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Optimization of Talent Training System for the Full Life Cycle of Construction Machinery Projects

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Abstract

With the deepening development of intelligent manufacturing and Industry 4.0, the construction machinery sector faces new requirements for workforce capabilities. Based on the concept of full life cycle management, this paper addresses existing issues in current university-level construction machinery training systems, including fragmentation, lagging equipment management, and insufficient innovation capacity development. The study proposes an optimized talent training system spanning four phases: project planning and design, manufacturing and assembly, operation and maintenance management, and decommissioning and disposal. The research organically integrates equipment full life cycle management with talent cultivation, establishing an integrated theoretical framework of equipment management and capability development. Through safeguard measures such as industry-education integration and digital platform construction, this study provides systematic theoretical reference and practical pathways for construction machinery institutions to enhance talent cultivation quality and optimize training equipment management.

Keywords

Construction Machinery; Full Life Cycle; Talent Training System; Industry-Education Integration.

1. Introduction

As a vital component of the equipment manufacturing sector, the construction machinery industry undergoes profound transformation toward intelligence and digitalization. Industry demands have shifted from singular operational skills toward systematic thinking and full-cycle management capabilities. However, current training systems in university construction machinery programs generally suffer from fragmented training content, disconnection from actual engineering projects, and insufficient innovation capacity development, struggling to meet evolving industry needs. Training equipment serves as the primary carrier for practical project implementation in universities and represents essential hardware for industry-education integration training, functioning as fundamental infrastructure in higher education teaching and talent cultivation processes. Universities enable students to master practical skills more rapidly through training equipment. Meanwhile, proper equipment operation and usage relate directly to student safety. However, current equipment management concepts and methods in Chinese universities lag significantly behind actual teaching requirements. Many institutions adopt a heavy investment, light maintenance approach and lack professional equipment management personnel, resulting in inadequate equipment maintenance and low equipment integrity rates. Numerous studies indicate that universities face issues of heavy procurement, light management, making procurement decisions to complete budgets without sufficient equipment suitability assessment, and employing non-professional equipment

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management personnel. These outdated approaches significantly hinder equipment effectiveness and value realization, making enhanced training equipment management effectiveness an urgent priority. Integrating modern management methods into training equipment management represents an inevitable trend for universities to achieve industry-education integration and enhance student practical capability.

2. Literature Review

Full life cycle management theory originated from product life cycle management and gradually expanded into equipment management. This theory emphasizes systematic management throughout the entire process from equipment planning, procurement, and usage to disposal, maximizing equipment value. From a historical research perspective, due to rapid economic development, foreign countries were first to recognize the importance of life cycle management for equipment and fixed assets. Eldon and Michael discovered that the United States was the first country to apply full life cycle management of equipment and fixed assets in practice [1]. In the 1960s, when the U.S. Department of Defense tracked a subordinate system, it found that besides initial equipment procurement costs, usage and maintenance expenses exceeded the original equipment value by tenfold. Therefore, equipment cost calculation needed to consider expenses throughout the entire life cycle. Building on this foundation, foreign countries gradually formed full life cycle management models for equipment and fixed assets, which gained recognition in several countries by the 1970s. Regarding life cycle phase division, Hao (2008) divided the equipment life cycle into three phases based on the concept of equipment full life cycle management: preliminary, usage and post-usage phases, proposing management content, methods and significance for each phase, providing reference for subsequent related research [2]. Huang et al. (2011) further integrated concepts of intensive unified management and equipment-centered humanized management into the equipment full life cycle, designing specific implementation plans for equipment full life cycle management [3]. When researching equipment asset management in power system engineering, Tang et al. concluded that introducing full life cycle management played a crucial role, demonstrating how to utilize full life cycle management to improve power equipment management efficiency [4].

