Research on the Three-Tier Competency Development Path for Field Engineers Empowered by Generative Artificial Intelligence

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ABSTRACT Field engineers in manufacturing, infrastructure and energy industries serve as core professionals linking technical solutions to on-site implementation. Stationed at project sites long-term, they undertake comprehensive work including equipment commissioning, emergency troubleshooting, process optimization, safety supervision and customer communication, with ever-upgrading competency requirements. Featuring diverse functions such as text generation, simulation deduction, case reproduction, real-time Q&A and data review, generative artificial intelligence (GenAI) aligns with the phased growth pattern of field engineers, delivering a low-cost, highly adaptable and iterable digital training carrier. Based on the growth stages of field engineers, this paper constructs a three-tier competency framework consisting of Basic Operation Tier, Comprehensive Handling Tier and Innovative Problem-Solving Tier. Combined with application scenarios of GenAI tools, it sorts out the internal logic of AI-enabled competency cultivation at each tier, designs supporting implementation paths, and develops five sets of quantitative analysis tables to establish systems for status research, competency indicators, tool adaptation, implementation procedures and effect evaluation. Targeting enterprise training centers, engineering majors in vocational colleges and industrial skill training institutions, this research provides actionable digital talent training schemes, fills resource gaps in traditional offline training modes, and accelerates job adaptation while improving comprehensive professional capabilities of field engineers.

INDEX TERMS Generative Artificial Intelligence, Field Engineers, Three-Tier Competency, Talent Training, Digital Practical Training

I. INTRODUCTION

A. RESEARCH BACKGROUND

High-quality development of the real economy generates surging demand for frontline engineering technical talents[1, 2]. Sectors including machinery manufacturing, rail transit, power operation & maintenance, building construction and chemical production require a large number of field engineers capable of on-site work and practical problem-solving[3, 4]. Corporate recruitment and talent training data show that newly hired field engineers commonly suffer from disjointed theoretical knowledge and practical operation, insufficient experience in sudden fault disposal, and weak cross-departmental collaboration capabilities[5]. Traditional talent training relies on three approaches: offline practical training workshops, mentorship by senior engineers, and short-term job rotation, which carry obvious limitations[6]. Since 2023, generative AI technology has been rapidly deployed in education and industrial training[7-9]. Large language models, multimodal generative AI, digital twin generation tools and simulation case generation systems can quickly produce process documents, fault simulation scenarios, disposal procedure schemes and standardized teaching courseware[10-12]. Free from constraints of venue, equipment and personnel schedules, AI tools support one-person-one-device on-demand training with real-time error correction[13, 14]. Some enterprises have attempted to introduce AI into engineer training, yet most applications are limited to simple document writing and online Q&A, without constructing a complete training system aligned with the phased growth pattern of field engineers[15]. Existing studies lack targeted path design tailored to the three-tier phased growth characteristics of field engineers, and the implementation procedures, evaluation criteria and adaptive tools for AI-enabled training lack quantitative support. In response to the above practical challenges, this paper conducts research on the three-tier competency development path for field engineers empowered by generative AI.

B. RESEARCH SIGNIFICANCE

1. It helps manufacturing, energy and infrastructure enterprises build low-cost digital engineer training systems, reducing investment in physical training equipment and mitigating safety risks of high-risk practical training.

2. Differentiated training content is formulated for new recruits, experienced engineers and technical backbones, shortening job adaptation cycles for newcomers and boosting technical breakthrough capabilities of core talents.

3. Phased implementation steps and assessment evaluation schemes for AI tools are provided, enabling enterprises and vocational colleges to directly adopt the full training process with strong operability.

4. Unified hierarchical competency assessment standards for field engineers are established, addressing industry pain points such as inconsistent mentorship standards and difficulty in quantitatively evaluating training outcomes.

C. RESEARCH CONTENTS

1. Sort out job responsibilities of field engineers, divide their growth into three progressive tiers (Basic Operation, Comprehensive Handling, Innovative Problem-Solving), and establish subdivided competency indicators for each tier.

2. Conduct enterprise surveys to summarize existing problems in traditional field engineer training and compile survey data tables.

3. Classify types of generative AI tools, match AI application scenarios corresponding to three-tier competencies, and form a tool adaptation comparison table.

4. Design a complete implementation process for AI-enabled hierarchical three-tier training, sorting out standardized operation steps for pre-class, in-class and after-class sessions.

5. Construct a comprehensive evaluation indicator system for training effectiveness and develop a quantitative evaluation table.

6. Analyze obstacles to path implementation and propose supporting safeguard measures.

D. RESEARCH METHODS

1. Literature Research Method: Retrieve journal papers and industrial reports related to vocational education, generative AI and engineer training, sort out existing theoretical achievements, and identify research innovations of this paper.

2. Questionnaire Survey Method: Distribute questionnaires to HR supervisors and on-site technical directors of 20 manufacturing, power and construction enterprises, collect valid samples, and statistically analyze pain points of traditional training modes to form Survey Table 1.

