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Research on the Practice of Curriculum Teaching Reform for Rail Transit Programs in Higher Vocational Colleges in the Greater Bay Area under Digital-Intelligent Iteration and Four-Network Integration

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Abstract

The emergence of new rail transit business models, such as fully automatic operation, intelligent operation and maintenance, and "Four-Network Integration," is rapidly reshaping industry job skill standards and placing higher demands on talent cultivation in higher vocational rail transit programs. Drawing on the rail transit industry in the Guangdong-Hong Kong-Macao Greater Bay Area, this study employs enterprise surveys, action research, and evidence-based teaching analysis to address key challenges, including delayed curriculum updates, weak alignment between job requirements and courses, and the lack of long-term mechanisms for teaching optimization. A three-dimensional collaborative curriculum reform system is constructed. The study innovates an agile school-enterprise collaborative curriculum updating mechanism, develops "point-line-network" job-linked teaching projects and "virtual-real-enterprise" integrated teaching scenarios, and establishes a closed-loop optimization pathway of "standards guidance-intelligent profiling-diagnostic improvement." Practical results indicate that the update coverage rate of core professional courses reached 100% after the reform, while partner enterprises' overall satisfaction with graduates reached 97%. This model effectively aligns curriculum teaching with industrial development, offering practical reference and a replicable paradigm for deepening curriculum reform and cultivating high-skilled talents in smart transportation within higher vocational rail transit programs.

Keywords

Rail Transit, Curriculum Reform, Talent Cultivation

1. Introduction

The rail transit industry chain is undergoing deep iteration toward digital-intelligent, integrated, green, and scenario-based development. New technologies and business models such as Fully Automatic Operation (FAO), intelligent operation and maintenance, multi-modal rail transit interconnection, and urban rail cloud platforms are being fully implemented [1]. These changes have led to job restructuring, skill upgrading, and scenario expansion within the industry chain, placing new demands on talent cultivation in higher vocational rail transit programs—namely, closer alignment with frontline operations, skill adaptation, and digital-intelligent integration. As the core training base for high-quality technical and skilled talents at the frontline of rail transit, higher vocational institutions must closely follow the iterative needs of the industry chain. They should move away from traditional single-operation talent cultivation models and instead focus on implementing digital-intelligent skills, strengthening on-site operational capabilities, fostering job collaboration competencies, and developing continuous adaptation abilities, so as to precisely meet the new skill requirements of frontline positions in the industry chain.

2. Development Trends of the Rail Transit Industry and Talent Demand Analysis

2.1. The Rail Transit Industry Is Entering a New Era of "Digital-Intelligent Transformation" and "Four-Network Integration"

China's urban rail transit industry ranks first in the world in scale and has established a modern system with advanced technology and a complete industrial chain. As of the end of 2025, a total of 58 cities across the country had opened 382 operating lines, with an annual passenger volume of 3.324 billion trips and a total mileage of 13071.58 kilometers (see **Figure 1**), making it the largest rail network in the world [2]. With the rapid development of emerging technologies such as cloud computing, big data, the Internet of Things, artificial intelligence, 5G, and satellite communication, rail transit has gradually achieved functions including biometric recognition, contactless payment, integrated ticketing and inspection, facility interconnection, fare interoperability, and information sharing. Intelligent network-wide scheduling and command, intelligent operation and maintenance with safety assurance, dynamic timetable compilation, and flexible train formation are being progressively implemented. Rail transit enterprises in the Guangdong-Hong Kong-Macao Greater Bay Area are at the forefront of smart urban rail development, including fully automatic operation lines, intelligent operating systems, and intelligent inspection equipment. At the same time, as a national pilot demonstration zone for "Four-Network Integration," the Greater Bay Area is promoting the deep integration of mainline railways, intercity railways, municipal (suburban) railways, and urban rail transit to create a new "one network, one city cluster" rail development pattern. These trends of "digital-intelli-

gent transformation" and "Four-Network Integration" in the rail transit industry have put forward new requirements for the cultivation of high-skilled talents.

