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Research on the Lifecycle Audit Path of Educational Engineering Projects

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ABSTRACT

With the continuous expansion of the scale of educational engineering projects and the increasing requirements for quality, cost, and efficiency, the traditional single-phase audit method can no longer meet the needs of full-cycle project management. Lifecycle Audit (LCA), as a comprehensive system evaluation tool, can effectively promote the sustainable development of a project by reviewing each phase of the project. This paper takes the construction project of a comprehensive teaching building for an educational institution as a case study, combines the lifecycle audit model, and explores the audit contents and application practices during the design, implementation, operation, and maintenance stages. The research shows that the implementation of the LCA model not only improves project management efficiency but also helps project managers better address potential challenges that may arise during the project, thus providing theoretical and practical references for similar projects.

Keywords: Lifecycle Audit, Educational Engineering Projects, Cost-effectiveness, Risk Control, Performance Evaluation.

INTRODUCTION

Educational engineering projects, as an important part of infrastructure construction, are much more complex than ordinary building projects. These projects not only cover multiple stages such as design, construction, operation, and maintenance, but also involve significant differences in management goals and risks at each stage [1][2][3]. Traditional single-phase audits often focus on controlling quality, cost, or progress during a specific phase [3][4]. However, as the project scale expands and management requirements increase, the single-phase audit model can no longer effectively address the challenges of full-cycle management [5]. Therefore, the proposal and implementation of Lifecycle Audits (LCA) have become an important trend in the management of educational engineering projects. Lifecycle audit involves systematically reviewing all stages of the project from initiation, design, construction, operation, to maintenance, helping project managers fully understand the entire project process, identify potential risks, and provide solutions [1][3][4][5]. This paper, through a case analysis of the construction project of a comprehensive teaching building for an educational institution, explores how to improve the scientific, refined, and intelligent management of the project through the LCA model to ensure the successful realization of goals at each stage and to provide references for similar projects in the future.

THEORETICAL BASIS OF LIFECYCLE AUDIT

The core of lifecycle audit is to ensure the achievement of quality, progress, and cost goals at each stage of the project and to identify and control various risks in the implementation process as early as possible [2][5]. In educational engineering projects, due to special requirements for functionality, flexibility, stability, and long-term sustainability, the implementation of lifecycle audit is particularly important.

Lifecycle audit covers multiple aspects, including feasibility review during the initiation phase, optimization evaluation during the design phase, progress control during the construction phase, and performance evaluation and maintenance management during the operation phase [1][2][3][4]. This process is not only a compliance check but also a forward-looking management tool aimed at providing strong support for the sustainability and efficient operation of the project through a comprehensive review of the entire process.

Definition and Features of Lifecycle Audit

Definition of Lifecycle Audit:

Lifecycle audit is a systematic review method that evaluates the entire project process from planning, design, to implementation, operation, and maintenance to ensure the realization of project goals [2]. The core concept is to cover all stages of the project and provide a comprehensive perspective to identify potential issues and propose improvement suggestions.

Special Requirements for Educational Engineering Projects:

Educational engineering projects, due to their role in supporting education and research, have higher audit requirements:

(1) Functionality and Flexibility: The project must meet multi-functional usage needs.
(2) Long-term Sustainability and Stability: The facilities must operate stably over the long term.
(3) Efficiency and Economy: The project must balance cost control and efficient management.

Lifecycle Phases of Educational Engineering Projects

Main Phases of the Project Lifecycle:

The lifecycle of an educational engineering project can be divided into the following phases:

(1) Initiation Phase: Define project goals and feasibility, with an audit focus on policy compliance and funding sources.
(2) Design Phase: Develop detailed design plans, with an audit focus on functionality, budget reasonableness, and risk evaluation.
(3) Construction Phase: Complete construction and equipment installation, with an audit focus on quality control, progress management, and compliance with fund usage.
(4) Operation and Maintenance Phase: Ensure the building is used and maintained properly, with an audit focus on performance evaluation and cost control.