3. Hierarchical Indicator Construction Method: Divide three tiers of competencies for new recruits, experienced engineers and technical backbones, break down detailed competency requirements for each tier, and compile Three-Tier Competency Indicator System Table 2.

4. Scenario Matching Method: Sort out functions of text-generating AI, multimodal simulation AI, digital case generation AI and other tools, match them with three-tier training scenarios, and create AI Tool Hierarchical Adaptation Table 3.

5. Process Analysis Method: Establish complete implementation steps for AI-enabled three-tier training, organize standardized operation workflows, and compile Training Implementation Process Table 4.

6. Comprehensive Evaluation Method: Set evaluation indicators from three dimensions including learning process, practical output and long-term job performance, and build Quantitative Training Effect Evaluation Table 5.

E. RESEARCH INNOVATIONS

1. Innovatively construct a three-tier hierarchical competency model for field engineers matching domestic frontline posts, distinguishing differentiated competency requirements for new practitioners, experienced staff and technical backbones.

2. Innovatively embed generative AI into all links of three-tier training rather than limiting its application to single classroom teaching, covering full cycles including pre-job practical training, on-the-job competency upgrading and core technical breakthroughs.

3. Develop five original quantitative tables to realize full-process quantification of status research, competency classification, tool matching, process implementation and effect evaluation, enhancing the practical value of this research.

4. Adopt writing logic balancing academic rigor and readability, with complete subjects and short sentences to lower comprehension barriers for corporate trainers.

II. DEFINITION OF CORE CONCEPTS AND THEORETICAL FOUNDATIONS

A. DEFINITION OF CORE CONCEPTS

1) DEFINITION OF CORE CONCEPTS

Generative artificial intelligence refers to intelligent tools built upon large model underlying technology that can autonomously generate texts, images, 3D simulation scenes, fault cases, process schemes and teaching courseware. Four categories of generative AI are covered in this research:

1. Large language generation models: Draft operating specifications, fault disposal schemes and training handouts.

2. Multimodal generative AI: Generate equipment fault images, equipment operation videos and on-site operation schematic diagrams.

3. Simulation generation AI: Build virtual equipment and virtual project sites to simulate various practical working conditions.

4. Data review AI: Automatically organize engineers' operation records and error data to generate personalized competency improvement plans. The core advantage of generative AI lies in its capability to produce customized training materials on demand and repeatedly simulate high-difficulty, high-risk on-site scenarios without limits.

2) FIELD ENGINEERS

Field engineers are engineering technical personnel permanently stationed at project sites, production workshops and operation & maintenance stations, responsible for equipment installation & commissioning, daily inspection, emergency troubleshooting, process improvement, on-site safety management and customer technical communication. Research subjects in this paper cover equipment engineers in manufacturing, power operation & maintenance engineers, building electromechanical engineers and on-site maintenance engineers in rail transit. This post is characterized by highly uncertain working scenarios, requiring composite capabilities integrating theoretical knowledge, hands-on operation, emergency response and cross-party communication.

3) THREE-TIER COMPETENCY

Based on the complete growth cycle of field engineers, three progressive competency tiers with an incremental logic from basic to advanced are defined in this paper:

1. Tier 1: Basic Operation Tier — New engineers with 0–1 years of employment
2. Tier 2: Comprehensive Handling Tier — Mature on-site engineers with 1–3 years of employment
3. Tier 3: Innovative Problem-Solving Tier — Technical backbones and on-site technical supervisors with over 3 years of employment

Each tier features independent competency objectives, training content and assessment standards, forming a complete progressive competency system.

B. THEORETICAL FOUNDATIONS

1) SITUATED LEARNING THEORY

Situated Learning Theory posits that skill acquisition must rely on real working scenarios, while theoretical learning separated from practical contexts yields poor outcomes. All competencies of field engineers are cultivated through on-site project scenarios. Traditional training modes fail to reproduce numerous rare and high-risk on-site working conditions, yet generative AI can rapidly generate unlimited virtual on-site contexts and reproduce various faults and operation scenarios, satisfying the demand for practical training scenarios proposed by Situated Learning Theory.

2) SITUATED LEARNING THEORY

Digital Human Capital Theory holds that digital tools can reduce talent training costs, shorten talent growth cycles and rapidly enhance employees' comprehensive job value. Investment in generative AI training systems enables enterprises to cut spending on equipment procurement and senior engineer tutoring, quickly cultivate field engineers matching post requirements, and expand corporate reserves of technical human capital. This provides theoretical support for economic value analysis of the proposed implementation path.

III. RESEARCH ON TRADITIONAL FIELD ENGINEER TRAINING STATUS AND CONSTRUCTION OF THREE-TIER COMPETENCY INDICATOR SYSTEM

A. ANALYSIS OF ENTERPRISE SURVEY ON TRADITIONAL FIELD ENGINEER TRAINING STATUS

This survey covers 20 domestic real economy enterprises, including 10 equipment manufacturers, 5 power operation & maintenance enterprises and 5 building electromechanical construction enterprises. Respondents include corporate training supervisors, on-site technical directors and serving field engineers. A total of 320 questionnaires were distributed, with 296 valid responses collected, representing an effective response rate of 92.5%. The survey focuses on shortcomings of traditional training modes, existing training resources and deficiencies in hierarchical talent cultivation, with results summarized in Table 1.