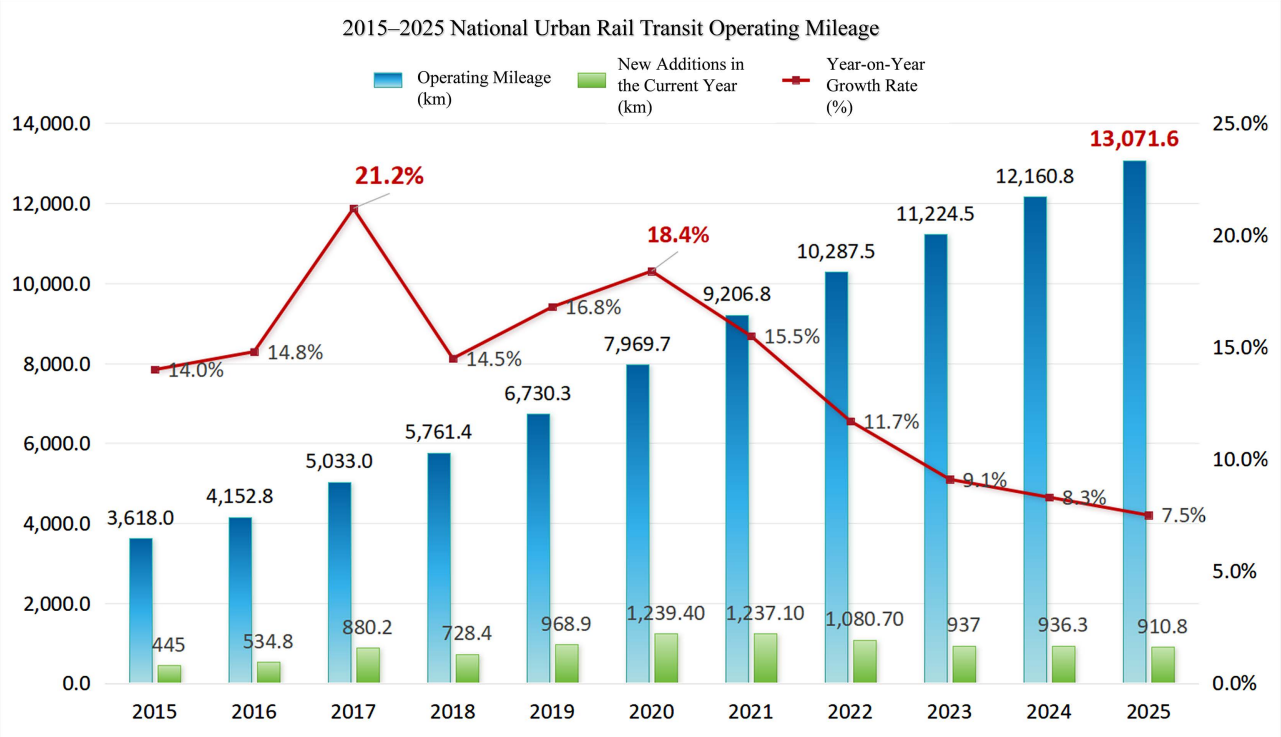


Figure 1. Development trend of national urban rail transit operating mileage over the past decade.

2.2. The Transformation and Upgrading of New Forms of Intelligent Urban Rail Operation Place High Demands on Technological Innovation Capabilities in Intelligent Operation and Maintenance

The deep integration of new technologies—centered on big data, artificial intelligence, the Internet of Things, and digital twins—with the entire rail transit operation process has fundamentally transformed traditional urban rail operation and maintenance models. This shift has given rise to new composite positions, such as "multi-functional team members," whose responsibilities include smart station services, intelligent train inspection, and remote equipment maintenance. These roles require employees to use intelligent technologies to perform integrated "operation and maintenance" tasks on fully automatic operation lines, such as train dispatching and receiving, as well as electromechanical equipment maintenance (see Figure 2). Such positions demand higher competencies in professional integration, intelligent technology application, complex problem-solving, and overall professional qualities. Practitioners are expected to possess a solid foundation in core rail transit disciplines, along with broad knowledge in automation, communication, electronics, and safety management to achieve interdisciplinary integration. They must also be proficient in operating various intelligent devices, demonstrate strong digital and intelligent operation and maintenance capabilities, pos-

sess the ability to handle emergencies and resolve complex operational challenges, and exhibit a high sense of responsibility, dedication, psychological resilience in emergencies, and strong teamwork skills.

