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A dynamic evaluation approach for operation and maintenance performance and status of large gymnasiums considering spatio-temporal dimensions

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Abstract: The operation and maintenance phase of established large gymnasiums lacks a holistic evaluation system and a dynamic evaluation method, which makes it difficult to reflect the overall performance and status of management. To solve the above problems, this study establishes an evaluation system for operation and maintenance performance and status indicators and proposes a dynamic evaluation method that integrates spatial and temporal dimensions. First, operation and maintenance performance and status indicators are identified and weighted using the fuzzy Borda method. Furthermore, the operation and maintenance performance and status of a single building is evaluated in the time dimension by variable-weighted composite method, and the comparison of operation and maintenance performance and status of gymnasiums in different spatial dimensions is realized by considering the time weights. The case validation evaluates the dynamics of five large gymnasiums in Beijing in both temporal and spatial dimensions.

Keywords: large gymnasium; operational and maintenance; performance and status; dynamic evaluation

1. Introduction

1.1. Research significance

In the contemporary era, large gymnasiums serve as the primary venues for international sports events and various activities, not only projecting the city's image but also facilitating cultural exchanges. The number of gymnasiums in China has been on the rise, increasing from 226.6 thousand in 2018 to 369.7 thousand in 2023. As the number of established gymnasiums entering the operational phase increases, so too does the demand for operation and maintenance (O&M) management of these facilities. The primary objective of gymnasium O&M is to guarantee the safety, functionality, and sustainability of the venue. This is achieved by optimizing energy use, extending the lifespan of the facility, enhancing user satisfaction, and reducing operating costs. For those responsible for the operation and maintenance of the gymnasium, it is crucial to have a comprehensive understanding of the facility's overall operational status in order to effectively manage its operations. While researchers have discussed the sustainability [1] and operational status [2] of gymnasiums, there is still a lack of comprehensive evaluation aspects in terms of overall O&M management evaluation. Accordingly, the objective of this study is to conduct a comprehensive and precise evaluation of the gymnasium O&M management system.

In order to conduct a multidimensional evaluation of O&M management in gymnasiums, this study employs the use of O&M status as a generalized indicator for the comprehensive evaluation of O&M management. The O&M performance and status parameter is utilized to describe and evaluate the performance and status of O&M management during the operational phase of a building, employing quantitative and qualitative indicators. The performance is evaluated through a quantitative analysis, which assesses the efficacy of the O&M management of a building. The state is assessed through a qualitative analysis, which determines the current condition of the O&M management of a building. In the case of large gymnasiums, the O&M performance and status encompasses a range of factors, including the safety of the facility, its energy consumption, environmental impact, economic viability, suitability for the intended functions, user satisfaction, and other indicators that collectively reflect the overall performance and status of the O&M management of the gymnasium.

Conducting an operational and maintenance (O&M) status assessment is of paramount importance for effective gymnasium management. Such an assessment can assist managers in identifying potential issues, optimizing resource allocation, enhancing operational performance and status, and providing a scientific foundation for decision-making. However, existing assessment methods frequently fail to consider the influence of temporal and spatial variables on O&M performance and status. The temporal dimension reflects changes in gymnasium performance over time, such as the aging of equipment or seasonal usage patterns. The spatial dimension, in contrast, considers the specific needs and performance of different functional areas. This study proposes a comprehensive evaluation method for the dynamics of the performance and status of large gymnasiums that considers the spatial and temporal dimensions. This method not only captures the dynamic changes in the O&M status of gymnasiums, but also provides more accurate assessment results for different areas. By incorporating the spatio-temporal dimension, our study addresses the limitations of existing assessment methods and provides a more comprehensive and precise assessment tool for gymnasium O&M management.

1.2. Advantages of dynamic evaluation

The evaluation methods typically employed for established large gymnasiums tend to prioritize a static assessment of the facility, focusing on a singular, point-in-time evaluation of its current status. This approach, however, fails to account for the dynamic changes that occur in the performance and status of the gymnasium over time. This static evaluation method is straightforward and readily comprehensible; however, it is unable to fully capture the developmental changes that occur throughout the gymnasium's life cycle. As the O&M stage progresses, the significance of the established indicator system will evolve. For instance, as the building structure and equipment age, the risk of safety issues increases, underscoring the growing importance of safety-related indicators. This shift aligns with the temporal dimension. This change reflects the temporal dimension of the evaluation, and static evaluations are unable to capture this dynamic characteristic. The temporal weight vectors are combined at each moment to enable a comparison of the performance and status of each gymnasium, which corresponds to the spatial dimension. This comparison reflects the spatial dimension of the evaluation, namely the horizontal comparison between different gymnasiums. In conclusion, the conventional static evaluation approach is no longer adequate for the comprehensive and dynamic integrated assessment of large gymnasiums. It is necessary to develop an evaluation method that can consider both the temporal and spatial dimensions in order to more accurately reflect the operational and maintenance status of gymnasiums in different periods and regions. This would provide more valuable reference information for management decisions. In this study, we propose a dynamic comprehensive evaluation method for large gymnasiums that integrates the variable-weight synthesis method and the hybrid time series operator. This method offers two key advantages over the traditional static evaluation approach:

(1) The importance of O&M performance and status indicators for the same gymnasium over time is recognized, and variable weight evaluation is employed to account for this change.

(2) Dynamic evaluation and comparison between different gymnasiums are achieved by considering time weights.

1.3. Research framework

Section 2 provides literature review of the evaluation indexes and dynamic evaluation methods used to assess the large gymnasiums. Section 3.1 outlines the evaluation system for assessing the large gymnasiums, organized according to six key aspects. Section 3.2 employs the fuzzy Borda method to Section 3.3.1 establishes the incentive and penalty intervals, calculates the new weights based on the measured values of the indexes of dynamics, calculates the variable-weighted evaluation values, divides the hierarchical evaluation intervals, and evaluates the same stadium over time horizontally. Section 3.3.2: The hybrid time-order operator (TOWA-TOWGA) is employed to calculate dynamic comprehensive evaluation values, which are then used to conduct a vertical comparison of the O&M performance of different gymnasiums, taking into account time weights and horizontal O&M performance evaluation values. Section 4 applies the proposed evaluation model to the dynamic comprehensive evaluation of five large stadiums. Section 5 discusses the results, and Section 6 draws conclusions.

2. Literature review

2.1. Indicators for evaluating the O&M performance and status of large gymnasiums

Table 1 presents the standards for the operation and maintenance (O&M) phase of existing buildings. In the past decade, green building assessment schemes (GBAS) have been developed rapidly in terms of standardization and software tools [3], and the evaluation of existing buildings encompasses numerous aspects, including sustainability and operation. Moreover, more comprehensive evaluation indexes have gradually attracted attention. In many countries and regions, the assessment of existing buildings is predominantly based on the goals of sustainability and greenness. These goals are primarily concerned with energy, the environment, management, the economy, society, and other aspects.

Table 1. Standards for the O&M phase of existing buildings.

Name	Details
BREEAM-In Use	Management, energy, health and comfort, transportation, water resources, materials, land use, pollution, ecology.
LEED-EB	Sustainable site design, efficient use of water resources, energy and environment, materials and resources, indoor environmental quality and innovative design.
DGNB	Ecological quality, economic quality, socio-cultural quality, technological quality, process quality, locational quality.
CASBEE-EB	Building environmental performance, quality (Q): indoor environment, service performance, outdoor environment. Building Environmental Load Reduction (LR): energy, resource materials, building site outdoor environment.
GB Tool	Resource consumption, environmental load, indoor environmental quality, management, economic performance, service quality, transportation.
ESGB	Land saving and outdoor environment, energy saving and energy utilization, water saving and water resource utilization, material saving and material resource utilization, indoor environmental quality, construction management, operation management.