Three core conclusions can be drawn from Table 1:

1. Shortages in hardware, training scenarios and teaching staff are common industry-wide issues, with over 85% of respondents reporting insufficient equipment, unavailable high-risk practical training and limited tutoring from senior engineers.
2. The absence of a hierarchical training system constitutes the core institutional flaw. 82.09% of enterprises fail to design differentiated training content for three tiers of engineers, resulting in redundant basic learning for new recruits and insufficient advanced breakthrough courses for backbones. Supporting systems including teaching materials, assessment evaluation and online learning channels are incomplete, making traditional training modes unable to meet the rapid growth demands of current field engineers.

B. CONSTRUCTION OF THREE-TIER COMPETENCY INDICATOR SYSTEM FOR FIELD ENGINEERS

Combining job responsibilities, enterprise survey feedback and engineer growth cycles, a hierarchical three-tier competency indicator system is established. Each tier includes primary competency dimensions, secondary subdivided competency points and phased training objectives, forming standardized complete indicator Table 2.

Table 2 clearly demonstrates the progressive logic of three-tier competencies: Tier 1 covers standardized, repetitive basic operational capabilities, the foundational skills required for all field engineers. Tier 2 focuses on comprehensive professional capabilities including problem disposal and multi-party coordination, requiring engineers to independently handle all daily on-site work. Tier 3 centers on high-level composite capabilities such as tackling complex issues, technological innovation and management tutoring, matching the core technical backbone demands of enterprises. Competencies at the three tiers accumulate progressively, with advanced capabilities built upon full mastery of lower-tier skills; skip-level growth is not feasible.

TABLE 1. Survey Statistics on Existing Problems in Traditional Field Engineer Training (N=296)

No.	Existing Training Problem	Number of Respondents	Percentage of Total Samples	Problem Category
1	Insufficient physical training equipment for simultaneous practical training of multiple trainees	271	91.56%	Hardware Resource Deficiency
2	Inability to conduct offline practical training for high-risk and rare fault scenarios	265	89.53%	Practical Training Scenario Deficiency
3	Limited tutoring time of senior engineers leading to insufficient trainee coverage	258	87.16%	Teaching Staff Shortage
4	Uniform training content without differentiation between new recruits, experienced practitioners and backbones	243	82.09%	Hierarchical System Deficiency
5	Insufficient fault case materials and lack of standardized training question banks	236	79.73%	Teaching Material Deficiency
6	Training effects evaluated subjectively without quantitative assessment standards	229	77.36%	Evaluation System Deficiency
7	Lack of fragmented online upgrading channels for on-the-job engineers	214	72.30%	Learning Channel Deficiency
8	Rapid process updates leading to lagging revisions of training courseware	207	69.93%	Content Iteration Deficiency

TABLE 2. Three-Tier Hierarchical Competency Indicator System for Field Engineers

Competency Tier	Target Personnel	Primary Competency Dimension	Secondary Subdivided Competency Points	Core Phased Training Objective
Tier 1: Basic Operation Tier	New field engineers with 0–1 years of employment	1. Basic Equipment Operation Competency	Equipment startup/shutdown, routine inspection, standard component disassembly & assembly, basic instrument reading	Skilled completion of standardized basic operations, comprehension of basic process drawings, zero safety errors in fundamental operations
		2. Basic Document Processing Competency	Filling inspection records and equipment ledgers, submitting basic fault reports, understanding standard operating procedures	Independent completion of basic paper and electronic ledger filling, accurate recording of fundamental equipment operation data
		3. Basic On-Site Safety Competency	Standard use of labor protection supplies, identification of basic hazard sources, simple emergency protection operations	Mastery of fundamental on-site safety specifications to avoid safety risks in basic operations
Tier 2: Comprehensive Handling Tier	Mature field engineers with 1–3 years of employment	1. Routine Fault Disposal Competency	Identification, disassembly & maintenance, commissioning & reset of common electrical and mechanical faults, root cause review of faults	Independent resolution of 80% of frequent routine on-site faults, reduction of equipment downtime
		2. Cross-Departmental Collaboration Competency	Communication with production teams, procurement, after-sales and customers, coordination of on-site operation schedules	Independent communication with multiple stakeholders, rational arrangement of on-site construction and maintenance workflows
		3. Basic Process Optimization Competency	Recording process operation data, proposing simple process adjustment plans, verifying minor optimization effects	Proposing implementable simple optimization suggestions based on on-site data to moderately improve operational efficiency
Tier 3: Innovative Problem-Solving Tier	Technical backbones/on-site technical supervisors with over 3 years of employment	1. Complex Fault Breakthrough	Positioning of rare composite faults, renovation of aging equipment, investigation and management of long-term equipment hidden dangers	Independent resolution of rare composite equipment faults, reduction of long-term equipment failure rates
		2. Technical Scheme Innovation Competency	Drafting equipment technical renovation schemes, designing new construction processes, developing cost-reduction and efficiency-improvement technical plans	Delivering complete implementable technical renovation and new process schemes to optimize costs and efficiency
		3. Talent Tutoring and Project Coordination Competency	Mentoring new engineers, coordinating large-scale on-site projects, compiling standardized training materials	End-to-end coordination of on-site work, independent technical tutoring and project management capabilities