Risks and Audit Focus at Different Phases:

(1) Initiation Phase: Risks mainly come from policy changes and uncertainty in fundraising, requiring a focus on feasibility studies and risk management plans.
(2) Design Phase: Risks mainly arise from poor design leading to cost overruns or functional defects, requiring evaluation of the feasibility and optimization of design plans.

(3) Construction Phase: Risks include construction delays, quality issues, etc., requiring on-site audits and progress monitoring to reduce risks.
(4) Operation and Maintenance Phase: Risks involve equipment aging and declining operational efficiency, requiring periodic evaluations and preventive maintenance to reduce long-term costs.

Theoretical Basis for Audit Path Planning
The Role of Performance Audits:
Performance audits focus on evaluating whether the project has achieved its expected goals, with the core aim of improving project benefits and resource utilization efficiency.

The Role of Compliance Audits:
Compliance audits focus on ensuring that the project complies with relevant laws, regulations, and policy requirements by reviewing documents and records to ensure the legality and compliance of the project.

The Integrated Role of Internal Control Audits:
Internal control audits combine performance and compliance audits, aiming to reduce operational risks and improve management efficiency by reviewing project management processes and internal control mechanisms [6][7][8][9][10]

MODEL FRAMEWORK AND AUDIT PATH OVERVIEW

The Lifecycle Audit (LCA) model combines multiple analytical dimensions to conduct in-depth audits and analyses of different phases of the project [1][7][8][9]. Below are five key audit models, each evaluating and optimizing project management from a different perspective [6][7][10].

Cost-Benefit Analysis Model (CBA)

The Cost-Benefit Analysis (CBA) model is a tool used to assess the economic feasibility of a project by comparing its inputs and outputs. In lifecycle audit, CBA is not just used to evaluate the initial return on investment but also serves as an economic benefit analysis throughout the entire project lifecycle [8][9][11]. CBA is primarily used to help decision-makers quantify the economic benefits and costs of the project. For educational engineering projects, CBA can be applied to analyze the economic feasibility of different options, such as design plans, construction plans, and operational strategies. Particularly in the design phase, CBA can help determine the return on investment of various design plans and optimize plan selection, ensuring that resources are used most effectively. [9][10]. Key factors affecting CBA include initial investment, long-term operating costs, and potential savings. By thoroughly analyzing these factors, CBA provides a clear economic decision-making basis for the project [6][7][11].

Risk Assessment and Control Model (RAC)

The Risk Assessment and Control (RAC) model is a tool that systematically identifies, assesses, and controls project risks [3][5][8][11]. In lifecycle audit, the RAC model helps managers identify potential risks and provides effective strategies for addressing them [8][9][11].

RAC is primarily used to identify the various risks a project may face at each phase and to rank and control these risks through quantitative assessment methods [6][7][8][9][10]. In educational engineering projects, possible risks include funding shortages, poor design, construction delays, and quality issues. Risk assessment focuses on factors such as the probability of risk occurrence, the impact of risk, and how control measures (such as design optimization, construction management, and operational maintenance) can reduce the likelihood and impact of risks.

Critical Path Method Model (CPM)

The Critical Path Method (CPM) is a tool for project schedule management, designed to identify the most critical tasks and activities within a project to ensure it is completed in the shortest possible time [6][10]. The CPM model helps auditors analyze key tasks in the project schedule and provides a basis for schedule control throughout the project lifecycle [6][7][10].

CPM is mainly used for progress control and time management in projects. By identifying the project's critical path, it ensures that key tasks are completed on time. During the construction phase, CPM helps auditors identify critical activities in the construction process, such as civil engineering, equipment installation, and commissioning, ensuring that these activities are completed on time. Factors influencing CPM include task dependencies, task durations, resource allocation, and team collaboration efficiency.