In terms of safety, large gymnasiums, as public buildings with intensive personnel activities, are of paramount importance in terms of their safety performance during the service period. After a long period of use of a building, the aging of the building structure and equipment will pose a safety risk to the building. Ensuring the stability of the building structure, non-structural components and equipment during the service life of the building helps to safeguard people’s lives and property. Structural deterioration will affect the functionality of the building and reduce its performance. The aging of fire protection facilities will pose safety risks to the active people in the building. Sun *et al.* [4] reviewed the feasibility of machine learning (ML) modeling in predicting and evaluating the structural performance of buildings. Structural health monitoring in infrastructures such as large gymnasiums can help improve structural longevity and public safety [5] Post-disaster building response and resilience is to assess the resilience of buildings against disasters. Noel *et al.* [6] evaluated the resilience performance metrics for different types of buildings.

In terms of energy, the amount of energy consumed by gymnasiums and the efficiency of energy utilization are important factors to consider during a building’s service life. In order to ensure the sustainability of buildings, more and more buildings are shifting from active utilization of existing energy sources to passive energy harvesting from nature to form a cycle that reduces energy consumption while reducing damage to nature. Lazar *et al.* [7] established sustainability indicators and a green building rating system for residential buildings in tropical climates of India from regional needs. A green building evaluation framework [8] was constructed to evaluate green building performance in five dimensions: the main building, the building envelope, HVAC, lighting equipment, and bonus points.

From an economic standpoint, the performance and status of large gymnasiums are contingent upon the economic performance of the facility. The operational and maintenance (O&M) management of gymnasiums encompasses the expenditure incurred for the routine functioning of the facility and the economic benefits derived from its operation [9,10]. Tang *et al.* [11] have established a comprehensive database of sustainable performance indicators for stadiums. These factors reflect the environmental, social, and economic characteristics of the gymnasiums. Financial balance reflects the operational status of the gymnasiums during the period of O&M management, and the economic nature [12] is also an important factor to be considered.

In terms of the indoor environment, it is of particular importance to maintain comfort levels during O&M management [12]. It is also necessary to consider the environmental impacts of building operations, such as waste and pollution, and carbon emissions [7,10,12]. Mansor *et al.* [13] utilized the Analytical Hierarchy Process (AHP) to select indoor environmental parameters and monitor the performance of office indoor environments in order to improve the well-being of users. Jain *et al.* [14] evaluated the performance of hospitals in terms of indoor environmental quality (IEQ), specifically addressing indoor air quality (IAQ), thermal comfort, lighting, and acoustics.

In terms of the function, gymnasiums are distinct from other types of public buildings. Their primary purpose is to provide venues, facilities, and services that meet the users’ sports needs. The functionality of the venue has become another important factor in judging its O&M performance and status. Venues can be evaluated from four perspectives [11]: venue function, location and size, scene transition, and intelligent venue.

From the perspective of the user, the primary concerns regarding gymnasiums are the comfort of the environment and the satisfaction of the service. However, objective indoor comfort parameters are unable to accurately reflect the subjective feelings of users. Therefore, it is essential to evaluate whether the current status of gymnasiums meets the needs of users from their subjective perspective. The comfort of the gymnasium environment can be divided into two categories: the outdoor environment of the gymnasium (aesthetics of the gymnasium, accessibility) and the indoor environment (thermal comfort, air quality, visual comfort, acoustic comfort, and the reasonable layout of the indoor space). Felseghi *et al.* [15] classified the indoor environmental attributes into five categories: thermal comfort (temperature, humidity, and air circulation), olfactory comfort (smell and breathing), acoustic comfort (noise), visual comfort (light and color effects), and other indoor environmental attributes. Visual comfort (light and color effects) and special factors (e.g., solar inputs, ionization, vibration, and movements of the building) were also considered. Lai *et al.* [16]

compared four key factors: air cleanliness, odor, noise, and thermal comfort. Thermal comfort was identified as the most important factor by building users. The concept of human-centeredness was then implemented to enhance the comfort and satisfaction of users. Salehabadi *et al.* [17] evaluated the environmental, economic, social, and resiliency aspects of green buildings through a user-centered sustainable assessment.

Table 2 presents a categorization of literature on key indicators for the evaluation of existing buildings. However, there is a paucity of studies related to the performance and status evaluation of specific building types (e.g., gymnasiums) during the O&M phase. Moreover, the existing studies focus on a single indicator type, lacking an evaluation of the overall O&M status of gymnasiums. Large gymnasiums are a distinctive type of public building, distinguished by their specific functionality. Accordingly, the established evaluation indices of public edifices serve as a basis for learning and referencing the generalized indices of safety, energy, economy, environment, and user perspective of gymnasiums. However, the extant research is largely confined to a single dimension and lacks a comprehensive, multi-dimensional assessment of large gymnasiums. Consequently, the objective of this study is to construct an indicator system that can reflect the overall O&M performance and status and evaluate the O&M performance and status of large gymnasiums as a basis for O&M management.

Table 2. Categorization of literature on key indicators for the evaluation of existing buildings.

Main criteria	Sub-criteria	Related literature
Safety	Safety accident	[9]
	Structural safety	[18]
	Fire safety	[7]
	Earthquake safety	[7][19]
	Emergency prevention	[13]
	Resilience quantification	[6]
Energy	Energy consumption	[9][10][11][14]
	Energy efficiency	[7][12]
Economy	Cost	[7][9][10][11][17]
	Financial balance	[9][11]
	Economical	[12]
Environment	Air quality	[7][8][9][12][13][14][17]
	Temperature and humidity	[8][10][12][13][14]
	Illumination	[7][8][12][13][14]
	Acoustical	[10][12][13][14]
	Waste and pollution	[7][10][12]
	Carbon emission	[7][10][12]
Function	Venue function	[11]
	Location and size	[11]
	Scene transition	[11]
	Intelligent venue	[11]
User perspective	User feedback	[9][10][14]

2.2. Dynamic evaluation

Dynamic evaluations are reflective of the dynamic nature of evaluation information in both temporal and spatial dimensions. The temporal dimension considers the characteristics of the evaluation object over time, such as seasonal changes or long-term development trends. In contrast, the spatial dimension focuses on the differences of the evaluation object in different geographic locations or levels of organizational structure. This multi-dimensional approach allows for a more comprehensive capture of the dynamic characteristics of the evaluation object, thereby enhancing the accuracy and practicality of the evaluation results. As static evaluation methods have become increasingly sophisticated, researchers have begun to turn their attention to dynamic evaluation methods.

The evaluation of different objectives in the spatial dimension is conducted using the same criteria that have been established. Multi-Criteria Decision-Making (MCDM) is a process used to evaluate and prioritize multiple conflicting criteria in decision-making scenarios. It is particularly useful when decisions need to be made in complex environments where various factors must be considered simultaneously. The Multi-Criteria Decision-Making (MCDM) approach provides decision makers with a systematic framework for the evaluation and comparison of different options under multiple criteria. Huang *et al.* [20] presents an MCDM approach for selecting energy-saving building programs, combining extended BWM and WASPAS methods in a Pythagorean fuzzy context, and demonstrates its application with a numerical example and practical insights for practitioners. Sathyan *et al.* [21] employed a fuzzy multi-criteria decision-making (MCDM) approach, encompassing fuzzy DEMATEL, fuzzy AHP, and fuzzy TOPSIS, to model and prioritize the responsiveness of the Indian automotive supply chain. Alkan *et al.* [22] further developed the CRITIC and DEVADA methods within the domain of MCDM by integrating Intuitional Fuzzy Sets (IFS) to address uncertainty in decision-making processes, thereby proposing a more robust multi-measurement system. By considering both Euclidean and cosine distances, the method is able to address the uncertainty inherent in dynamic decision-making systems and incomplete information. Its efficacy has been validated and comparatively analyzed in a waste treatment location selection problem, demonstrating its superiority and advantages. In order to address the issues inherent in the LEED certification process for green buildings, a method of dynamic simulation for green buildings was adopted [23]. The results of LEED and dynamic simulation, as applied by different operators, were evaluated using the Round-Robin Comparison Test (RRT) to facilitate a horizontal comparison of the evaluation results of nine universities from the spatial dimension.