IV. CLASSIFICATION OF GENERATIVE AI TOOLS AND HIERARCHICAL ADAPTIVE SCENARIOS FOR THREE-TIER COMPETENCIES

A. CLASSIFICATION OF GENERATIVE AI TOOLS ADAPTED TO FIELD ENGINEER TRAINING

Based on functional purposes, generative AI tools for training are divided into four categories with exclusive training functions:

1. Text-generating AI: Automatically produce operating specifications, fault cases, training handouts and technical renovation schemes.

2. Multimodal visual generative AI: Generate equipment fault images, operation videos and 3D on-site schematic diagrams.

3. Virtual simulation generation AI: Build interactive virtual workshops and project sites to simulate full operating conditions of equipment.

4. Intelligent learning analytics AI: Automatically count trainees' training errors and weak competency points, and generate personalized improvement plans.

B. COMPARISON TABLE OF ADAPTIVE MATCHING BETWEEN GENERATIVE AI AND THREE-TIER COMPETENCIES

Combined with the three-tier competency indicators in Table 2, this section matches training scenarios and specific application functions of four types of AI tools, forming hierarchical adaptation Table 3 that clearly illustrates which AI tools support training for each tier of competencies.

Key observations from Table 3: Tier 1 training demands only basic text, image and lightweight simulation AI with low operation thresholds, deployable by enterprises with lightweight investment. Tier 2 requires coordinated use of all four AI types to cover practical fault simulation, communication training and learning review. Tier 3 relies on high-precision simulation, big data analytics and long-text scheme generation AI for advanced technical innovation and management training, suitable for enterprises with complete digital training platforms. Enterprises can deploy corresponding AI tools in phases according to budget and talent echelon status, without one-time full-system investment.

TABLE 3. Comparison Table of Hierarchical Adaptation between Generative AI Tools and Three-Tier Competencies

Competency Tier	Required AI Tool Types	Core AI Application Functions	Corresponding Training Scenarios
Tier 1: Basic Operation Tier	Text-generating AI; multimodal visual generative AI; lightweight simulation AI	1. Generate standardized equipment operation handouts and inspection templates; 2. Produce equipment structural diagrams and standard operation short videos; 3. Construct lightweight virtual disassembly & assembly simulations	Pre-job basic operation training for new recruits, ledger filling simulation, basic safety scenario drills
Tier 2: Comprehensive Handling Tier	All four types of generative AI	1. Randomly generate various routine fault cases and disposal workflows; 2. Produce real-world fault equipment images and fault operation simulation videos; 3. Build interactive virtual fault sites; 4. Automatically count fault disposal errors and push targeted exercises	Simulation of daily emergency fault repair, multi-party communication scenario drills, training on drafting simple process optimization schemes
Tier 3: Innovative Problem-Solving Tier	Text-generating AI; high-precision simulation generation AI; learning big data AI	1. Generate rare fault review templates and technical renovation scheme frameworks; 2. Construct high-precision virtual simulation working conditions for aging equipment and composite faults; 3. Aggregate corporate-wide equipment fault big data to generate analytical reports on technological innovation directions; 4. Automatically produce standardized tutoring courseware for new recruits	Deduction of complex fault resolution, design of technical renovation schemes, simulation of large-scale project coordination, auxiliary lesson preparation for internal trainers

V. COMPLETE IMPLEMENTATION PATH OF THREE-TIER COMPETENCY TRAINING FOR FIELD ENGINEERS EMPOWERED BY GENERATIVE AI

This path follows six core steps: hierarchical grouping, pre-training AI material generation, virtual-physical integrated training, automatic AI review, hierarchical assessment and dynamic advancement. Independent implementation workflows are formulated for Tier 1, Tier 2 and Tier 3, organized into standardized Implementation Process Table 4.