Life Cycle Cost Analysis Model (LCCA)

The Life Cycle Cost Analysis (LCCA) model is a tool that calculates all costs of a project throughout its entire lifecycle [1]. The core idea of LCCA is to assess the project's initial investment and subsequent operating and maintenance costs from the perspective of long-term economic benefits [1][9][10].

LCCA helps auditors evaluate the economic feasibility and sustainability of a project by considering all costs from design to decommissioning [6][7][10]. Particularly in the design phase, LCCA can be used to compare the long-term operating costs of different design options, helping decision-makers select the optimal plan. Key factors affecting LCCA include initial investment, energy consumption, maintenance costs, operational efficiency, and the facility's lifespan [1][5][9][10].

Performance Evaluation and Fault Prediction Model (PEFPM)

The Performance Evaluation and Fault Prediction Model (PEFPM) is used to assess the performance of equipment and predict potential failures [9][11]. This model monitors the operational status of equipment to forecast future failures, providing support for preventive maintenance [9][11].

PEFPM helps managers monitor the performance of building facilities and predict potential fault risks, particularly during the operation and maintenance phases [10]. By implementing preventive maintenance, equipment failure rates can be reduced, and building operational efficiency can be improved. Key factors influencing PEFPM include the operational status of equipment, environmental factors, usage frequency, and maintenance history.

PROJECT BACKGROUND

An educational institution plans to construct a comprehensive teaching building, aimed at providing a multifunctional space for teaching, research, and academic exchange [7][8][9][10]. The project faces challenges such as design optimization, construction quality, and operational cost control [7][8][9][10]. Therefore, the application of the lifecycle audit model is crucial for ensuring the smooth completion of the project and for applying and analyzing audit models at each phase.

Audit Analysis and Model Application in the Design Phase

Cost-Benefit Analysis Model (CBA) is used to assess the economic feasibility of the project design [1][9]. The benefit of design optimization is measured by calculating the Net Present Value (NPV). The formula is as follows:

$$\text{NPV} = \sum_{t=1}^{n} \frac{C_{\text{oper},t}}{(1+r)^t} - I_0$$

Where I_0 is the initial investment,$C_{\text{oper},t}$ is the operational savings in year t,r is the discount rate,n is the project's useful life.

Life Cycle Cost Analysis Model (LCCA) helps evaluate the total life cycle cost (LCC) of the design plan [1]. LCC includes both the initial construction costs and the operational and maintenance costs. The formula is:

$$LCC = I_0 + \sum_{t=1}^{n} \frac{C_{\text{maint},t}}{(1+r)^t} + \sum_{t=1}^{n} \frac{C_{\text{energy},t}}{(1+r)^t}$$

Where $C_{\text{maint,t}}$is the maintenance cost in year t, $C_{\text{energy,t}}$ is the energy cost,r is the discount rate, n is the project's useful life.

This ensures that the design plan is scientific, economic, and compliant. It reviews the functional rationality and budget control of the design plan. It also evaluates the potential risks in the design phase. Optimized design solutions can significantly reduce operational phase costs while meeting functional requirements. It is recommended to strengthen budget management and cost control during the design process.

Audit Analysis and Model Application in the Implementation Phase

Risk Assessment and Control Model employs a risk matrix to quantify potential project risks [6][9][10]. Each risk is scored based on its probability of occurrence and its impact magnitude, resulting in a total risk value. The formula for calculating the risk matrix is:

$$\mathrm{R_{total}} = \sum_{\mathrm{i}=1}^{\mathrm{m}} \mathrm{P_i} \times \mathrm{I_i}$$

where R_{total} represents the total risk value, P_i is the probability of occurrence for i, I_i is its impact magnitude, and m is the total number of identified risks.

Critical Path Method identifies the project's critical path to minimize the total completion time for all tasks. The duration of the critical path is calculated using the following formula:

$$\text{Critical Path Duration} = \max\left(\sum_{i=1}^{n}(T_i + D_i)\right)$$

where T_i is the duration of i task, D_i is its delay, and n is the total number of tasks.