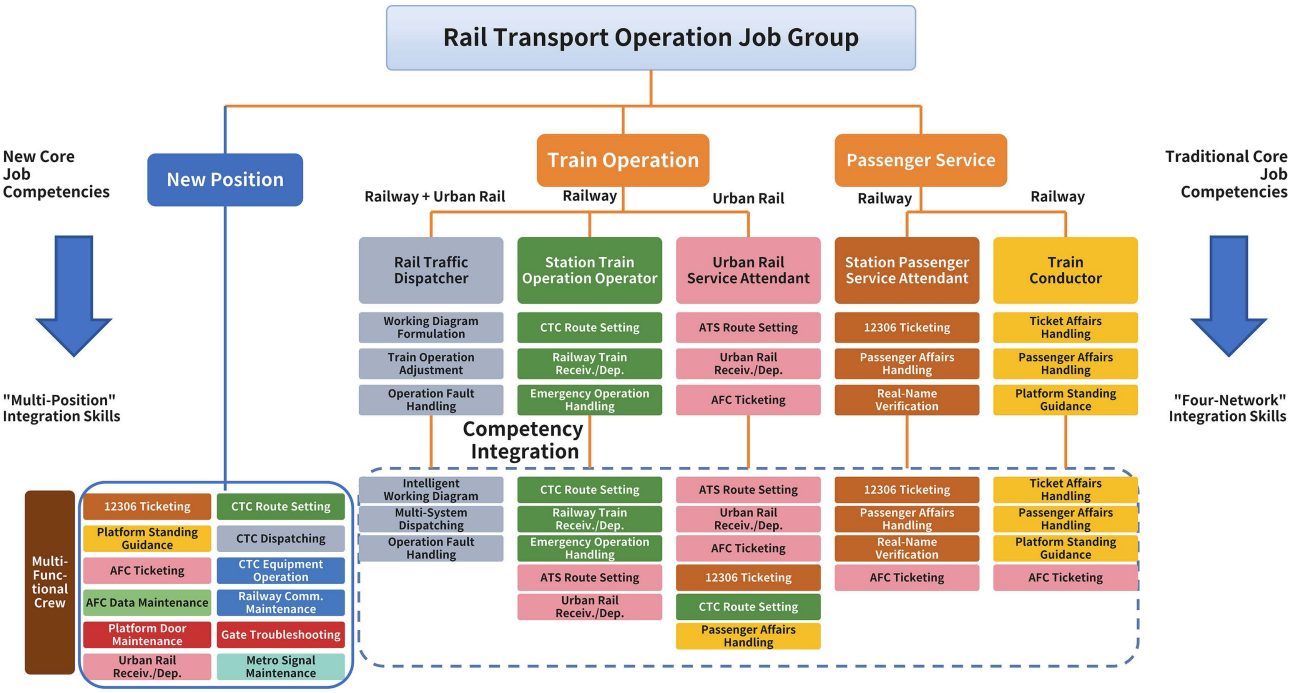


Figure 2. Changes in job competency requirements under the intelligent development of rail transit.

2.3. The Transition of Rail Transit from Single-Mode to Multi-Modal Operation Places High Demands on Cross-Modal Collaborative Operation Capabilities

As the integrated development of urban agglomerations and metropolitan areas in the Guangdong-Hong Kong-Macao Greater Bay Area continues to advance, inter-regional population mobility and factor flows have become increasingly frequent. Rail transit has gradually shifted from independent operation of single modes to a multi-modal integrated operation pattern characterized by "mode complementarity, network linkage, and integrated operation" [3]. In this transition, connections between different rail systems—such as urban rail transit, municipal railways, and intercity railways—are becoming tighter, transfer organization more complex, and operating scenarios more diverse and overlapping. The traditional model of independent operation relying on single positions and single modes can no longer meet the new operational requirements. Multi-modal integrated operation is no longer an independent task of a single position or specialty; instead, it requires collaborative coordination across multiple positions and modes, covering overall cooperation in train operation organization, passenger services, equipment support, and safety management. In particular, in key processes such as intelligent passenger flow control, intelligent train dispatching, intelligent equipment operation and maintenance, and emergency response, higher

requirements are placed on rail transit professionals' cross-modal and cross-position collaborative capabilities. Personnel must not only master their own job responsibilities but also understand the operational logic of related modes and associated positions, while possessing overall process coordination awareness and multi-disciplinary collaboration skills.