In the time dimension, the importance of considering parameter information at different stages reflects the dynamic nature of evaluation. Peng *et al.* [24] proposed a model for dynamically evaluating the financial risk of new energy automobile industry based on q-ROF multi-criteria decision methodology, which uses the q-ROFS to deal with uncertainty and uses nonlinear comprehensive weighting and dynamic aggregation operator for evaluation with strong data adaptability. Moradi *et al.* [25] used a system dynamics (SD) approach and fuzzy TOPSIS logic to assess and improve the sustainable management of passenger rail transportation companies by modeling rail sustainability indicators and causal loops to achieve sustainability in environmental, social and economic dimensions, providing experts with the ability to assess the sustainable management and improve the performance of transportation companies Provides support for experts to assess the sustainable management and improve the performance of transportation companies. Hu *et al.* [26] conducts dynamic daylighting assessment of large-span space structure buildings, using sDA and UDI metrics to simulate and optimize year-round lighting conditions on the parametric software Ladybug and Honeybee. Compared to static assessment, dynamic daylighting assessment helps the designer to better control the year-round lighting effect of the building to optimize the performance design of the building. During the operation and maintenance phase of the building, the adopted dynamic strategies need to be fed back through dynamic evaluation. Dynamic shading is used to improve building comfort and energy efficiency, and Wu *et al.* [27] optimizes the annual daylighting and energy performance of a complex, dynamic, origami-based shading system using an improved Parametric Behavioral Mapping (PBM) method for dynamic performance evaluation. Guo *et al.* [28] combined the variable weighting method and the cloud model to dynamically evaluate the process of shading tunnels passing through buildings. The variable weighting method takes into account the dynamic changes of the evaluation indices and their influence on the evaluation results, and the results show that the weight calculation results of the variable weighting method are more reasonable compared with the traditional weighting model.

Considering both temporal and spatial dimensions, Zhang *et al.* [29] combines the characteristics of energy consumption and the similarity of weather parameters for monthly segmentation, and divides the building energy performance into base season, transition season, heating season, cooling season, transition season, heating season, cooling season, and two dimensions of time and space, and captures the characteristics of building operation patterns through time series prediction modeling, so as to realize the dynamic evaluation of energy management.

To obtain dynamic data, Sun *et al.* [30] investigated an automated model-based calibration method to automate the calibration of the model to actual building energy data by dynamically adjusting the building energy simulation model using monthly utility bill data to ensure that the simulation results match the actual energy consumption. Validation and calibration of the simulation model using building energy audit data and post-occupancy assessment enables dynamic evaluation of the building energy system [31].

However, for large gymnasiums, the existing dynamic evaluation methods are mostly single dynamic in time dimension or space dimension, which is difficult to comprehensively reflect the complex dynamic characteristics of the evaluation object, and there are fewer related studies on the evaluation of performance and status of large sports. As a complex public facility, the performance and status of large gymnasiums are affected by both temporal factors (e.g., years of use, seasonal activities) and spatial factors (e.g., geographic location, functional zoning). Therefore, this study aims to construct a more comprehensive and accurate dynamic integrated evaluation model of the performance and condition of large gymnasiums by considering the dual dimensions of time and space. By integrating time series analysis and spatial distribution analysis, this study will be able to better capture the dynamic change patterns of the O&M status of gymnasiums, identify the influencing factors, and provide more comprehensive and accurate decision support for the O&M management of large gymnasiums.

3. Methodology

3.1. Framework of the methodology

This study proposes a dynamic evaluation method for large gymnasiums that integrates the variable weight synthesis method and the hybrid time series operator. The method is designed to evaluate the O&M performance and status of the gymnasiums from two dimensions, time and space. It is intended to provide a decision-making basis for the O&M management. For example, it can assist managers in the prioritization of maintenance tasks, the optimization of resource allocation, the development of long-term improvement plans, and the evaluation of the effectiveness of various management strategies. First, an evaluation system for the O&M performance and status indicators of large gymnasiums is established from six aspects. The fuzzy Borda method is then utilized to assign weights to the indicators. Subsequently, a variable-weighted composite value is calculated based on the variable-weighted composite method, which considers the dynamic change of indicator importance. This value is then integrated with the temporal weight vector, calculated using the hybrid temporal operator, to yield a dynamic composite value. Finally, the feasibility of the method is verified based on the performance and status evaluation considering spatio-temporal dimensions in real cases. The overall framework is shown in Figure 1. The benefit of this comprehensive evaluation method is that it furnishes managers with a more comprehensive and dynamic understanding of the status of gymnasium operations.

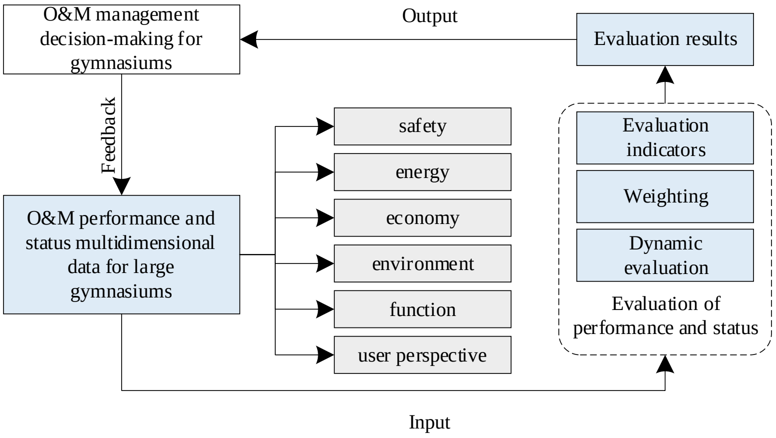


Figure 1. Research framework for dynamic evaluation of O&M performance and status of large gymnasiums.

The overarching structure is illustrated in Figure 1, which encompasses three principal levels: input, output, and feedback. At the input level, the primary consideration for large gymnasiums is safety, encompassing multiple aspects of structural safety, fire safety, and emergency planning. The efficiency of energy utilization is an important indicator for achieving sustainable building development. The financial performance of the economy [11,17] serves to illustrate the significance of economic viability for the long-term operation of the facility. The indoor and outdoor environment [13] is designed to ensure user comfort.

The functionality of the venue represents a distinctive attribute that differentiates large gymnasiums from other public edifices. From the user perspective, the concept of human-centeredness is implemented with the objective of optimizing the services provided by the gymnasium. At the output level, the input data are subjected to a dynamic comprehensive evaluation, the results of which are then output. At the feedback level, the management of operations and maintenance (O&M) makes decisions based on the evaluation results with the objective of optimizing the performance and status of O&M, thereby forming a closed loop.

Figure 2 illustrates the implementation process of the methodology for evaluating the O&M performance and status of large gymnasiums, taking into account the spatio-temporal dimension. In the first step, the factors influencing the O&M performance and status of large gymnasiums were identified, and these indicators were determined through an extensive literature review. The O&M performance and status evaluation system was constructed and the weights of the indicators were calculated using the fuzzy Borda method. In the second step, the variable-weighted composite method is employed to determine the variable weights of the same object at different moments, and the variable-weighted composite value is calculated to obtain the evaluation results in the time dimension. The dynamic evaluation results of different objects after fusing the temporal weight vectors are obtained using the hybrid temporal operator, which is used to compare the evaluation results of different objects in the spatial dimension. Figure 3 illustrates the fusion principle of the method and the current status of the results. The figure illustrates the methodology employed in this study to evaluate the performance and status of large gymnasiums in terms of spatio-temporal dimensions, encompassing three key areas: time, space, and indicators. The shading indicates the evaluation grade of gymnasiums G3 at the moment t3.