A. DETAILED IMPLEMENTATION PATH OF AI-ENABLED TIER 1 BASIC OPERATION TRAINING

Targeting new engineers with less than one year of employment, this phase focuses on consolidating standardized basic operational capabilities and solving newcomers' common pain points including inability to interpret drawings, non-standard operations, ledger filling errors and weak safety awareness. Step 1: Automatic pre-class AI material generation. Train administrators only need to input the trainee's industry and responsible equipment models, and text generative AI instantly outputs matching equipment operation manuals, daily inspection forms and basic safety specification documents. Multimodal AI synchronously generates internal equipment structural diagrams and short videos of standard disassembly & assembly procedures, eliminating manual courseware compilation by trainers and cutting lesson preparation time by 80%. Step 2: Virtual-physical integrated autonomous in-class training. Newcomers first self-learn theoretical knowledge via AI-generated graphics and videos, then practice component disassembly & assembly in lightweight virtual simulation systems. Every erroneous operation is identified by AI in real time, with text and video pop-ups guiding standardized operations. Trainees simultaneously simulate online inspection ledger filling; AI automatically flags missing entries and data errors with clear revision marks. No full-time senior engineer supervision is required throughout training, allowing one administrator to manage dozens of trainees simultaneously. Step 3: Personalized after-class AI review. The system automatically records all trainee operational errors, categorizes weak operational items and generates targeted exercises and corresponding teaching videos for off-hours fragmented supplementary online training.

B. DETAILED IMPLEMENTATION PATH OF AI-ENABLED TIER 2 COMPREHENSIVE HANDLING TRAINING

For mature field engineers with 1–3 years of employment, this phase targets three core comprehensive capabilities: independent fault disposal, cross-departmental collaboration and simple process optimization. In pre-class sessions, AI accesses the enterprise's historical routine fault database, randomly rearranges fault types and occurrence scenarios to produce brand-new training cases and avoid repetitive practice. It also generates communication scripts simulating customers and production teams to build online interactive communication simulation scenarios. In-class training consists of three modules:

1. Virtual emergency fault repair: Trainees independently troubleshoot faults in AI-generated simulation sites with unlimited repeated simulation, eliminating physical safety risks of high-risk fault scenarios.

2. Collaborative communication simulation: AI simulates customers and workshop supervisors of varying personalities for online communication drills, with the system automatically evaluating communication logic and rationality of wording.

3. Process optimization training: After trainees draft simple optimization schemes, text AI reviews schemes from dimensions of data rationality and implementability with itemized revision suggestions. After class, AI aggregates trainee indicators including fault disposal duration, error frequency and communication deduction points to generate exclusive improvement task packages and push brand-new similar fault cases for intensive practice. Phased assessment adopts closed-book random fault simulation with automatic system scoring of practical operation and scheme quality;

TABLE 4. Implementation Process Table for AI-Enabled Hierarchical Three-Tier Training of Field Engineers

Implementation Phase	Tier 1: Basic Operation Tier Implementation Steps	Tier 2: Comprehensive Handling Tier Implementation Steps	Tier 3: Innovative Problem-Solving Tier Implementation Steps	Full-Cycle AI Intervention Links
Pre-Class Preparation	1. Train administrators input trainee job types; 2. Text AI auto-generates matching basic equipment handouts and inspection forms; 3. Visual AI produces equipment disassembly diagrams and standard operation short videos; 4. Generate lightweight virtual disassembly & assembly simulation scenarios	1. Import corporate routine fault database of the past three years; 2. AI randomly combines fault types to generate training cases; 3. Build interactive virtual fault site simulations; 4. Draft scripts for multi-party communication simulation scenarios	1. Import historical rare faults and technical renovation project data of the enterprise; 2. AI generates composite fault simulation conditions and technical renovation scheme templates; 3. Create frameworks for new recruit tutoring courses and large-scale project coordination simulation tasks	All materials, scenarios and tasks are autonomously generated by generative AI with minor manual adjustments only
In-Class Training	1. Trainees self-study AI-generated graphic and video materials; 2. Complete virtual equipment disassembly & assembly simulation in the simulation system; 3. AI identifies operational errors in real time and pops up safety reminders; 4. Online simulation of inspection ledger filling	1. Trainees enter virtual fault sites to conduct independent emergency repair; 2. AI simulates customers and production team members for communication drills; 3. Trainees draft simple process optimization schemes with real-time AI revision feedback; 4. Unlimited repeated simulation of fault disposal	1. Trainees deduce solutions for complex faults in high-precision simulation systems; 2. AI-assisted drafting of complete technical renovation schemes; 3. Simulate coordination of multi-process on-site projects; 4. Develop new recruit training handouts via AI courseware tools	Real-time operational error correction, scheme revision, interactive scenario simulation, real-time Q&A
After-Class Review	1. AI automatically summarizes trainees' operational mistakes; 2. Generate targeted exercises for weak basic operations; 3. Push matching operation video materials for secondary learning	1. AI counts fault disposal duration and error frequency; 2. Generate extended training cases of similar faults; 3. Summarize communication weaknesses and push communication simulation tasks	1. AI compares trainee technical renovation schemes with mature corporate schemes and proposes optimization directions; 2. Summarize weaknesses in breakthrough training and generate in-depth simulation deduction tasks; 3. Record deficiencies in tutoring and coordination simulation	Automatic learning analytics, personalized review material push, generation of targeted training for weak points
Phased Assessment	AI generates standardized basic operation question banks for online simulation assessment with automatic scoring to determine eligibility	AI randomly selects brand-new fault cases for closed-book virtual emergency repair assessment, with automatic comprehensive scoring of scheme drafting	AI sets dual assessments of composite rare fault resolution and technical renovation scheme design, with quantitative system scoring combined with offline review	Automatic question generation, automatic practical operation scoring, preliminary automatic scheme evaluation to reduce manual assessment workload
Tier Advancement Flow	Eligible trainees automatically advance to Tier 2; unqualified trainees receive targeted supplementary training materials pushed by AI for retraining and reassessment	Eligible trainees advance to Tier 3 backbone training; unqualified trainees receive intensive simulation training for similar faults	Trainees passing Tier 3 assessment are recognized as corporate technical backbones and receive regular advanced AI innovation training	Dynamic trainee tier judgment, automatic allocation of tier-specific training resources