Control measures are implemented to ensure construction quality and compliance with financial regulations, manage progress, and ensure contract performance. The integration of risk assessment with the critical path method effectively guarantees project quality and schedule adherence. Recommendations include optimizing supply chain management and enhancing resource allocation.

Audit Analysis and Model Application in the Operation Phase

Performance Evaluation Model evaluates operational efficiency using specific indicators such as classroom utilization rates and equipment availability rates [9][11]. The formulas are as follows:

$$U_{\text{classroom}} = \frac{\text{Total Usage Hours}}{\text{Total Available Hours}} \times 100\%$$

where $U_{\text{classroom}}$ is the classroom utilization rate, "Total Usage Hours" is the actual classroom usage time, and "Total Available Hours" is the total available classroom time.

$$R_{\text{equipment}} = \frac{\text{Total Working Hours of Equipment}}{\text{Total Available Hours of Equipment}} \times 100\%$$

where $R_{\text{equipment}}$ is the equipment availability rate, "Total Working Hours of Equipment" is the total operating time of the equipment, and "Total Available Hours of Equipment" is its total available operating time.

An energy consumption analysis model is used to evaluate building energy efficiency by calculating cost savings from energy-saving measures:

$$C_{\text{energy}} = E_{\text{before}} - E_{\text{after}} \times C_{\text{rate}}$$

where E_{before} and E_{after} are the energy consumption levels before and after implementing energy-saving measures, respectively, and C_{rate} is the unit energy cost.

Enhancing building usage efficiency and controlling operational costs are emphasized. While the building demonstrates high utilization, there is potential for further energy savings. Recommendations include improving energy efficiency measures.

Audit Analysis and Model Application in the Maintenance Phase

Maintenance Cost Prediction Model predicts long-term maintenance costs, assuming a correlation between maintenance costs, equipment age, and failure rates [9][11]. The formula is:

$$C_{\mathrm{maint}} = \sum_{i=1}^{n} (F_i \times C_{\mathrm{unit}})$$

where C_{maint} is the maintenance cost, F_i is the failure frequency in i year, C_{unit} is the maintenance cost per failure.

Fault Prediction Model monitors equipment conditions to predict potential failures, enabling preventive maintenance [1][6][9][11]. The fault prediction formula is:

$$F_{\mathrm{predict}} = F_{\mathrm{base}} \times (1 + \beta \times t)$$

where F_{predict} is the predicted failure rate, F_{base} is the baseline failure rate, β is the failure rate growth factor, and t is time.

Maintaining cost control and ensuring the long-term functionality of facilities are key objectives. Preventive maintenance has successfully reduced long-term costs, and the fault prediction model effectively prevents equipment failures.

Model Analysis

In the lifecycle audit model, establishing appropriate thresholds is critical, as they help identify potential risk points, assess compliance with predetermined performance standards, and determine whether corrective measures are necessary. Below, we establish and discuss reasonable thresholds based on the formulas provided earlier.

Design Phase

The Cost-Benefit Analysis (CBA) model, using the Net Present Value (NPV) formula, benefits from threshold settings to evaluate whether a project is economically viable. If the NPV is greater than 0, the project's economic benefits are positive, and design optimization can enhance the project's long-term benefits. If NPV is less than 0, the project may fail to achieve the expected economic returns, requiring a reevaluation of the design plan. The recommended threshold for NPV is:

$$\mathrm{NPV} \geq 0$$

If the NPV is less than 0, auditors should evaluate whether excessive costs or suboptimal design choices are limiting benefits and consider revisiting the design.

The Lifecycle Cost Analysis (LCCA) model evaluates the lifecycle cost (LCC) of a design. [1]. By setting thresholds, auditors can determine if the design adheres to budget constraints. If the LCC exceeds the budget or the expected range for the design phase, it indicates the design may lead to high long-term operational costs. A typical budget constraint can be expressed as:

$$\text{LCC} \leq \text{Budget Ceiling}$$

Setting a reasonable budget ceiling ensures total lifecycle costs are controlled. If LCC significantly exceeds this ceiling, auditors should reassess the design's economic feasibility.