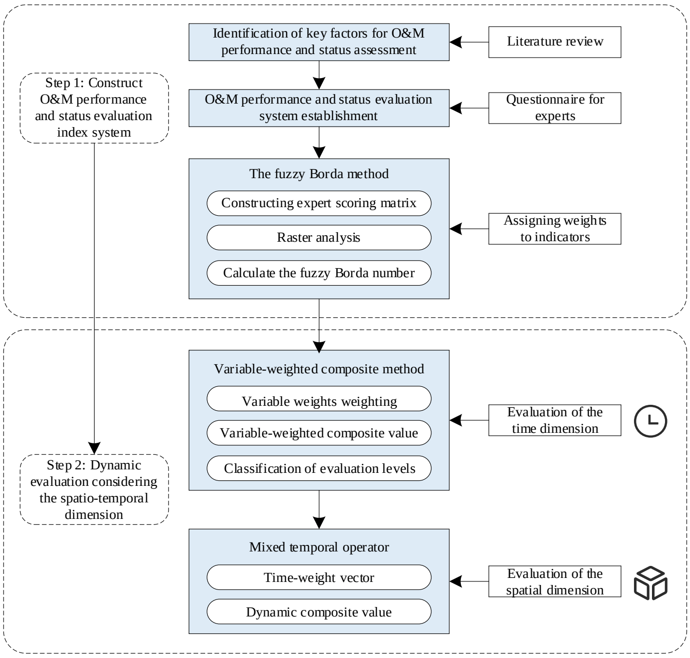


Figure 2. Implementation process of the methodology for evaluating the O&M performance and status.

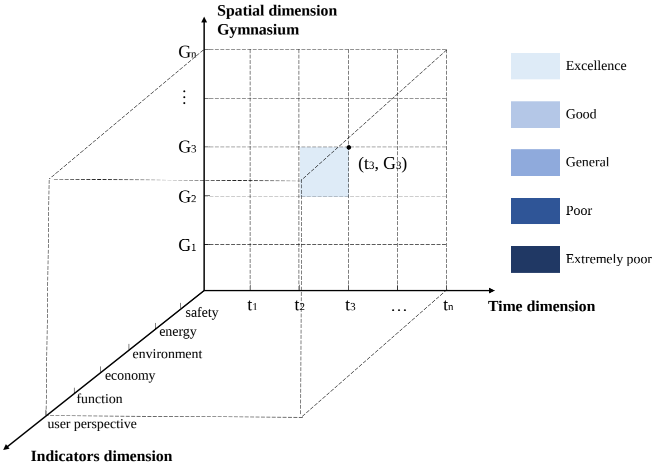


Figure 3. Spatio-temporal integration mechanism and evaluation results display.

3.2. Construction of O&M performance and status indicator system for large gymnasiums

Combining the existing standards and regulations with the existing research, the operation and maintenance performance and status of large gymnasiums includes six aspects: safety, energy, economy, environment, venue function and user perspective. In this study, the preliminary selection of O&M performance and status indicators of large gymnasiums from the standard specifications and literature is shown in the following table, taking into account the difficulty of obtaining the indicators and their comprehensiveness. A total of 15 O&M managers, experts, and academics were selected and added or subtracted according to the criteria in Table 3.

Table 3. Indicator selection criteria.

Selection Criteria	Description
Relevance	Metrics are directly related to the operational and maintenance performance and status of large gymnasiums.
Measurable	Indicators are easy to quantify and measure.
Availability	Data can be accessed through regular channels.
Representativity	Indicators are representative of the important characteristics of a particular aspect.

Safety in the O&M phase of a building is affected by both building facilities (A11, A12, A17) and O&M management (A13, A14, A15, A16). The “structural safety assessment level” is determined by experts based on the findings of the structural safety appraisal of the gymnasium. Building facilities include structural safety and the intact rate of fire protection facilities, while the number of years the building has been in use reflects to some extent the life of the building. The safety of O&M management is mainly reflected in emergency management, so the number of fire drills, safety training, emergency evacuation drills, and the completeness of emergency plans for various types of disasters are selected as quantitative indicators. For energy, the three types of resources, electricity (A21), water (A22) and gas (A23), are categorized in this level of indicators, and their consumption per unit of floor area (A24) is used to indicate energy consumption. With reference to the Green Building Rating System, renewable energy generation is added to the index system. Considering the economic indicators required for the actual operation of the gymnasium, three aspects of expenses (A31, A32, A33, A34, A35), income (A36, A37) and profit (A38) are selected. Temperature and humidity, CO2 and PM2.5 were selected as indoor environment evaluation indicators. Temperature and humidity (A41, A42) are the main influences on indoor thermal comfort, and CO2 (A43) and PM2.5 (A44) are the main influences on indoor air quality. The outdoor environment was expressed in terms of green cover. The functional aspects of the gymnasium are selected with reference to the literature [11]. Finally, a total of six primary indicators and 35 secondary indicators are selected in this study as evaluation indicators of the performance and status of large gymnasiums, as shown in Table 4.

Table 4. Evaluation index system for O&M performance and status of large gymnasiums.

Main Criteria	Sub-Criteria	Sources of Indicators
A1. Safety	A11. Structural Safety Assessment Level	DB11/T 849-2021
	A12. Completeness rate of Fire-Fighting Facilities	XF/T 3005-2020
	A13. Number of Fire Drills	XF/T 3005-2020
	A14. Number of Security Training Sessions	-
	A15. Number of Emergency Evacuation Drills	-
	A16. Completeness of Contingency Plans for all Types of Disasters	-
	A17. Age of the Building	-
A2. Energy	A21. Electricity Consumption	GB/T 51161-2016
	A22. Water Consumption	GB 50555-2010
	A23. Gas Consumption	T/CECS 608-2019
	A24. Renewable Energy Generation	-
A3. Economy	A31. Maintenance Costs of Sports Grounds and Facilities	-
	A32. Labor Cost	-
	A33. Energy Cost	-
	A34. Maintenance Costs of Construction Equipment	-
	A35. Depreciation of Equipment	-
	A36. Revenue from Sports Events and Activities	-
	A37. Daily Operating Income	-
	A38. Net Profit of Gymnasiums	-
A4. Environment	A41. Temperature	GB/T 50378-2019
	A42. Humidity	GB/T 50378-2019
	A43. Concentration of CO2	GB/T 18883-2022
	A44. Concentration of PM2.5	GB/T 18883-2022
	A45. Green Coverage	JGJ/T 391-2016
A5. Function	A51. Number of Races and Events Organized	[11]
	A52. Activity Capacity	[11]
	A53. Average Audience Attendance at Events	[11]
	A54. Number of Days the Venue is Open	[11]
	A55. Scene Transition Time	[11]
	A56. Completion rate of Sports Facilities	[11]
A6. User Perspective	A61. Environmental Comfort	T/CECS 608-2019
	A62. Aesthetics of Gymnasium	T/CECS 608-2019
	A63. Rationality of Interior Space Layout	T/CECS 608-2019
	A64. Transportation Convenience	T/CECS 608-2019
	A65. Service Satisfaction	T/CECS 608-2019

3.3. Weighting of indicators

The fuzzy Borda method [32] is a straightforward algorithm that is relatively simple to operate. Its objective is to synthesize the assignments of several experts in order to alleviate the influence of subjective factors. The index weights are calculated by calculating the fuzzy Borda number.

(1) Constructing an expert scoring matrix

Table 5 is employed to quantify the level of importance of indicators. A grid was constructed to represent the level of importance of the indicator, where the quantified values are continuous and non-repetitive.

Table 5. Quantification of the level of importance of indicators.

Importance	**Very Important**	**Comparatively Important**	**Important**	**General**	**Unimportant**
Quantification	5	4	3	2	1

The letters G, I, T, and E represent the following: G stands for large gymnasiums, I stands for evaluation indicators, T stands for evaluation time period, and E stands for rating experts. The letters in lowercase represent the serial numbers (e.g., g stands for the g-th gymnasium). O stands for the object of evaluation, which is the O&M performance and status of large gymnasiums. The evaluation matrix $O(t)$ of the g-th large gymnasium in the t-th time period is then:

$$O(t) = [O_{ie}(t)]_{I\times E} \tag{1}$$

In Equation (1), $O_{ie}(t)$ represents the scoring value of the i-th evaluation indicator ascribed by the e-th scoring expert.