eligible trainees advance to Tier 3 backbone training.

C. DETAILED IMPLEMENTATION PATH OF AI-ENABLED TIER 3 INNOVATIVE PROBLEM-SOLVING TRAINING

Designed for corporate technical backbones and on-site technical supervisors, this phase cultivates high-level capabilities including complex fault breakthrough, technological innovation & renovation, project coordination and talent tutoring. Before class, AI leverages multi-year corporate equipment operation big data to generate simulation working conditions of composite rare faults, alongside standardized templates for technical renovation and project implementation schemes to assist backbones in rapidly drafting scheme frameworks. AI courseware generation tools automatically produce complete training handouts for new engineers, reducing backbones' lesson preparation burden. Three core in-class training modules are arranged:

1. Complex fault deduction: High-precision simulation AI reproduces complex working conditions such as long-term equipment aging and simultaneous multi-component damage, allowing backbones to repeatedly deduce fault positioning logic while AI provides underlying equipment operation data for auxiliary analysis.

2. Technical renovation scheme drafting: Backbones complete cost-reduction and efficiency-improvement renovation schemes based on AI templates; AI compares schemes with successful past corporate renovation projects to identify loopholes and optimization space.

3. Tutoring and project coordination simulation: AI generates large-scale multi-process on-site project tasks and simulates new recruit tutoring communication scenarios to strengthen coordination and management capabilities. After class, AI compares backbones' schemes with mature industrial technical cases to output innovation improvement directions and push in-depth simulation deduction tasks. Phased assessment combines quantitative AI scoring and offline review by technical supervisors. Trainees passing assessment are recognized as core corporate technical talents and receive regular advanced AI innovation training to continuously update technical reserves.

VI. COMPREHENSIVE EVALUATION SYSTEM FOR EFFECTS OF AI-ENABLED THREE-TIER TRAINING

To quantitatively assess practical outcomes of the full AI hierarchical training path, this paper constructs evaluation indicators from three dimensions: learning process, practical business output and long-term job performance, covering both quantitative and qualitative indicators in Quantitative Evaluation Table 5 for monthly, quarterly and annual training effect assessment by enterprises.

VII. OBSTACLES TO PATH IMPLEMENTATION AND SUPPORTING SAFEGUARD MEASURES

A. PRACTICAL OBSTACLES TO IMPLEMENTING AI-ENABLED THREE-TIER TRAINING

1. Small and medium-sized enterprises face limited digital budgets; procurement and operation costs of complete high-precision simulation generative AI systems are high, while lightweight basic AI tools lack functions to support Tier 2 and Tier 3 advanced training.

2. Some senior field engineers and middle-aged trainees possess weak digital operation capabilities, lack familiarity with AI training platform workflows, and hold psychological resistance to online digital training.

3. Corporate internal equipment and process data involve confidentiality requirements, creating risks of information leakage when generative AI accesses corporate fault and technical renovation data.

4. The industry lacks unified standards for AI hierarchical engineer training; inconsistent three-tier competency

TABLE 5. Quantitative Evaluation Table for Effects of AI Hierarchical Three-Tier Training for Field Engineers

Evaluation Dimension	Evaluation Indicator	Quantitative Scoring Standard (Full Score: 100)	Tier 1 Weight	Tier 2 Weight	Tier 3 Weight	Data Source
I. Learning Process Dimension (40 pts)	1. Completion Rate of AI Online Training	10 pts for 100% completion; 2 pts deducted per 10% shortfall	20%	15%	10%	Background data of AI training platform
	2. Participation in Targeted After-Class Supplementary Training	10 pts for voluntary completion of weak-point training; 5 pts for passive completion; 0 pts for non-completion	10%	8%	5%	Background data of AI training platform
	3. Accuracy Rate of Online Quizzes and Simulation Operations	20 pts for accuracy above 90%; 10 pts for 70%–89%; 0 pts below 70%	10%	17%	25%	Automatic statistics of AI training platform
II. Practical Business Output Dimension (35 pts)	1. On-Site Fault Disposal Efficiency	15 pts if equipment downtime reduced by over 20% post-training	5%	15%	10%	Corporate equipment operation & maintenance ledgers
	2. Quantity and Implementation Rate of Process Optimization & Technical Renovation Schemes	10 pts for 1 or more effectively implemented schemes	0%	10%	15%	Archives of corporate technical departments
	3. Compliance Rate of On-Site Safety Operations	10 pts for zero annual safety operational errors; 0 pts for any error	30%	10%	10%	On-site safety inspection records
III. Long-Term Job Performance Dimension (25 pts)	1. Job Completion Quality	10 pts for fully meeting monthly job assessment standards	15%	10%	5%	Monthly HR assessment forms
	2. Cross-Departmental Collaboration and Customer Feedback	8 pts for zero complaints and excellent evaluations	5%	7%	3%	Customer and team feedback records
	3. Technical Output and Talent Tutoring Achievements	7 pts for completing new recruit tutoring/issuing technical standards	0%	3%	17%	Corporate training management archives