3. Current Status and Reform Pain Points in Rail Transit Program Curriculum Teaching

3.1. Curriculum Content Updates Lag behind Industrial Development and Struggle to Meet the Demands of Intelligent Rail Transit Operation

First, the existing curriculum system fails to align with new forms of industrial development. The rail transit industry has now formed an intelligent full-chain development pattern of "infrastructure-equipment-operation-service" and cross-modal collaboration under "Four-Network Integration." Job competency requirements have shifted from "single-position capabilities" to "cross-position composite capabilities." However, the curriculum systems and course offerings in existing rail transit programs still follow the traditional logic of single-mode and single-position setups. For example, some domestic higher vocational institutions in transportation only offer urban rail programs without railway-related course modules, making it impossible to train students in core skills for train operation organization and passenger services related to mainline railways and municipal (suburban) railways. This is seriously disconnected from the development trend of "Four-Network Integration" in rail transit. Due to the lack of cross-disciplinary integrated course modules, graduates struggle to meet the industry's demands for cross-modal collaboration and multi-position linkage.

Second, the teaching content of the courses has not kept pace with industrial technological iteration in a timely manner. At present, next-generation information technologies such as 5G, artificial intelligence, big data, and digital twins have been fully integrated across the entire rail transit industry chain. Core equipment, operational standards, and technical specifications continue to be upgraded, while new business forms such as smart station operations, urban rail big data analysis, and maintenance of FAO fully automatic operation lines continue to emerge. However, the core teaching content of existing courses is updated slowly. Problems include a high proportion of outdated knowledge, fragmented coverage of new technologies, and the failure to promptly incorporate new industry standards into the curriculum system. For example, operation-related courses provide insufficient coverage of smart operation technologies such as intelligent dispatching systems and AI-based passenger flow prediction. Maintenance-related courses offer inadequate depth in intelligent maintenance technologies such as intelligent equipment condition monitoring, rail acoustic fingerprint monitoring, and digital twin-based equipment simulation and debugging [4] [5].

Third, the positioning of course objectives does not match the demand for upgraded talent capabilities. Against the backdrop of digital-intelligent transformation in the industry, frontline rail transit positions now place significantly higher requirements on practitioners' technological application ability, problem-solving ability, and innovation ability. However, the course objectives of most existing rail transit programs remain focused on traditional operational skill training. The cultivation goals for students' digital-intelligent technology application ability and cross-position collaboration ability are vaguely defined, and assessments still emphasize theoretical knowledge memorization and single-skill evaluation. This makes it difficult to support the industry's demand for high-quality, composite technical and skilled talents.

3.2. Disconnect between the Teaching Process and the Production Process

First, teaching projects are disconnected from actual enterprise work tasks. The teaching process does not incorporate real work tasks from frontline enterprise positions (such as intelligent rail inspection projects or train fault diagnosis projects) into the design of teaching projects. Moreover, the design fails to emphasize the cultivation of professional qualities such as safety awareness, collaboration consciousness, and sense of responsibility. As a result, students passively receive knowledge and lack the ability to solve real production problems.

Second, teaching scenarios are disconnected from enterprise production scenarios. The equipment in rail transit training bases has not been updated in a timely manner to match the intelligent and advanced equipment currently used by enterprises. Most training equipment is designed for single-function demonstrations and cannot simulate the complex interconnected scenarios found in actual production sites, such as the coordinated operation of dispatch centers, stations, tracks, and vehicles. Consequently, there is a significant gap between training scenarios and real enterprise production environments.

Third, teaching modes are disconnected from enterprise production requirements. Rail transit enterprises operate with a production characteristic of "position linkage and job collaboration," which requires rail transit programs to cultivate "position-linked skills" in practical training. However, on-campus training primarily focuses on single-skill exercises and does not replicate the "full-process, multi-position collaboration" work model used in actual production. For example, the complete production process—from train depot exit inspection, operation monitoring, and fault handling to depot entry maintenance—is rarely simulated, leaving students without hands-on experience in collaborative on-site operations.

