financial management dimension, the FM1 (profit ratio) and FM2 (unit profit) are the key indicators, and the importance of the remaining four is well-balanced. The weight of ScM1 (the time-saving rate) is the highest in the schedule management, while the other indicators' weights are close to each other. Within the quality management, QM1 (the final quality), QM2 (the sub-engineering quality), and QM5 (the quality accident occurrence) are the key indicators, the measures of variation is

0.141 in this dimension, which is a little high. The weight of SM1 (safety and security inspections passed rate) is the highest in safety management, the weights of remaining indicators are 0.150 around. As BIM has been promoted by a compulsory provision in China, the sum of the weights of the two indicators IM1 and IM2 is 0.218, which represent people's attention to BIM. With respect to the greenization management GM1 (the satisfaction degree of residents around) and GM2 (green site award) are the most important indicators. From the above weight index distribution, it can be concluded that the importance of each indicator is basically consistent with the current situation of the construction industry in China.

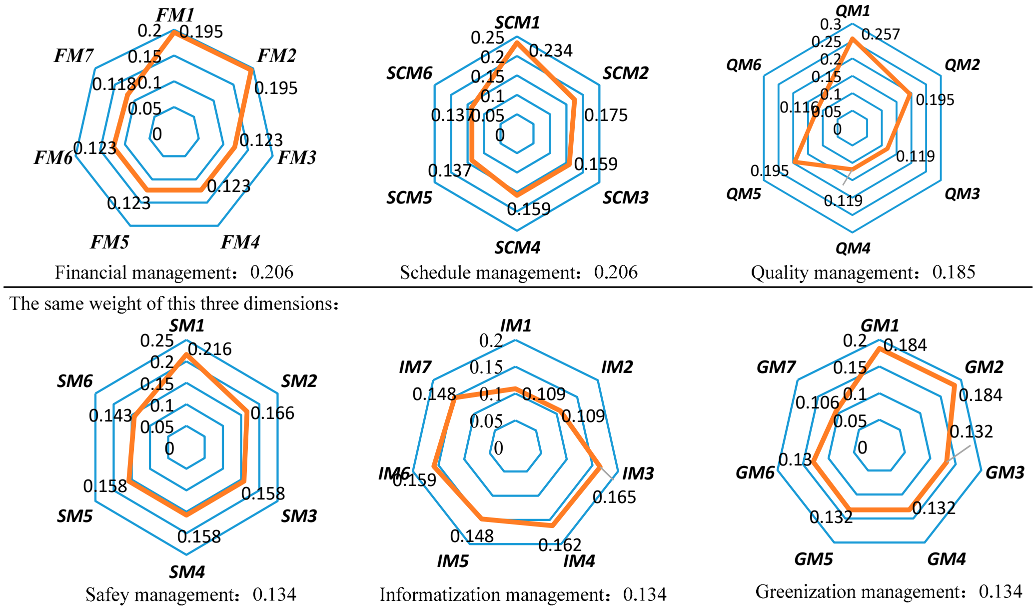

Figure 3. The weight of the index system.

5. Case Application

5.1. Project Background

In order to verify the effectiveness of the evaluation indicators and model for CPM performance, this research takes the electromechanical installation of the GZML7, which was constructed by Sichuan Huashi group corporation limited, as an example. The Zhongcun station covers a floor area of about 23,954 m^2 and is mainly a two-story underground building, with the length of 471.6 m and the width of 19.9 m. The other station is a three-story underground building, which is 156.8 m long and 25.9 m wide.

The composition of the electromechanical installation for GZML7 is composed of the following 10 aspects: Plumbing and fire extinguishing system, lighting and low voltage distribution system, ventilation and air condition system, intelligent building fire alarm system, building automation system, high-pressure water mist system, access control system, decoration engineering, relocating and rewiring engineering, and cooperation and coordination system.

5.2. The General Situation of SCPM

During the construction stage of the GZML7, the outcome of financial and schedule management was pretty good. Compared to the planning of construction, in reality, the project was completed ten days ahead of schedule, and only 69 million yuan was spent in reality. Besides, the outcome quality qualification rate is 100%, no safety accident occurred during the construction stage, safety construction facilities were fully equipped, and safety education training for workers was carried out well.