Compared with traditional equipment management concepts, equipment full life cycle management offers advantages in comprehensiveness, systematization, and foresight, achieving widespread application in automotive manufacturing, healthcare, university laboratories, and other fields. In university equipment management, Song et al. integrated equipment full life cycle management into Chinese university instrument equipment management practice based on previous enterprise applications [5]. Through comparative research with traditional equipment management theory, they found full life cycle management models demonstrated higher effectiveness. Subsequently, more scholars began transferring equipment full life cycle management concepts from enterprise equipment applications to institutional equipment practice. Lai et al. focused on large university equipment, dividing its full life cycle into preparation, procurement, usage and disposal periods [6]. Based on these four phases, they analyzed different management models and provided measures and recommendations for strengthening equipment management. Lin analyzed numerous problems in university equipment management, discovering that equipment full life cycle models demonstrated higher effectiveness in data, cost, and efficiency aspects [7]. The study further indicated that adopting measures such as formulating scientific procurement plans, training operators, strengthening usage management, recording equipment operation, and emphasizing post-usage management represented key application points for the full life cycle management model. Wu focused on analyzing challenges and difficulties facing large instrument equipment throughout the full life cycle in universities, proposing management

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optimization for large instrument equipment asset management from demonstration, procurement, usage and disposal periods [8]. The research argued that beyond management model innovation, establishing an integrated management platform remained necessary to strengthen management.

From the full life cycle perspective, training equipment management can be divided into four phases: planning and demonstration, procurement and acceptance, usage and maintenance, and decommissioning and disposal. Research demonstrates that university training equipment meets two basic conditions for full life cycle management methods: first, possessing different phase characteristics throughout the life cycle; second, equipment having time limitations. Therefore, introducing full life cycle management concepts into training equipment management proves scientifically sound and reasonable. Equipment full life cycle management has been widely applied in fields with substantial equipment assets such as power grids, automotive manufacturing, healthcare, petrochemicals, and metallurgy, with numerous studies confirming positive practical results [9-10]. Full life cycle management emphasizes continuous attention to each equipment phase throughout its finite life cycle, implementing unified, dynamic, and coordinated management to achieve optimal equipment management outcomes. Through intervention from the equipment planning phase, followed by unified dynamic management through procurement, usage, and disposal phases, scientific and effective equipment layout planning becomes achievable. Target equipment suitable for full life cycle management methods must meet two basic conditions: possessing different phase characteristics throughout the life cycle and having time limitations. University training equipment meets these two basic conditions, making the introduction of full life cycle management concepts into training equipment management scientifically sound and reasonable. Introducing this concept into construction machinery professional talent cultivation not only optimizes training equipment management but also cultivates systematic thinking and holistic perspectives among students.

3. Optimization Design of the Full Life Cycle Talent Training System for Construction Machinery Projects

In recent years, as the importance of universities in China's education system has gradually become more prominent, training equipment, serving as the primary carrier for on-campus practical projects and essential hardware for industry-education integration training, has attracted increasing scholarly attention. Currently, research on training equipment management focuses mainly on two aspects: first, building informatized training equipment management platforms based on the continuous maturation of internet and related technologies, gradually achieving technological replacement of manual operations; second, concerning training equipment usage efficiency, various scholars attempt to enhance equipment utilization rates through budget performance management, procurement management, and maintenance management approaches, enabling training equipment to truly realize its teaching value.

The usage phase of training equipment consistently remains a research focus, as improving usage efficiency maximizes training equipment resource value. Regarding how to enhance training equipment usage efficiency, different studies emphasize slightly different aspects. From the budget performance dimension, the representative viewpoint involves controlling from the source when equipment enters the school, ensuring high matching between equipment and teaching tasks to improve usage efficiency. From the procurement management dimension, most scholars recognize that improving procurement reliability through procurement demonstration and multi-level, multi-angle indicator evaluation of training equipment procurement suppliers ensures equipment necessity and reliability. From the

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maintenance management dimension, most research suggests that regular maintenance and autonomous upkeep are both indispensable, ensuring normal training equipment operation through efficient maintenance activities, thereby avoiding damaged and unrepaired conditions. Training equipment management informatization platform construction continues optimizing alongside the continuous development of internet technology, the Internet of Things, and artificial intelligence. With the development and widespread application of IoT technology, many scholars have combined QR codes, RFID, and other technologies with online systems, creating closed-loop online-offline informatized training equipment management platforms. Simultaneously, demand for on-campus equipment sharing continues increasing, with more scholars beginning to focus on creating informatized training equipment management platforms that enable campus-wide sharing to improve daily equipment utilization rates [11].