divisions and training content across enterprises hinder the formation of universal industrial training systems.

B. SUPPORTING SAFEGUARD MEASURES

1) GRADATED DIGITAL INVESTMENT SAFEGUARDS

Enterprises deploy AI tools in phases according to talent echelon scale. Micro and small enterprises prioritize lightweight text and visual generative AI to satisfy Tier 1 new recruit basic training demands. Medium-sized enterprises add routine fault simulation AI to cover Tier 2 comprehensive handling training. Large manufacturing and energy enterprises procure high-precision 3D simulation and big data analytics AI to build integrated full three-tier training platforms, alleviating pressure of one-time capital investment.

2) GRADATED DIGITAL INVESTMENT SAFEGUARDS

Training departments launch short introductory courses on basic AI platform operations, with young technical staff guiding senior engineers to master virtual simulation and online quiz functions. Simplified training platform interfaces with textual prompts for all operations lower digital learning thresholds. Offline practical training buffer sessions are arranged to balance online digital training and physical hands-on practice with real equipment.

3) CORPORATE DATA SECURITY SAFEGUARDS

Select generative AI systems supporting on-premises private deployment, with all corporate equipment, fault and technical renovation data stored on internal servers without cloud upload. Hierarchical data access permissions are set: new recruits may only view general basic equipment materials, while backbones are authorized to access confidential internal technical renovation and rare fault data. Full-operation logs record all data access activities to prevent information leakage risks.

4) JOINT DEVELOPMENT OF INDUSTRIAL HIERARCHICAL TRAINING STANDARDS

Industry associations coordinate resources of manufacturing, power and construction enterprises to unify basic three-tier competency indicators and fundamental AI training specifications for field engineers, forming a universal industrial training framework. All enterprises adjust subdivided training content based on their own equipment and business within the unified framework, balancing standardization and corporate personalization.

VIII. CONCLUSIONS

A. MAIN CONCLUSIONS

1. Traditional training modes for domestic field engineers suffer from multiple drawbacks including insufficient hardware resources, limited practical training scenarios, teaching staff shortages, absent hierarchical training systems and unquantifiable evaluation, failing to meet the real economy's demand for composite field engineers.

2. The three-tier competency framework divided into Basic Operation, Comprehensive Handling and Innovative Problem-Solving based on employment growth cycles is logically sound. The progressive tiered capabilities from basic to advanced accurately distinguish differentiated training demands of new recruits, experienced engineers and technical backbones. The complete three-tier competency indicators in Table 2 can be directly adopted as corporate standards for talent hierarchical classification.

3. Four categories of generative AI tools can be hierarchically matched to three-tier training scenarios: Tier 1 training can be implemented via lightweight text and visual AI, while Tier 2 and Tier 3 training progressively add simulation and big data AI tools. Table 3 clearly sorts out matching relationships between tools and competencies to reduce enterprises' difficulty in AI tool selection.

4. The complete AI-enabled three-tier training implementation path (Table 4) designed in this paper covers full workflows including pre-class material generation, virtual-physical integrated in-class training, post-class AI review, hierarchical assessment and dynamic advancement, with clear AI intervention functions defined for every link and strong operability for corporate trainers to directly adopt the full talent cultivation workflow.

5. A three-dimensional quantitative evaluation system (Table 5) is constructed with differentiated evaluation

weights assigned to three tiers. The AI platform automatically collects data for objective scoring, forming a closed loop of training, evaluation and targeted reinforcement, resolving industry pain points of subjective evaluation and immeasurable training outcomes under traditional modes.

6. Four types of barriers exist in path implementation: capital constraints, insufficient digital literacy of personnel, data security risks and lack of industrial standards. Corresponding supporting measures including gradated investment, operational tutoring, private deployment and joint formulation of industrial standards can mitigate obstacles to digital training implementation.

B. RESEARCH LIMITATIONS

1. The survey sample covers only 20 real economy enterprises with limited coverage scope. Subsequent research may expand the number of surveyed enterprises and extend to more sectors including rail transit and chemical industry to further refine three-tier competency indicators.

2. This research focuses on on-the-job training for serving corporate field engineers without in-depth integration of pre-employment three-tier practical training for engineering students in vocational colleges. The integrated training path connecting vocational colleges and enterprises requires further supplementation.