(2) Raster analysis

In the expert rating, the degree of affiliation μ_{ie} of the importance of the i-th evaluation index is calculated as follows:

$$\mu_{ie} = \frac{O_{ie}(t)}{max\{O_{ie}(t)\}} \quad (0 \le \mu_{ie} \le 1) \tag{2}$$

The fuzzy frequency number, f_{hi}, is calculated as follows:

$$f_{hi} = \sum_{e=1}^{E} \delta_e^h(O_{ie}(t))\,\mu_{ie} \tag{3}$$

When $O_{ie}(t)$ is ranked in the h-th position in the e-th expert evaluation superiority relation, then $\delta_e^h(O_{ie}(t)) = 1$, whereas it is equal to 0 otherwise. If $O_{ie}(t)$ and $O_{je}(t)$ have the same degree of affiliation $\mu_{ie} = \mu_{je}$, then the two elements should be ranked in the h-th and (h+1)-th positions in the superiority relation and $\delta_e^h(O_{ie}(t)) = \delta_e^h\big(O_{je}(t)\big) = 0.5$. Define $R_i = \sum_h f_{hi}$.

(3) Calculate the fuzzy Borda number $FB(O_{ie}(t))$.

If it is stipulated that the score of the evaluated object $O_{ie}(t)$ ranked at the h-th position in the superiority relation is Q_h, such that:

$$Q_h = \frac{1}{2}(G-h)(G-h+1) \tag{4}$$

Then:

$$FB(O_{ie}(t)) = \sum_{h} \frac{f_{hi}}{R_i} Q_h \tag{5}$$

$$W_i = {FB(O_{ie}(t))}\Big/{\sum_{i=1}^{I} FB(O_{ie}(t))} \tag{6}$$

In Equation (6), W_i represents the weight of each indicator.

3.4. Dynamic evaluation approach considering spatio-temporal dimensions

3.4.1. Evaluation of the time dimension

This study uses the month as a time slice to divide the time interval of the variable weighting method. According to the frequency of changes in the measured value of the indicators and whether the changes have an impact on the actual evaluation, this study divides the indicators into long-term, medium-term and short-term indicators, as shown in Table 6. Long-term indicators have a low frequency of change per month. Medium-term indicators have a moderate frequency of change per month, and the calculation by adding up does not affect the evaluation within the month (e.g., the statistics of energy consumption values only need to calculate the usage value at the end of the month). Short-term indicators change more frequently from month to month, and this change must be taken into account (e.g. the average indoor temperature in a month does not reflect the temperature status of gyms, but the percentage of time in the comfortable range during working hours should be taken into account). As illustrated in Table 6, medium-term indicators are more appropriately calculated on a monthly basis. This is due to the fact that medium-term indicators represent the largest proportion of the variables under consideration. Consequently, the time slice of the month has been selected as the division of the time interval for the variable weighting method.

Table 6. Classification of indicators by time.

Temporal Type of Indicator	Indicator
Long term	A11, A17 A45 A61, A62, A63, A64, A65
Medium term	A12, A13, A14, A15, A16 A21, A22, A23, A24 A31, A32, A33, A34, A35, A36, A37, A38 A41 A51, A52, A53, A54, A55, A56
Short term	A42, A43, A44

The above categorization explains the changes in the time dimension of the gymnasium, and some of the indicators have special patterns. The characteristics of the indicator changes are usually expressed in terms of periodicity, trend, directness and cumulativeness. The energy consumption indicators (A21, A22, A23, A24) usually show seasonal cycles, with significant differences in consumption between summer and winter. Building age (A17) and equipment depreciation (A35) show an increasing trend over time. Indicators that require real-time monitoring and evaluation, such as environmental indicators (A41, A42, A43, A44), have a high temporal resolution, requiring the evaluation system to be able to react and process real-time data immediately. Indicators such as the number of safety training sessions (A14) and emergency drills (A15) are usually calculated on an annual cumulative basis and reflect the long-term safety management level of the venue.

In the operation and maintenance stage of large gymnasiums, the importance of different indicators will change with the above four dynamic characteristics, and this study realizes the dynamics of evaluation through the variable weighting theory. Punishment-incentive type variation represents a fundamental concept within the field of variation theory. This approach involves the introduction of a penalty mechanism, whereby the weight of an assessment indicator is increased when the associated score is deemed to be inadequate. This penalty serves to negatively impact the overall assessment outcome, effectively acting as a deterrent for shortcomings. Conversely, incentive-type variation is the antithesis of punishment-type variation. Incentive-type variation is an incentive for strengths, whereby the weight of an assessment indicator is increased when the indicator's score is too high. This results in an overall assessment result that is higher. This study employs the incentive-type variable weighting approach. When the measured value of the indicator is in a favorable status, the evaluation result is incentivized, and the weight of the indicator is increased. Conversely, when the indicator value is unfavorable, the evaluation result is penalized, and the weight is reduced. Specifically, variable-weighted weights (V_i) are calculated based on the coefficient of variation ($F(O_i)$) in combination with the established fixed weights. The expert provides a status score (O_e) for the measured values, which leads to the calculation of variable-weighted composite values (H). The results of the O&M performance and status evaluation of a single large gymnasium are derived based on the class classification.

(1) Variable weights weighting formula:

$$V_i = \frac{W(t)F(O_i)}{\sum_{i=1}^{I} W(t)F(O_i)} \ ,(i = 1,2,\dots,I) \tag{7}$$

where $F(O_i)$ is the coefficient of variation.

$$F(O_i) = \begin{cases} e^{0.2\left|\frac{O_i - O_{goal}}{O_{min} - O_{goal}}\right|}, & O_i < O_{goal}, Incentive\ interval \\ 1\ , & O_i = O_{goal}, Qualifying\ Interval \\ e^{-0.2\left|\frac{O_i - O_{goal}}{O_{min} - O_{goal}}\right|}, & O_i > O_{goal}, penalty\ interval \end{cases} \tag{8}$$

where O_i represents the standardized measured value, $F(O_i)$ denotes the coefficient of variation of the i-th indicator, O_{goal} is the target value of the indicator, and O_{min} is the minimum value of the indicator.

(2) Variable-weighted composite value (H) formula:

$$H = \sum_{i=1}^{I} h_i = \sum_{i=1}^{I} V_i O_e \tag{9}$$

Where O_e represents the status scoring of the experts on the measured or assessed values of each indicator, as shown in Table 7. The variable-weighted composite value h_i of each indicator is accumulated and calculated to obtain the variable-weighted composite evaluation value H. $h_i^* = V_i(O_e^{max} - O_e)$, and h_i^* indicates the room for improvement of each indicator.

Table 7. Scoring criteria for the status of evaluation indicators.

Indicator Status	Very Poor	Poor	Middle Level	Good	Very Good
O_e	0 ~ 2	2 ~ 4	4 ~ 6	6 ~ 8	8 ~ 10

(3) O&M performance and status levels for large gymnasiums

The operational and maintenance (O&M) performance and status of large gymnasiums were classified into five level using the equal spacing method, as illustrated in Table 8.

Table 8. O&M performance and status levels for large gymnasiums.

Variable-Weighted Composite Value (H)	O&M Performance and Status	Level
[0,2]	Extremely poor	Ⅴ
(2,4]	Poor	Ⅳ
(4,6]	General	Ⅲ
(6,8]	Good	Ⅱ
(8,10]	Excellence	Ⅰ

3.4.2. Evaluation of the spatial dimension

This paper employs the hybrid temporal operator (TOWA-TOWGA) to assess the dynamic synthesis of O&M performance and status in large gymnasiums. The specific process is as follows: first, the temporal weight vector γ_t is calculated, and then the dynamic composite value Q_o is computed by considering the functionality and equilibrium of the TOWA and TOWGA operators.

(1) Time-weight vector

$$\begin{cases} \max\left(-\sum_{t=1}^{k}\gamma_t \ln\gamma_t\right) \\ \lambda = \sum_{t=1}^{k}\frac{k-t}{k-1}\gamma_t \\ \sum_{t=1}^{k}\gamma_t = 1 \;, 0 \le \gamma_t \le 1 \\ \quad t = 1,2,\dots,k \end{cases} \tag{10}$$

The temporal degree, denoted by $\lambda(\lambda \in [0,1])$, represents the temporal weight. The temporal weight vector, γ_t, denotes the strength of the data at each time period during the operator assembly process. The magnitude of λ, therefore, represents the strength of the data at each time period during the operator assembly process.