Implementation Phase

The Risk Assessment and Control (RAC) model helps identify potential risks such as construction delays and quality issues during the implementation phase. By setting a risk value threshold, projects can be maintained within acceptable risk levels. The maximum acceptable total risk value R_{total} is typically defined based on the project's risk tolerance:

$$R_{\text{total}} \leq 0.7$$

Here, 0.7 represents a hypothetical risk tolerance value; exceeding this value necessitates additional risk control measures. If R_{total} exceeds the threshold, auditors should intensify oversight of construction progress and quality, especially in high-risk areas.

The Critical Path Method (CPM) determines the shortest construction timeline for a project. Setting a maximum allowable delay for the critical path ensures that progress remains on schedule. For instance, the total delay on the critical path should not exceed a specific percentage:

$$\text{Critical Path Delay} \leq 10\%$$

If the critical path delay exceeds 10%, it signifies significant progress issues, which may require remedial measures, such as allocating additional resources or extending work hours.

Operation Phase

The Performance Evaluation Model (PEFPM) measures building efficiency during the operation phase by assessing classroom utilization rates and equipment reliability. Reasonable thresholds include:

- Classroom utilization rate: $U_{\text{classroom}} \geq 80\%$
- Equipment reliability rate: $R_{\text{equipment}} \geq 95\%$

If classroom utilization falls below 80% or equipment reliability drops below 95%, it indicates inefficiencies in building operations, potentially necessitating space utilization or maintenance optimization.

The Energy Consumption Analysis Model evaluates energy efficiency, requiring energy-saving measures to meet predetermined cost-saving targets. The annual cost savings threshold is typically:

$$C_{\text{energy}} \geq 0.15 \times E_{\text{before}}$$

If actual cost savings fall below 15%, auditors should investigate potential issues such as poor energy management or ineffective implementation of energy-saving measures.

Maintenance Phase

The Maintenance Cost Prediction Model forecasts maintenance costs, helping manage long-term facility maintenance needs. Setting an annual maintenance cost ceiling prevents excessive long-term expenses:

$$C_{\text{maint}} \leq \text{Budget Ceiling}$$

If predicted maintenance costs exceed the budget ceiling, measures such as hiring additional personnel or adopting more efficient equipment may be required to reduce frequent breakdowns and repairs.

The Fault Prediction Model (FPM) monitors equipment conditions to predict failures, allowing thresholds to be set based on predicted failure rates. The acceptable maximum failure rate is:

$$F_{\text{predict}} \leq 5\%$$

If the failure rate exceeds 5%, auditors should assess the maintenance schedule and quality, consider early equipment replacement, or adjust maintenance strategies.

Establishing reasonable thresholds facilitates effective identification of potential issues, ensuring timely detection and resolution of risks at each stage of the project. Continuous monitoring of these models and thresholds significantly improves project management, ensuring that projects are completed within budget, quality, and time constraints. The design phase should focus on optimizing economic efficiency and sustainability, particularly in cost control. The implementation phase should prioritize monitoring construction quality and progress to ensure risk control. The operation phase emphasizes improving building efficiency, energy conservation, and cost control. The maintenance phase aims to ensure long-term stable operation of facilities while reducing maintenance costs. By establishing these thresholds and conducting real-time monitoring, auditors can identify weaknesses in projects and propose corresponding improvements, ensuring the project's long-term success.

CONCLUSION AND OUTLOOK

This study applied lifecycle audit models to a comprehensive teaching building project at an educational institution, verifying the efficacy and feasibility of lifecycle analysis (LCA) across various project stages. Findings indicate that LCA effectively mitigates risks, optimizes resource allocation, and enhances project outcomes, providing theoretical and practical guidance for similar projects. Future research could explore integrating intelligent tools with LCA to improve real-time capabilities and predictive accuracy, offering more precise management support for complex educational infrastructure projects.

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