3.1. Principles and Concepts for Optimization Design

Optimization design of the full life cycle talent training system for construction machinery projects must follow systematic and scientific principles. First is the full life cycle integration principle [12]. Drawing on equipment full life cycle management phase division methods, the construction machinery project life cycle is divided into four phases: planning and design, manufacturing and assembly, operation and maintenance management, and decommissioning and disposal, with training content systematically designed around these four phases. This design breaks through the fragmented curriculum shortcomings in traditional training systems, enabling students to completely experience an entire construction machinery project process from inception to termination, cultivating systematic thinking and holistic perspectives [13]. Second is the innovation capability orientation principle. During training, not only should skill training receive attention, but student innovation awareness should be stimulated through project-based learning and other methods, enabling students to achieve knowledge creation and capability enhancement through practical processes. This teaching model emphasizes active student participation and exploratory spirit, allowing them to exercise innovative thinking and practical abilities while solving actual problems. Third is the deep industry-education integration principle. Responding to requirements in the Opinions on Deepening the Reform of Modern Higher Education System Construction, actual enterprise projects are introduced into training teaching, enterprise engineers are invited to participate in guidance, and university-enterprise resource sharing is realized. Through modern apprenticeship systems, customized cultivation and other methods, training content seamlessly connects with position requirements, ensuring students can rapidly adapt to work positions after graduation [14]. Fourth is the equipment management coordination principle. Adopting design principles of balancing stability with optimization, combining qualitative guidance with quantitative management, equipment full life cycle management is organically integrated with talent cultivation. During student participation in project training processes, equipment management capabilities are cultivated simultaneously, realizing learning through usage, managing through learning, enabling students not only to master construction machinery operational skills but also to understand the importance and methods of equipment management. Fifth is the digitalization support principle. An integrated digital management platform is constructed to realize functions including training equipment informatization management, teaching process data collection, and learning resource sharing. Virtual simulation technology is utilized to compensate for physical equipment shortages and expand training space [15]. These digitalization methods not only improve management efficiency but also provide students with richer and more diverse learning resources and learning methods.

3.2. Four-Phase Integrated Training System Architecture

The core of the full life cycle talent training system for construction machinery projects is establishing a systematic cultivation pathway spanning four phases. In the planning and design phase, the cultivation objective is enabling students to master market research, demand analysis, technical solution design and demonstration capabilities, understanding basic processes and methods for construction machinery project initiation [16]. Training content includes three aspects: construction machinery market research and demand analysis, technical solution design and demonstration, and project feasibility analysis. Students need to conduct market research in group format, analyzing demand characteristics for construction machinery across different application scenarios, utilizing CAD/CAE software for 3D modeling and simulation analysis to complete conceptual design of typical construction machinery. During this process, students must also learn to apply the Analytic Hierarchy Process (AHP) for technical-economic evaluation of design solutions, comprehensively demonstrating design solutions from multiple dimensions including technical feasibility, economic feasibility, and environmental impact. Implementation methods adopt Project-Based Learning (PBL) models, with each learning group undertaking a complete design project. Enterprise engineers serve as part-time mentors participating in solution reviews, introducing actual enterprise needs and technical standards into teaching [17]. Assessment and evaluation employ multi-dimensional standards including design report quality, solution defense performance, solution innovation and team collaboration performance.