The GZML7 also won the 'Libing Cup of the civil engineering award and national quality engineering award' issued by the Ministry of Housing and Urban–Rural Development in 2017.

The greenization management of construction projects has achieved remarkable outcomes, reducing environmental pollution, controlling the noise and flying dust well, and having less impact on residents around. Moreover, the effluent and garbage have been reduced through the optimization of green construction planning.

In the field of informatization management for electromechanical installation, the arrangement of pipelines was complex. The collision inspection was carried out by using the BIM during the design stage, and the unreasonable areas were corrected. In the construction stage, the BIM technology was used to simulate the construction process for the complex construction nodes, which could improve the familiarity of workers' operation and avoid problems such as the installation of pipeline equipment and elevation errors.

5.3. Performance Evaluation

5.3.1. Connectivity and Evaluation Level Analysis

After obtaining the basic information, the project managers were invited to introduce the detail situation of GZML7 and established an evaluation team consisting of the managers in this construction enterprise. With a full understanding of the level standard, the actual value of the GZML7 project was calculated based on the specific data. According to the calculation formula in the last chapter, the research calculated the identity–discrepant–contrary coefficients of the evaluation indicators and determined the evaluation level. Only the association degree and evaluation level of the greenization and informatization dimensions are listed in Table 1.

Table 1. Association degree and the level of greenization and informatization management dimensions.

Indicator	Level Standards				Actual Value	Association Degree				Level
	Poor IV (0, S3)	Fair III (S3, S2)	Good II (S2, S1)	Excellent I (S1, -)		μ_{I4}	μ_{I3}	μ_{I2}	μ_{I1}	
GM1	(0,70)	(70,80)	(80,90)	(90,100)	92	−1	−1	0.6	1	I
GM2	(0,70)	(70,85)	(85,95)	(95,100)	91	−1	−0.2	1	0.2	II
GM3	(0,70)	(70,80)	(80,90)	(90,100)	65	1	0.85	−1	−1	IV
GM4	(0,0.1)	(0.1,0.2)	(0.2,0.3)	(0.3, -)	0.22	−1	0.6	1	−0.6	II
GM5	(0,0.1)	(0.1,0.2)	(0.2,0.3)	(0.3, -)	0.26	−1	−0.2	1	0.2	II
GM6	(0,0.7)	(0.7,0.8)	(0.8,0.9)	(0.9,1)	0.85	−1	0	1	0	II
GM7	(0,70)	(70,80)	(80,90)	(90,100)	77	−0.4	1	0.4	−1	III
comprehensive score/association degree					63.58	−0.67	0.05	0.60	−0.07	II
IM1	(0,70)	(70,80)	(80,90)	(90,100)	96	−1	−1	0.8	1	I
IM2	(0,70)	(70,80)	(80,90)	(90,100)	87	−1	−0.4	1	0.4	II
IM3	(0,70)	(70,80)	(80,90)	(90,100)	95	−1	−1	0	1	II
IM4	(0,70)	(70,80)	(80,90)	(90,100)	85	−1	0	1	0	II
IM5	(0,70)	(70,80)	(80,90)	(90,100)	88	−1	−0.6	1	0.6	II
IM6	(0,64)	(64,80)	(80,96)	(96,100)	97	−1	−1	0.5	1	I
IM7	(0,64)	(64,80)	(80,96)	(96,100)	85	−1	0.37	1	−0.37	II
comprehensive score/association degree					90.51	−1	−0.55	0.75	0.55	II

Table 1 shows that the comprehensive score of greenization and informatization management is 63.58 and 90.51, respectively. It is irrational to compare each dimension only based on comprehensive scores because of the differences in the scoring standard of them. Combining with the association degree, the highest score of greeniztion management is 0.60, which belongs to the level II of good, and the informatization management association degree is up to 0.75, which also reaches a good level. In the greenization dimension, the evaluation level of the secondary indicators indicates that the level of GM3 and GM7 is the lowest. This is consistent with the fact that the project has not been awarded as a green construction site and that the green construction planning is not good.

The project managers attached much importance to the application of information technology. The full use of the information management system, the complete configuration of software and hardware, the detailed application process of BIM technology in the construction stage, and the utilization of information technology to guide construction are the reasons for the project to achieve remarkable results. Therefore, the comprehensive evaluation of information indicators is better.