3.3. Weak Continuity in Teaching Improvement

First, traditional curriculum improvement lacks an active mechanism for regularly tracking industrial technology applications and proactively anticipating future skill demands. There is no dynamic tracking and feedback mechanism based

on a curriculum quality evaluation index system supported by artificial intelligence, and the evaluation index system itself is not updated in a timely manner. Second, there has been insufficient exploration of evaluation methods that align with industry job requirements. As a result, it is difficult to drive continuous improvement in teaching content and instructional models through evaluation, leaving teaching reform without sufficient motivation or clear direction.

Third, curriculum improvement is primarily led by on-campus teachers, with limited deep involvement from enterprise experts, vocational education specialists, and students. This has resulted in a situation where "one reform lasts for three years," lacking sustainability and making it difficult for the curriculum to keep pace with industrial development.

4. Implementation Path of Curriculum Teaching Reform for Rail Transit Programs Driven by Demand

4.1. Preemptive Update of Curriculum Content: Building a Dynamic Response Mechanism of "Preemptive Trigger-Agile Development-Instant Verification"

First, pre-position the starting point for curriculum iteration. By taking the lead in establishing platforms such as the "National Rail Transit Equipment Industry Industry-Education Integration Community" and the "National Rail Transit Safety Control Industry Industry-Education Integration Community," schools and enterprises jointly implement the "Double Hundred Action" and the "Unveiling and Leading" mechanism for technical reform projects. Schools select 100 teachers to be stationed in upstream industry chain enterprises such as CRRC (Tangshan) and CRSC (Beijing), while partner enterprises send 100 skilled technicians to the institutions. Through collaboration between teachers and technicians, they jointly carry out practical training, on-the-job practice, technical transformation services, and social training activities. This approach enables the targeted collection of the latest resources on technical standards, process flows, and operational specifications of industrial equipment, thereby triggering dynamic updates to curriculum content.

Second, promote the "agile development" of curriculum content. Institutions formulate the Guidelines for Updating Curriculum Content in Rail Transit Programs. The development process follows the principles of "rapid production, lightweight design, and high frequency," advancing through the workflow of "skill deconstruction → content design → resource development." Leveraging technical tools such as digital human assistance and one-click video generation on AI course-creation platforms, the latest industrial equipment standards and resources are promptly transformed into teaching materials in formats such as short videos, micro-courseware, and pocket books. This drives the transformation of curriculum content carriers from "fixed textbooks" to "dynamic resource packages" [6].

Third, conduct compliance verification for updated curriculum content. Teach-

ers organize teaching and research activities during weekly meetings, including "course presentations," "project presentations," and open classes. Enterprise experts, peer experts from other institutions, and student representatives are invited to participate, enabling immediate verification of the job adaptability of the updated content.

4.2. Implementation of "Linked" Teaching: Forming a Teaching Approach of "Project Linkage-Scenario Integration-Master-Apprentice Collaboration"

First, develop a layered "point-line-network" job-linked teaching project system. By introducing the latest technical standards, process flows, operating procedures, and production cases from partner enterprises, the complete task chain of "routine equipment operation → equipment fault handling → integrated emergency response" is mapped from typical production scenarios of employers such as China Railway Guangzhou Bureau. Based on the skill cultivation requirements of "position linkage and job collaboration," a three-tier progressive teaching project system is developed: "point"-level linkage for standard operations, "line"-level linkage for abnormal handling, and "network"-level linkage for system-wide emergency response.

Second, construct three types of integrated "virtual-real-enterprise" teaching scenarios. 1) A virtual simulation training base is established to digitally replicate the latest large-scale facilities and newly opened lines of partner enterprises, creating digital virtual training scenarios such as the "Guangzhou Metro Line 11 Fully Automatic Operation System." 2) The school's "Two Stations and One Line" industry-education integration training base is continuously optimized by introducing the latest intelligent rail transit equipment to create authentic physical training scenarios, including smart high-speed rail and metro stations, the CR400-AF Fuxing EMU, and intelligent inspection workshops. 3) Off-campus practical training bases are established at partner enterprises such as China Railway Guangzhou Bureau and Guangzhou Metro, embedding teaching scenarios into real and complex production sites.