In the manufacturing and assembly phase, the cultivation objective is enabling students to master mechanical processing technology formulation, CNC programming operation, assembly and commissioning, quality inspection, and other capabilities, strengthening process standardization awareness and safety awareness. Training content covers component processing technology training, CNC machining and intelligent manufacturing training, assembly and commissioning training, and quality testing training. Students need to learn to formulate processing technologies for typical construction machinery components, mastering knowledge of process route design, procedure arrangement, tooling selection, utilizing advanced equipment such as CNC machine tools and machining centers to complete key component processing. By introducing industrial robots, automated production lines, and other intelligent manufacturing equipment, students engage with cutting-edge industry technology [18]. Students must also complete assembly of construction machinery assemblies, such as hydraulic systems, transmission systems, according to assembly process regulations, conducting functional commissioning and performance testing, utilizing various testing instruments to inspect processing precision and assembly quality. In this phase, particular emphasis is placed on integrating equipment procurement and acceptance management content into teaching, having students participate in training equipment procurement demonstration processes, learning supplier evaluation rules and equipment acceptance procedures. Through transformation among the triple roles of learner-user-manager, understanding of equipment full life cycle management deepens. Implementation methods establish on-campus productive training bases, introducing actual enterprise processing tasks, adopting modern apprenticeship models, implementing a dual mentor system with on-campus teachers responsible for theoretical guidance and enterprise masters responsible for skill transmission, encouraging student team collaboration and resource sharing [19]. Assessment and evaluation comprehensively considers multiple aspects including workpiece processing precision, assembly quality, operational standardization, and safety awareness.

In the operation and maintenance management phase, the cultivation objective is enabling students to master equipment operation, maintenance and upkeep, fault diagnosis and troubleshooting, spare parts management, and other capabilities. This represents the core phase of construction machinery full life cycle management. Training content includes safety operation standard training, daily maintenance and upkeep training, fault diagnosis technology training, maintenance management information system application, and equipment condition monitoring and predictive maintenance. Students need to learn construction machinery operation procedures and safety protection measures, mastering knowledge of daily maintenance items, maintenance cycles, lubrication management, capable of independently completing daily maintenance operations. In fault diagnosis, students must learn common fault phenomena, diagnostic methods, and troubleshooting procedures, utilizing intelligent diagnostic systems, condition monitoring technology, and other modern methods for fault diagnosis, learning to use digital management platforms for equipment usage registration, maintenance records, spare parts management, and other operations. Students must also utilize sensors and data acquisition systems for real-time monitoring of equipment operational status, learning predictive maintenance techniques. This phase represents the key phase for deeply integrating equipment full life cycle management concepts into talent cultivation [20]. Specifically, regarding equipment usage management, standardized operational procedures are formulated, usage registration and permission management systems are established, and students must strictly follow operational procedures when using training equipment and truthfully record equipment usage situations. Regarding equipment maintenance management, referring to preventive maintenance concepts, daily maintenance and regular upkeep plans are formulated, students take turns serving as equipment maintenance personnel responsible for daily inspection and maintenance of training equipment, establishing maintenance archives. Regarding equipment fault management, fault reporting and response mechanisms and fault diagnosis and repair procedures are established. When training equipment malfunctions occur, student teams conduct fault diagnosis and repair with necessary teacher guidance, forming complete fault handling records. Regarding digital management platform application, integrated digital management platforms realize functions including equipment ledger informatization, maintenance and upkeep plan reminders, real-time equipment operational status monitoring, and maintenance cost statistical analysis. Students master modern equipment management technology through platform operations [21]. Implementation methods adopt rotation systems, with every student experiencing different roles including operator, maintenance personnel, and diagnostic personnel. Equipment management responsibility systems are established, dividing classes into several equipment management groups, with each group responsible for full-process management of several training equipment units, integrating cultivation of knowledge, skills, and qualities. Assessment and evaluation includes multiple dimensions including operational standardization, fault diagnosis accuracy, repair skills, management record standardization and safety awareness.