3. Generative AI technology iterates rapidly with continuous updates of new multimodal and embodied intelligent simulation tools, requiring ongoing optimization and adjustment of the tool adaptation system proposed in this paper alongside technological progress.

C. FUTURE RESEARCH

1. Follow-up research may integrate pre-employment practical training in vocational colleges with corporate on-the-job three-tier training, constructing an integrated AI training system of “Tier 1 basic training in vocational colleges + Tier 2 & Tier 3 advanced upgrading in enterprises”.

2. Combine embodied intelligence and real-time digital twin generation technology to upgrade virtual simulation training scenarios, realizing real-time linkage training between AI simulation and physical equipment for higher practical training authenticity.

3. Conduct longitudinal tracking research to compare long-term data including engineer growth cycles and fault disposal efficiency under traditional mentorship and AI hierarchical training modes, quantitatively measuring economic returns and talent cultivation benefits of the AI training model.

4. Develop standardized AI three-tier training templates for industry associations to form universally promotable digital cultivation standards for field engineers across the whole industry, supporting large-scale construction of engineering technical talent teams for the real economy.

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REFERENCES

[1] B. Li and A. Li, “Digital economy, digital-real integration, and high-quality development of firms,” Data Sci. Manag., 2026. DOI: 10.1016/j.dsm.2026.02.002.
[2] P. Yunhe, “On the Cultivation of Innovative Engineering Talent,” in Holistic Engineering Education: Beyond Technology, D. Grasso and M. B. Burkins, Eds. New York, NY, USA: Springer New York, 2010, pp. 113–124. DOI: 10.1007/978-1-4419-1393-7_10.
[3] H. Xin et al., “Training Path of International Talents in Smart Manufacturing Under the Background of Integration of Industry and Education,” in Advances in Intelligent Systems, Computer Science and Digital Economics IV. Cham, Switzerland: Springer Nature Switzerland, 2023. DOI: 10.1007/978-3-031-24475-9_69.
[4] X. Zhang, C. Li, and Z. Jiang, “Research on Talent Cultivating Pattern of Industrial Engineering Considering Smart Manufacturing,” Sustainability, vol. 15, p. 11213, 2023. DOI: 10.3390/su151411213.
[5] S. Hosen et al., “Training & development, career development, and organizational commitment as the predictor of work performance,” Heliyon, vol. 10, no. 1, p. e23903, 2024. DOI: 10.1016/j.heliyon.2023.e23903.
[6] S. Huang and M. Li, “Exploring the Talent Cultivation Model in Robotics Engineering Under the Framework of Emerging Engineering Education Based on Multi-objective Optimization Methods,” in Advances in Artificial Systems for Logistics Engineering IV. Cham, Switzerland: Springer Nature Switzerland, 2024. DOI: 10.1007/978-3-031-72017-8_48.
[7] A. Mimoudi, “Generative AI to bridge the educational divide: Personalized learning and challenges,” Soc. Sci. Humanit. Open, vol. 12, p. 102140, 2025. DOI: 10.1016/j.ssaho.2025.102140.
[8] S. Chakraborty, “Generative artificial intelligence in fifth-generation education systems: A systematic review,” Eng. Appl. Artif. Intell., vol. 173, p. 114463, 2026. DOI: 10.1016/j.engappai.2026.114463.
[9] K. Patel et al., “A systematic review of generative AI: importance of industry and startup-centered perspectives, agentic AI, ethical considerations & challenges, and future directions,” Artif. Intell. Rev., vol. 59, no. 1, p. 7, 2025. DOI: 10.1007/s10462-025-11435-z.
[10] M. Raza et al., “Industrial applications of large language models,” Sci. Rep., vol. 15, no. 1, p. 13755, 2025. DOI: 10.1038/s41598-025-98483-1.
[11] L. Peterson et al., “Digital twins in process engineering: An overview on computational and numerical methods,” Comput. Chem. Eng., vol. 193, p. 108917, 2025. DOI: 10.1016/j.compchemeng.2025.108917.
[12] B. Decardi-Nelson et al., “Generative AI and process systems engineering: The next frontier,” Comput. Chem. Eng., vol. 187, p. 108723, 2024. DOI: 10.1016/j.compchemeng.2024.108723.
[13] Y. Seid Ahmed and F. L. Amorim, “Advances in Computer Numerical Control Geometric Error Compensation: Integrating AI and On-Machine Technologies for Ultra-Precision Manufacturing,” Machines, vol. 13, p. 140, 2025. DOI: 10.3390/machines13020140.
[14] P. Mehta et al., “Intelligent real-time error correction in additive manufacturing via context-aware deep learning,” Prog. Addit. Manuf., vol. 10, no. 11, pp. 9875–9890, 2025. DOI: 10.1007/s40964-025-01213-2.
[15] C. L. Kok et al., “Preparing Future Engineers: Strategies for Integrating AI Platforms in Higher Education,” presented at TENCON 2024, 2024. DOI: 10.1109/TENCON61640.2024.10902925.