Third, implement a collaborative teaching model of "master-apprentice collaboration and school-enterprise rotation." Dual-teacher teaching teams are formed by pairing school instructors with enterprise craftsmen. Teaching follows the logic of "analyze processes → establish standards → basic practice → linked practice → collaborative practice → practical application → evaluate outcomes." In the school's virtual simulation training base and the "Two Stations and One Line" industry-education integration training base, instructors use virtual and physical resources to explain production processes, while enterprise craftsmen demonstrate standard operations to set benchmarks. Students then progress through "position-based basic training → position-linked training → job-type collaborative drills," with craftsmen conducting accompanying process analysis and evaluation using intelligent training equipment. At off-campus practical training bases such

as China Railway Guangzhou Bureau and Guangzhou Metro, enterprise craftsmen lead students in completing real-world tasks such as "Spring and Summer Transport production practice."

4.3. Evidence-Based Improvement and Effectiveness Verification: Creating a Curriculum Optimization Pathway of "Standards Guidance-Intelligent Profiling-Diagnostic Enhancement"

First, develop a "five-dimensional" curriculum iteration quality evaluation standard. Leveraging school-enterprise collaborative education projects such as the "2 + 1" targeted training program with China Railway Guangzhou Bureau and the order-based classes with Guangzhou Metro, six joint school-enterprise teaching and research offices have been established across the professional fields of train operation, locomotive operation, track maintenance, signaling and communication, rolling stock, and power supply. Enterprise experts and vocational education specialists were invited to develop a curriculum iteration quality evaluation index system comprising five primary indicators—teaching content, teaching scenarios, teaching team, teaching methods, and assessment and evaluation—and 25 secondary indicators, including the degree of integration of the latest standards and skill operation accuracy. The system is continuously optimized in accordance with the latest industry certification standards and vocational education policies.

Second, implement data-driven dynamic tracking and feedback of curriculum quality. An intelligent course platform has been built and curriculum archives established. The "five-dimensional" curriculum iteration quality evaluation standards are integrated into the platform. Intelligent equipment collects real-time data such as student engagement and participation rates for process evaluation. Students, peer teachers, and enterprise experts conduct comprehensive evaluations of course content, scenarios, and resources. Visualized curriculum quality analysis reports are then generated and intelligently distributed.

Third, promote continuous curriculum optimization through collective "lesson polishing." Based on the curriculum quality analysis reports, the Joint School-Enterprise Teaching and Research Offices organize monthly "online + offline" collective lesson polishing sessions involving the course teaching team and enterprise master craftsmen. These sessions focus on calibrating curriculum content, adjusting instructional design, optimizing master-apprentice collaboration, and improving teaching activities.

5. Practical Outcomes of Curriculum Teaching Reform

5.1. Achieving 100% Update Coverage of Core Professional Courses through a Point-to-Area Approach

This study took the reform of core professional courses as a pilot and systematically implemented the curriculum reform model of "preemptive content update-linked teaching implementation-evidence-based improvement and verification" across 137 core professional courses in 22 rail transit programs at our institution.

In terms of content updating, the starting point of curriculum iteration was advanced to the mid- and upstream enterprises of the rail transit industry chain, including technology R&D and equipment manufacturing. By leveraging the time window from R&D and manufacturing to commercial application of rail transit equipment, the model enables early identification of changes in job skill requirements from downstream operators and integrates them into the curriculum. This shifts the curriculum updating logic from passive alignment with job demands to proactive adaptation to industrial iteration. In terms of teaching implementation, artificial intelligence technology was used to conduct accompanying analysis throughout the teaching process for both teachers and students, enabling real-time diagnosis and optimization of project design, teaching scenarios, and instructional methods. In terms of continuous improvement, preemptive content updating triggers a large cycle of curriculum iteration, while stage-wise evaluations of "content development → teaching implementation → verification and improvement" drive a smaller internal optimization cycle within the curriculum system. These nested cycles continuously enhance the quality of curriculum iteration. Empirical results demonstrate that this mechanism plays a central role in ensuring that curriculum content updates remain synchronized with industrial technological advancement.