In the decommissioning and disposal phase, the cultivation objective is enabling students to master equipment status assessment, decommissioning decision-making, disassembly and recycling, environmental disposal, and other capabilities, strengthening resource recycling utilization awareness and environmental awareness. Training content includes equipment technical status assessment, decommissioning decision-making and approval procedures, decommissioned equipment disassembly training, resource recovery and environmental disposal, and asset disposal management. Students need to learn equipment performance evaluation methods, comprehensively considering factors including equipment technical performance, economic benefits, and safety risks to determine whether equipment should be decommissioned [22], understanding equipment decommissioning approval procedures, asset disposal regulations, and other management knowledge. Through disassembly of decommissioned training equipment, students can identify reusable components and materials, learning waste classification, resource recovery, environmental disposal methods and standards, cultivating circular economy concepts, and learning to establish complete equipment decommissioning disposal archives. Implementation methods utilize retired university training equipment as training objects, organizing students to conduct actual disassembly and assessment, inviting enterprise equipment management experts to lecture on decommissioning decision-making methods, organizing visits to equipment recycling and processing enterprises, conducting circular economy concept education [23]. Assessment and evaluation focuses on evaluation report quality, disassembly standardization, environmental awareness and archive organization.

3.3. Industry-Education Integration Implementation Strategy

Industry-education integration represents the critical pathway for enhancing talent cultivation quality, requiring deepened university-enterprise cooperation across multiple levels. Regarding university-enterprise collaborative education mechanisms, professional development steering committees are established with participation from universities, industry enterprises, research institutes, and other parties, jointly formulating talent cultivation plans, developing training projects, and constructing curriculum resources. Enterprises deeply participate in teaching processes, not only providing internship positions but also engaging in core activities including curriculum design, project guidance, and quality evaluation [24]. Simultaneously, dual-qualification teacher teams are constructed, requiring professional teachers to regularly engage in enterprise practice, participate in enterprise projects, and enhance practical capabilities, while hiring enterprise engineers and technical experts as part-time teachers to bring cutting-edge industry technology and work standards into classrooms. Regarding authentic project introduction pathways, long-term cooperative relationships are established with construction machinery manufacturing enterprises and user enterprises, introducing authentic enterprise design projects, processing tasks, and maintenance cases into training teaching. For example, undertaking enterprise conceptual design tasks during the planning and design phase, processing components needed by enterprises during the manufacturing and assembly phase, and participating in enterprise equipment maintenance and upkeep work during the operation and maintenance management phase. School-in-factory or factory-in-school facilities are established, realizing deep integration of teaching processes with production processes. On-campus training bases are arranged and managed according to enterprise production sites, with students learning in authentic production environments, shortening the adaptation period from school to enterprise. Regarding modern apprenticeship pilot programs, pilot work is conducted in selected classes, implementing a model of enrollment as recruitment, school entry as factory entry, joint university-enterprise cultivation. Students possess dual identities as both school students and enterprise apprentices. The cultivation process adopts a work-study alternation model, with students spending periods learning theoretical knowledge and basic skills at school, and periods following masters at enterprises for position practice. Enterprise masters and on-campus teachers jointly undertake teaching tasks, forming a dual mentor system. Enterprise masters focus on skill transmission and work experience transfer, while on-campus teachers focus on theoretical guidance and systematic thinking cultivation [25]. This model facilitates organic unity between theory and practice.

3.4. Digitalization Support System Construction

Digital technology represents an important means for enhancing training system effectiveness. Regarding integrated digital management platform construction, drawing on digital management platform concepts, an informatized platform is constructed integrating training equipment management, teaching process management, and learning resource sharing. The platform should possess functional modules including equipment full life cycle information management, training teaching management, learning process data collection and analysis, and online learning and communication [26]. Equipment full life cycle information management encompasses full-process information including equipment ledgers, procurement demonstration, usage registration, maintenance records, fault management, and decommissioning disposal. Training teaching management includes activities such as training plan formulation, training project release, training process monitoring, training achievement submission, and training grade evaluation. The learning process data collection and analysis function records student learning behavior data, utilizing learning analytics technology to provide basis for personalized teaching and precise tutoring. Online learning and communication functions provide services including digital teaching resources, online Q&A, and learning communities.