（2）Dynamic composite value

The dynamic composite values of O&M performance and status of large gymnasiums, designated as X_o and Y_o, respectively, were obtained based on the TOWA and TOWGA algorithms. The calculation of these values is as follows:

$$X_o = \sum_{t=1}^{k}\gamma_t H_o(t) \tag{11}$$

$$Y_o = \prod_{t=1}^{k}[H_o(t)]^{\gamma_t} \tag{12}$$

The variable-weighted composite value at a given moment, denoted by $H_o(t)$, is used to calculate the dynamic composite assessment value of the evaluated large gymnasium performance and status O.

$$Q_o = \eta_1 X_o + \eta_2 Y_o \tag{13}$$

The dynamic composite evaluation value, denoted by Q_o, is obtained by combining the weights of the dynamic composite evaluation value obtained based on the TOWA and TOWGA algorithms. These weights, denoted by η_1 and η_2, are constrained to satisfy the condition $\eta_1 + \eta_2 = 1$, with the additional constraint that η_1 and η_2 are restricted to the interval [0, 1].

4. Case Validation

4.1. Weighting of indicators

In this paper, a total of fifteen practitioners and scholars of O&M of gymnasiums were selected to carry out questionnaire surveys and the scoring of the existing 35 indicators according to the degree of importance. Nine of them are managers and six are scholars, and their structural distribution is shown in Figure 4. The fuzzy Borda method is used to find the weights that form the experts' scoring matrix $O(t)$. Based on Equations (1)–(6), the fixed weights W_i are obtained.

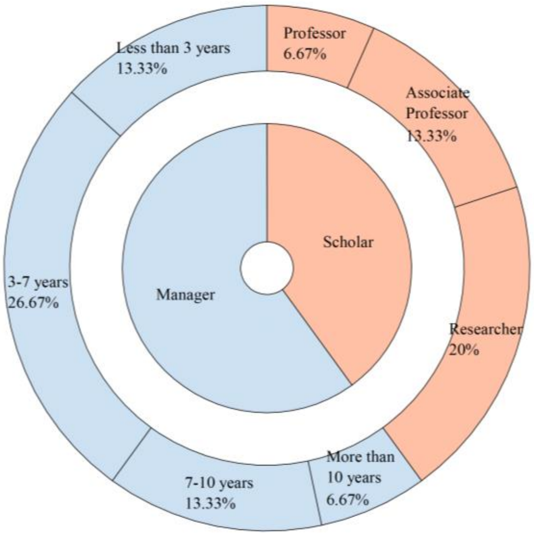


Figure 4. Distribution of experts.

4.2. Dynamic evaluation

This study conducts data research on five selected large gymnasiums in Beijing at the end of each month, a total of 12 months of data. The indicators in the "User Perspective" category are scored on a scale of 1 to 10 according to the respondents' subjective feelings in five areas: environmental comfort, the aesthetic quality of the venues, the reasonable spatial layout, accessibility, and satisfaction with the services provided. This is achieved through on-site questioning or questionnaire surveys conducted in the vicinity of the gymnasiums. The five gymnasiums were surveyed on a monthly basis, with 30 data points serving as the benchmark for each survey. A total of 1,794 valid data points were received. The mean of the subjective ratings for each of the five gymnasiums for each month was employed as the user-perspective evaluation result. For further details on the characteristics of gymnasiums, please refer to Table 9. Taking this as the data basis, combined with the dynamic evaluation system proposed in this study, the five gymnasiums were analyzed horizontally in time and vertically in space from both temporal and spatial dimensions.

Table 9. Gymnasium basic information.

Number	Location (Beijing)	Type of Venue	Building Area (m^2)	Years of Use	Structural Form
G1	Fourth ring road	Badminton center	36332	16	Prestressed chord-supported dome steel structure
G2	Third ring road	Soccer stadium	41828	62	Spoke-wheel suspension structure
G3	Fourth ring road	Basketball center	12000	35	Mesh shell construction
G4	Fourth ring road	Swimming pool	4000	15	Lightweight roof steel structure
G5	Fourth ring road	Table-tennis center	805	20	Reinforced concrete structure

In consideration of the temporal aspect, five sizable gymnasiums, variable-weighted composite values, and each evaluation level were taken into account. The data were subsequently normalized, and 15 experts were tasked with scoring the status of the measured values of each index in accordance with the criteria outlined in Table 7. The variable weights of the gymnasiums for the 12-month period were obtained by applying Equations (7) and (8) to the initial fixed weights W_i. The resulting variable-weighted composite value H was then calculated.

In order to clearly demonstrate the contribution of different perspectives of the gymnasium to H, this case calculates the contribution of different perspectives on the basis of single-value evaluation; at the same time, the five indicators with the lowest O_e in each month of the gymnasium are selected, and the improvement space h_i^* of each indicator is calculated and reordered, so as to improve the interpretability of the evaluation results.

From the spatial dimension, the dynamic composite evaluation value of five large gymnasiums after merging the time weights is considered to compare the O&M performance and status among the five gymnasiums. According to reference [33], λ is set to 0.4 to emphasize the recent data and consider the contribution of the early data. In this study, both η_1 and η_2 were set to 0.5 [34]. The time weight vector is computed according to the hybrid time series operator, which results in the dynamic composite evaluation value Q_o after the gyms are fused with time weights.

4.3. Results

4.3.1. Overall evaluation results

Table 10 shows the weights of the indicator system of the O&M performance and status of large gymnasiums.

Table 10. O&M performance and status indicator system weightings.

Main Criteria	Weight	Sub-Criteria	Weight
A1	0.2389	A11	0.0421
		A12	0.0392
		A13	0.032
		A14	0.0314
		A15	0.0345
		A16	0.0301
		A17	0.0296
A2	0.1155	A21	0.0376
		A22	0.0232
		A23	0.0193
		A24	0.0354
A3	0.2143	A31	0.0234
		A32	0.0207
		A33	0.0262
		A34	0.0238
		A35	0.0213
		A36	0.0332
		A37	0.0298
		A38	0.0359
A4	0.1208	A41	0.0311
		A42	0.0261
		A43	0.0293
		A44	0.0259
		A45	0.0084
A5	0.1853	A51	0.039
		A52	0.0338
		A53	0.03
		A54	0.0337
		A55	0.0099
		A56	0.0389
A6	0.1252	A61	0.0326
		A62	0.0187
		A63	0.0239
		A64	0.0254
		A65	0.0246

In the temporal aspect, Table 11 shows the 12-month variable-weighted composite evaluation results of five large gymnasiums (G1–G5) in Beijing. Table 12 shows the statistical values of G1–G5 results. In this study, the variable-weighted composite value and the variable-weighted evaluation results of each month from G1 to G5 are visualized in the data, which is shown in Figure 5 of five large gymnasiums and each evaluation level are considered. To ascertain the efficacy of the variable-weighted approach, this study employed the fixed-weighted method for G1 to evaluate the performance of the two techniques. The findings are presented in Figure 5c.