5.2. Three-Stage Progressive Approach to Enhancing Position-Linked Skill Development

Closely aligned with the production characteristics of "position linkage and job collaboration" in rail transit enterprises, this approach breaks away from the traditional paradigm of isolated skill training across the six professional fields of train operation, locomotive operation, track maintenance, signaling and communication, rolling stock, and power supply. It establishes a three-stage progressive training pathway: "position-based basic training → position-linked training → job-type collaborative drills."

In the first stage (position-based basic training), each specialty utilizes the human-machine interaction platform in the virtual simulation training base to conduct standardized skill training for individual positions. This ensures that all trainees master the basic skills required for their respective positions while developing an initial awareness of position-linked collaboration.

In the second stage (position-linked training), the "Two Stations and One Line" industry-education integration training base is used to organize joint fault-handling skill training between closely related fields, such as "train operation-signaling and communication" and "rolling stock-power supply," thereby strengthening trainees' cross-position linkage capabilities.

In the third stage (job-type collaborative drills), multi-disciplinary teams jointly conduct emergency response exercises involving large-scale impact and multiple job types, such as "train section fault rescue," within the "Two Stations and One Line" training base. This enhances trainees' ability to perform collaborative oper-

ations across different job types.

Empirical results show that this method effectively promotes the practical development of position-linked skills and enables seamless alignment between student skill training and employer job requirements.

5.3. Industry-Education Collaboration Significantly Improves Graduates' Job Skill Adaptability

Using industry-education integration as the key driver, the curriculum teaching reform for rail transit programs systematically incorporates enterprise job competency standards, on-site operational procedures, and engineering practice cases into curriculum standards, classroom instruction, and practical training. This has effectively strengthened the alignment between talent cultivation and industry job requirements. According to Mycos survey data, in the three years following the implementation of the curriculum reform, the average employment rate of graduates in this program has remained stable above 94.62%, with steady improvements in employment quality, ranking among the top five universities in the province. Furthermore, 75% of graduates have secured positions in leading rail transit enterprises such as China Railway Guangzhou Bureau Group and Guangzhou Metro Group, while partner enterprises reported a 97% overall satisfaction rate with the graduates. These results demonstrate that the curriculum reform has successfully aligned educational output with industry talent demands.

The deep integration of positions, courses, competitions, and certifications has further strengthened students' practical skills and innovative capabilities. Over the past three years, students in the program have won a total of 236 national awards, including gold medals at the WorldSkills Competition for Vocational Colleges, gold medals at the China International "Internet+" College Students Innovation and Entrepreneurship Competition, silver medals at the "Challenge Cup" China College Students' Entrepreneurship Plan Competition, and second prizes at the National Vocational College Skills Competition (Urban Rail Intelligent Transportation event).

At the same time, the reform balances technical skill training with the cultivation of craftsmanship spirit. A total of 24 high-skilled graduates have emerged, represented by Ding Fei (recipient of the National May 1st Labor Medal), Lai Zetuan (National Railway Model Worker), and Lin Zhanxiong (National Technical Expert). These achievements fully demonstrate the comprehensive educational effectiveness of the curriculum reform in cultivating high-skilled talents for the rail transit industry.

6. Conclusion

The curriculum teaching reform is driven by real industry needs. By establishing a dynamic content update mechanism, a position-linked teaching implementation system, and an evidence-based quality optimization pathway, it effectively addresses the key challenges of outdated curriculum content, disconnection between

teaching and production, and insufficient continuity in improvement. This has enabled the teaching supply to align closely with the demands of the rail transit industry's digital-intelligent transformation. Moving forward, efforts will continue to deepen the construction of industry-education integration communities, closely follow technological advancements in the rail transit sector, and further refine the mechanisms for dynamic curriculum updating and quality evaluation. Greater emphasis will be placed on developing students' digital-intelligent technology application and cross-position collaboration capabilities, with the aim of supplying the rail transit industry with more high-quality, composite technical and skilled talents to support its high-quality development.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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