Similarly, the comprehensive evaluation levels of other dimensions can be calculated based on 13 valuation indicators and evaluation level standards.

Table 2 shows that the comprehensive evaluation level of the project is I. The company has rich management experience in the aspects of finance, safety, schedule, and quality. The performance evaluation of the informatization and greenization management of the construction project was lower in the historical cases. In the GZML7 project, the level of informatization and greenization management has reached the level II of good, which could give a strong reference value for other projects.

Table 2. The comprehensive evaluation levels of six performance management dimensions.

NO.	IM	GM	FM	SM	SCM	QM
level	II	II	I	I	I	I

5.3.2. Coordination Analysis

The coordination analysis of the dimension of informatization and greenization management based on the identity–discrepant–contrary coefficients are displayed in Table 3.

Table 3. The coordination analysis of greenization and informatization management.

Dimension	a	b1	b2	c
Greenization management	0.57	0.14	0.14	0.14
Informatization management	0.71	0.29	0	0

The value of a, b and c is the gauge of the coordination analysis, the greenization management system has good coordination, but the trend towards homogeneity and the improvement is weak. On the other hand, the association degree between the greenization dimension and level II is 0.60, the association with level III is 0.05, and the association degree with level I is 0.07. As discussed above, it shows that the ability of the greenization management system to convert from level II to level I is weak. In order to improve the situation where the trend of the system to excellent transformation is weak, construction enterprises should pay more attention to the indicators with the lowest score, such as green site award situation and whether the green construction planning is good or not. Similarly, the coordination analysis of informatization management can be obtained.

All in all, as a comprehensive evaluation method, SPA can reflect the overall state and make a quantitative evaluation, and can totally ensure the reliability and accuracy of the evaluation. In addition, all the single indicators are combined together organically by the calculation of the comprehensive association degree, making the evaluation of SCPM easier to understand. It plays a guiding role in the optimization and improvement of SCPM competence.

6. Conclusions

Performing the sustainable evaluation for the SCPM is a significant measure to increase environmental protection and informatization utilization, to enhance the competitive edge of construction companies to market changes. The process adoption began by putting forward a SCPM performance evaluation index system, based on existing norms and established research, to which the dimensions of greenization and informatization were added. The final index system contains the above two dimensions and the remaining four dimensions: Finance, safety, schedule, quality management. Next, the identified six dimensions of SCPM performance indicators were further analyzed by 55 expert questionnaires. The iG1 method was then applied to reduce the impact of subjective elements and to analyze the final weight of the dimensions in the entire system. Finally, based on the iG1 weight method and the SPA, the case of GZML7 was evaluated for SCPM performance. This SCPM evaluation model can not only provide a guideline for construction companies in China, but also serve as reference cases for other countries to carry out relevant research work.

In this research, the SCPM performance evaluation index system consisted of 39 secondary indicators from six dimensions. From the results of the weight (finance 0.206, schedule 0.206, quality 0.185, safety 0.134, informatization 0.134, and greenization 0.134), finance, schedule and quality management were still top three important in SCPM, but surprisingly, the greenization and informatization management were as significant as safety management. The importance of greenization and informatization gained popular recognition of construction professionals. Through a GZML7 case application by SPA, it shows that the evaluation level of the greenization management is II and the system converts from level II to level I was weak. Similarly, the evaluation level and coordination analysis of other dimensions could be obtained. Based on the results, the project managers could go back to find worse indicators and improve the management system in construction enterprises and successfully support sustainable development.

Flowing from this research, the following conclusions are obtained. Firstly, the establishment of evaluation index system based on the Huashi construction enterprise management database, which was valid and implementable. Secondly, this integrated assessment approach could reflect the coordination and development trend of the various dimensions of the system, and provided a theoretical basis and practical reference for the optimization of project management. Finally, this study offered a basis and useful reference to construction enterprises aiming to set up their own SCPM performance evaluation system, which is a guideline for project managers to improve the competitive edge of construction enterprises.

A limitation of this study, however, is that only representative indicators were employed, given the limited data available. Other indicators, such as human resources, procurement and communication, can also reflect the construction industry's level of sustainable development. These indicators will be analyzed in future research, as and when data become available. On the other hand, as the increasing level of informatization, we will further study the optimization model and methods for SCPM by data mining for selecting and optimizing the management databases.

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