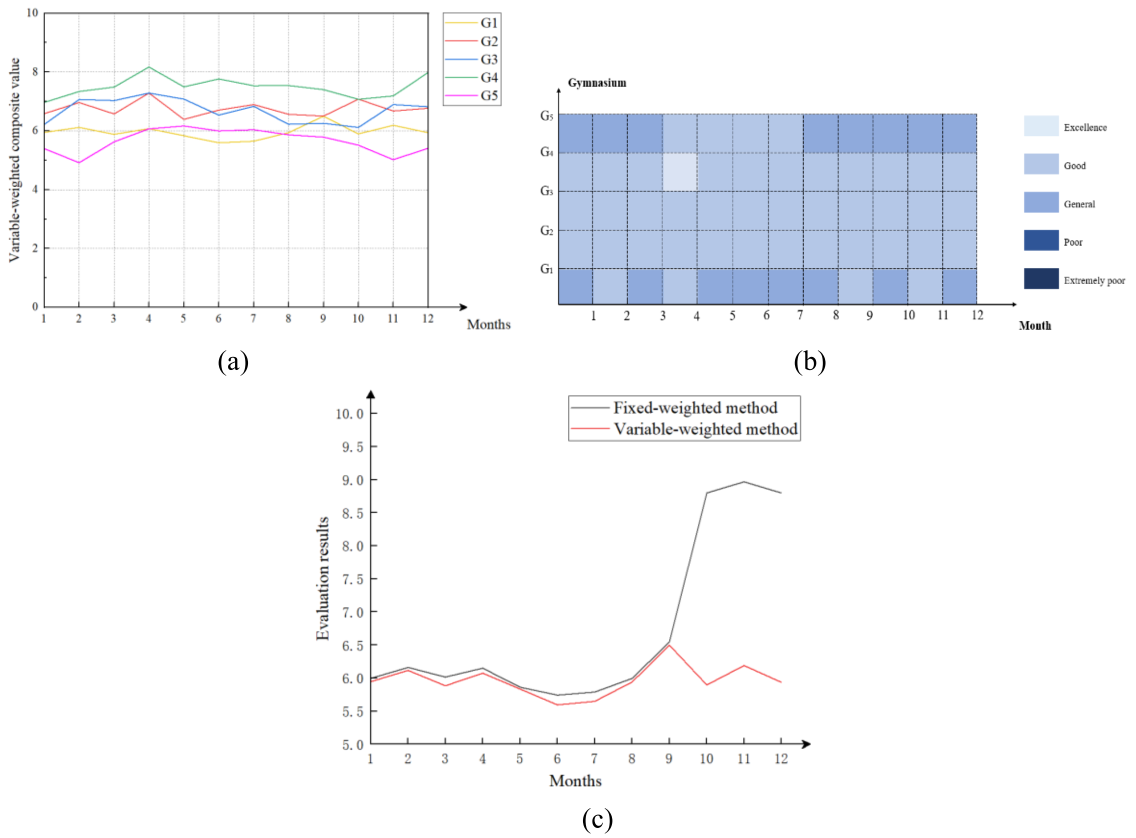
The coefficient of variation (CV) is defined as the ratio of the standard deviation to the mean and is utilized to quantify the relative degree of variability present in the data set. A smaller coefficient of variation (CV) indicates that the data points are closer to the mean, thereby indicating a higher degree of consistency and stability in the results. In the context of the O&M performance and status evaluation, a smaller coefficient of variation (statistically, it is generally accepted that the coefficient of variation should be less than 0.25) signifies that the gymnasium's evaluation outcomes remain relatively consistent from one month to the next. This reflects the stability of the O&M status. A low coefficient of variation indicates a reduction in the variability of the evaluation results over the 12-month period, suggesting that the implemented management measures and operational strategies are more stable from month to month. A stable O&M status reduces the probability of unforeseen events or failures occurring, thereby enabling the management team to prioritize long-term planning without the need for frequent adjustments to short-term strategies. Conversely, a high coefficient of variation indicates that the gymnasium is more volatile over the course of a year, necessitating the implementation of short-term strategies to achieve stability in O&M management.

Table 11. G1–G5 variable-weighted composite values.

Month/Gymnasiums	G1	G2	G3	G4	G5
January	5.947	6.586	6.224	6.969	5.396
February	6.116	6.963	7.067	7.340	4.918
July	5.885	6.577	7.030	7.490	5.630
April	6.075	7.285	7.283	8.172	6.070
May	5.835	6.391	7.080	7.497	6.168
June	5.596	6.708	6.538	7.766	6.000
July	5.649	6.895	6.833	7.537	6.040
August	5.941	6.564	6.225	7.542	5.865
September	6.498	6.502	6.259	7.403	5.788
October	5.898	7.078	6.118	7.076	5.515
November	6.190	6.677	6.896	7.190	5.019
December	5.937	6.769	6.820	7.990	5.415

Table 12. G1–G5 resulting statistical values.

Statistical Values/Gymnasiums	G1	G2	G3	G4	G5
Average	5.964	6.749	6.698	7.498	5.652
Standard deviation	0.240	0.261	0.406	0.351	0.411
Coefficient of variation	0.040	0.039	0.061	0.047	0.073



(a) (b)

(c)

Figure 5. Results of variable-weighted evaluation of the time dimension. (a) Line graph of variable-weighted composite value; (b) Variable-weighted composite evaluation rating; (c) Variable-weighted and Fixed-weighted evaluation results.

To further characterize the distribution of rating score data by month, this study plotted a box-and-line plot of the variable-weighted composite scores of G1-G5, as shown in Figure 6.

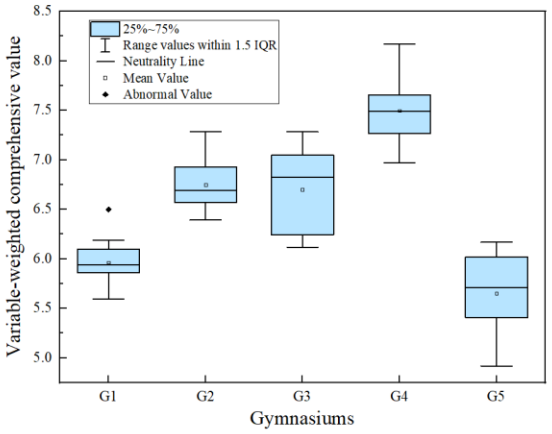


Figure 6. G1–G5 box-and-line plot of the variable-weighted composite scores.

In the spatial dimension, Table 13 indicates the G1-G5 dynamic composite assessment value.

Table 13. G1–G5 dynamic composite value.

Gymnasiums	Dynamic Composite Value
G1	5.938
G2	6.749
G3	6.758
G4	7.471
G5	5.659

Through the dynamic evaluation method of O&M performance and status of large gymnasiums considering spatio-temporal dimensions proposed in this study, the five gymnasiums from G1–G5 were subjected to data collection and analysis, and the following results were obtained based on the data of 12 months counted:

(1) The coefficients of variation of the five gymnasiums are all less than 0.25, which proves that the evaluation results among the five gymnasiums in 12 months have a high degree of harmonization and are within the acceptable range. Among them, the coefficient of variation of G5 is larger (0.073), which indicates that there is a higher degree of variability among its 12-month evaluation results; the coefficient of variation of G2 is smaller (0.039), which indicates that there is a lower degree of variability among its 12-month evaluation results.

(2) From the standard deviation of the variable-weighted composite value, G1 is the smallest (0.24), indicating that its O&M performance and status for one year is relatively stable; G5 is the largest (0.41), indicating that its O&M performance and status for one year fluctuates more.

(3) As can be seen from Figure 5, the evaluation grades of G2 and G3 remain basically unchanged, and the evaluation grades of G1, G4 and G5 change, but the degree of fluctuation of the changes is small.

(4) As shown in Figure 6, the mean and median of G1 and G4 are close to each other, indicating that the distribution of their 12-month evaluations is relatively uniform, while the distribution of the evaluations of G2, G3 and G5 is slightly skewed. The narrowest range of the G1 box and the highest degree of data concentration indicate that the degree of consistency of the 12-month evaluations is high. There are outliers in G1, the reasons for which are discussed in the discussion section.

(5) According to the magnitude of the dynamic composite value, it is concluded that the O&M performance and status of the five gymnasiums are ranked as follows: G4 > G3 > G2 > G1 > G5, *i.e.* the O&M performance and status of G4 is the best and that of G5 is the worst.

(6) The data in G1 without variable-weighted methods demonstrate a notable increase in the latter months (October and November), whereas the variable-weighted data exhibit a relatively stable trend.

4.3.2. Evaluation results for the month of May

The month of May is situated midway through the year, the climate is relatively mild, the residents' willingness to engage in physical activity is stronger, and it is representative of the overall year. Consequently, May was selected for this study to facilitate a detailed examination of the data. Figure 7 demonstrates the contribution of variable-weighted composite values for gymnasiums in May. The figure clearly shows the contribution of the six perspectives of variable-weighted composite value for each gymnasium in May, with safety, function and economy accounting for the highest proportion, and environment, energy and user perspective accounting for a lower proportion. The five gymnasiums present roughly the same approximately equivalent, indicating that they are not affected by the salient indicators and that the overall evaluation results are more stable.