Regarding virtual simulation training resource construction, virtual simulation training projects for construction machinery are developed, compensating for issues including insufficient physical equipment quantities and difficulty implementing high-risk operations. Virtual simulation can be applied to multiple activities including solution demonstration during the planning and design phase, process simulation during the manufacturing and assembly phase, fault diagnosis training during the operation and maintenance management phase, and disassembly process demonstration during the decommissioning and disposal phase[27]. Simultaneously, digital teaching resource repositories are constructed, including content such as micro-lecture videos, operation demonstrations, case libraries and exercise banks, supporting student autonomous learning and fragmented learning. Resources should be updated promptly, integrating new industry technologies, new processes, and new standards to ensure teaching content remains synchronized with industry development. Regarding intelligent training environment construction, IoT technology is utilized for intelligent transformation of training equipment, realizing real-time monitoring and data collection of equipment operational status. Parameters including equipment temperature, vibration, and pressure are collected through sensors and uploaded to cloud platforms for analysis. This can be used both for equipment condition monitoring and predictive maintenance, and as teaching data resources enabling students to learn big data analysis and intelligent diagnostic techniques. AR/VR technology application in training teaching is explored. AR technology is utilized for equipment structure display and assembly guidance, with students viewing equipment internal structures and assembly step prompts through AR glasses. VR technology is utilized for virtual operation training, with students able to practice repeatedly in virtual environments, reducing physical equipment wear and safety risks [28]. These intelligent methods not only improve training efficiency but also enable students to master new technologies and methods required in the intelligent manufacturing era [29].

4. Conclusion

Based on full life cycle management concepts, this research systematically constructs an optimization plan for the construction machinery project talent training system, possessing important theoretical significance and practical value. From the theoretical level, this research extends application of full life cycle management concepts in the higher engineering education field. Previous research on equipment full life cycle management primarily concentrated on enterprise equipment asset management and university laboratory equipment management, with few studies focusing on integrated design of university training equipment full life cycle management and talent cultivation. This research draws on equipment full life cycle management theory and methods, innovatively integrating them into the entire talent cultivation process, constructing an integrated theoretical framework of equipment management-capability cultivation, enriching theoretical connotation of higher engineering education training system research. From the practical level, this research provides operationalizable training system optimization plans for construction machinery universities. First, through four-phase training design spanning the project full life cycle, it effectively resolves current issues of fragmented training content and disconnection between theory and practice, cultivating student systematic thinking and engineering practice capabilities. Second, the proposed equipment full life cycle management system, encompassing four phases of planning and demonstration, procurement and acceptance, usage and maintenance, and decommissioning and disposal, can significantly enhance university training equipment management levels, improving equipment usage efficiency and integrity rates. Third, digital management platform construction provides modern technological support for training teaching, realizing equipment informatization management, teaching process data collection, and learning resource sharing. Fourth, the proposed industry-education integration implementation strategy provides specific pathways for university-enterprise collaborative education, authentic project introduction, and modern apprenticeship pilot programs, helping shorten student adaptation periods from school to enterprise.

This research also possesses certain limitations. First, accompanying deepening higher education reform and technological environment transformation, new issues may emerge in training equipment usage and management methods, requiring continuous adjustment and refinement during actual implementation processes. Second, this research emphasizes theoretical frameworks and system design, with specific implementation steps requiring further refinement in practice. Future research can focus on the following directions: first, tracking new changes brought by higher education reform and technological development, continuously optimizing training systems; second, conducting empirical research to evaluate training system implementation effectiveness; third, exploring possibilities of extending full life cycle management concepts to other engineering disciplines, providing more reference for overall higher engineering education reform.

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