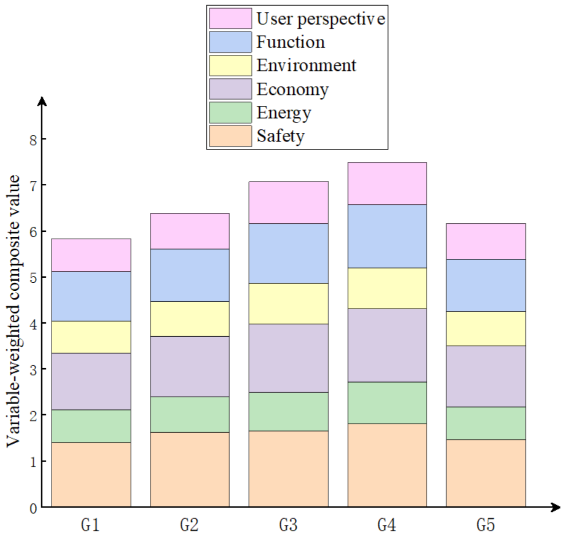


Figure 7. Contribution of variable-weighted composite values of gymnasiums in May.

Table 14 demonstrates the h_i^* ordering of the G1–G5 indicator improvement space. The indicators in the improvement table should be prioritized when making adjustments to gymnasium operation and maintenance strategies. For G1, it is recommended to introduce different types of activities, clean the arena regularly, and optimize the maintenance process of sports venues and facilities to improve efficiency. For G2, a detailed budget and financial plan should be developed to ensure a good ventilation system and improve the completeness of the emergency plan for all types of disasters. For G3, adjust the layout according to the needs of activities, develop an annual fire drill plan, and improve the efficiency of renewable energy generation. For G4, regularly inspect and maintain sports facilities, timely update or upgrade old facilities, optimize the spatial layout, and increase the number of bus routes and frequencies to the venues. For G5, repair minor faults in sports facilities in a timely manner, consider renewable energy generation systems, and invest in high-quality, durable building equipment.

Table 14. G1–G5 indicator improvement space h_i^* ordering.

Gymnasiums	**Indicator**	h_i^*
G1	(5, A51)	0.3120
	(5, A61)	0.2608
	(5, A31)	0.1872
G2	(5, A38)	0.2154
	(5, A41)	0.1866
	(5, A16)	0.1805

Table 14. *Cont.*

Gymnasiums	Indicator	h_i^*
G3	(5, A52)	0.2365
	(5, A13)	0.2240
	(5, A24)	0.2124
G4	(5, A56)	0.1944
	(5, A52)	0.1689
	(5, A64)	0.1270
G5	(5, A56)	0.3501
	(5, A24)	0.3186
	(5, A34)	0.1904

5. Discussion

The overall rating for G1 for the year is fourth place, indicating a lower rating overall. However, the ratings for G1 are more stable and consistent. The variable-weighted composite value for September represents an outlier, and can be attributed to two factors. Firstly, the G1 gymnasium was maintained as a collegiate gymnasium throughout the holiday season, with the objective of enhancing comfort. Secondly, a number of events that received financial support, such as commencement ceremonies, were held, which increased the institution's financial resources. The combination of these factors resulted in the occurrence of outliers. G2 was rated moderately high (third) for one year, exhibiting less volatility in its rating scale and less variability between evaluations. The gymnasium is currently performing well overall after being reinforced, and the O&M management measures taken show a high degree of stability that can be continued. G3 was rated higher (second) for one year, with less volatility in its rating scale. This indicates that the current state of the gymnasium is satisfactory and that management could devote more attention to long-term planning. The evaluations also indicated that G4 had the highest rating for one year (first place), with a relatively even distribution of ratings and a high degree of consistency. This suggests that the gymnasium is in optimal condition compared to the other four gymnasiums, and that more resources can be devoted to them. G5 had the lowest rating for one year (fifth place), and the high variability between its ratings suggests that the gymnasium has been in poor condition in the recent past, and that short-term strategies need to be adjusted to improve the gymnasium's condition.

The fixed-weighted method is employed in the actual process due to the constant weights. However, over time, the importance of some indicators may change (e.g., due to seasonal changes in energy consumption). Additionally, the initial weights may not be applicable to all gymnasiums, which makes it challenging for the fixed-weighted method to reflect the real situation. The variable-weighted method provides an incentive for well-performing indicators and a penalty for poorly performing indicators through a penalty-incentive mechanism. Additionally, it adapts the initial weights to align with the established gymnasium evaluations through a variable weighting approach.

The variable-weighted composite and dynamic composite evaluation values of G1–G5 gymnasiums reflect the performance and status of large gymnasiums in the dimensions of time and space, respectively. As evidenced by the aforementioned results, the time dimension is employed in the evaluation of individual gymnasiums, reflecting the fluctuations observed in their 12-month assessment outcomes. Group gymnasiums are evaluated on the basis of time-weighted variable-weighted composite values, with dynamic evaluation values used to compare the performance and status of group gymnasiums in different locations. In the case of individual gymnasium, the model is currently employed to ascertain whether the long-term and short-term decisions taken are conducive to optimal operational and maintenance performance and status. The absence of retrospective justifications for the evaluation results necessitates further investigation.

The final result derived from this paper is actually a single-value assessment method, so the contribution values from different angles need to be considered to ensure the stability of the evaluation results. At the same time, in order to enhance the practicality of the method, the improvement space h_i^* of each indicator is calculated, and according to the size and order of h_i^*, it can provide the direction for the O&M management strategy of the gymnasium.

In regard to the adaptability of the indicator system, it should be noted that the evaluation indicator system is established based on the characteristics of large gymnasiums. As a result, it is not applicable to other types of public buildings in specific aspects (e.g., the function of the venue). However, the quantitative indicators of safety, energy, economy, environment, and user perspective common to public buildings can be used for reference. With regard to the adaptability of the evaluation method, the evaluation method that considers time and space dimensions provides a reference for the dynamic evaluation of other indicator systems. A promising avenue for future research is the integration of computer simulation modeling with dynamic evaluation.

6. Conclusion

In this study, a dynamic evaluation method of O&M performance and status of large gymnasiums is proposed, specifically, a system of O&M performance and status of large gymnasiums is constructed, and a dynamic evaluation method of large gymnasiums with fused spatial and temporal dimensions based on variable weighting method and hybrid time series operator is proposed. The O&M information of five gymnasiums in Beijing for 12 months in one year is studied, and the dynamic evaluation is realized according to the above method, and the following conclusions are drawn:

(1) In contrast with the conventional system that is centered on a singular dimension, the operation and maintenance performance and status evaluation system encompasses six aspects: safety, energy, economy, environment, venue function, and user experience. It is oriented towards user feedback and offers a more comprehensive and scientific decision-making support by analyzing data from multiple perspectives.

(2) In comparison to the conventional fixed-weighted evaluation approach, the incorporation of a variable-weighted methodology and a hybrid time-series operator allows for a more comprehensive consideration of the evolving dynamics inherent to the evaluation indices. The dynamic evaluation method considers the degree of importance of the measured

value of the indexes, allowing the weights of the indexes to be modified accordingly. This approach can be gradually applied to different gymnasiums at different times, aligning more closely with the actual needs of the long-term O&M management stage of the gymnasium.

(3) The dynamic evaluation method of large gymnasiums integrating temporal and spatial dimensions reflects the results of the change of O&M performance and status of individual gymnasiums over time in the temporal dimension, as well as the comparison of good and bad O&M performance and status among different gymnasiums in the spatial dimension. This method can be used as an evaluation method for both single and group gymnasiums.

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Conflicts of Interests

The authors declare that they have no conflicts of interest in this paper.

Authors contribution

Zhansheng Liu: Methodology, Conceptualization, Investigation, Funding acquisition, Data curation, Writing—review & editing. Mingming Li: Methodology, Visualization, Writing—review & editing. Weiyu Ji: Methodology, Software, Supervision, Investigation. Zhe Sun: Data curation, Validation.

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