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Design and Development of an Integrated Virtual-Reality Training Simulation Sand Table for Rail Systems

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Abstract: With the rapid development of the economy, it is imperative to improve the quality of training for operational and managerial talents in the railway industry. To address issues such as efficiency, safety, and cost in railway industry practical training, it is crucial to establish a more comprehensive and efficient high-value virtual–real integration simulation experimental training resource. Therefore, this paper takes the actual work process as the core driving force, utilizes advanced information technology and intelligent devices, and is based on the comprehensive training platform for automatic control of physical trains combined with unmanned aerial vehicle (UAV) equipment. It achieves the integration of hardware and software construction to design and develop a comprehensive simulation training sand table system that incorporates functions such as training, demonstration, testing, and experiments. This system builds an integrated platform for training simulation functions, capable of simulating a railway centralized traffic control system, enabling railway dispatching simulation, driving simulation, and inspection simulation experiences. Additionally, it designs experimental processes at three levels: cognition, practical operation, and enhancement, tailored to the needs of talent development. The rail transportation training simulation sand table effectively reduces training costs and enhances the practical ability training quality of railway operation management personnel, meeting the requirements for talent development in the railway and related industries under new circumstances.

Keywords: railway transportation; virtual simulation; training sand table; drone

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1. Introduction

Rail transportation is a crucial component of national economic development and holds strategic significance. In recent years, there has been rapid growth in railway construction, necessitating an enhancement of talent development quality and the strengthening of core competitiveness within the railway industry. Current practical training in the railway field has proven less than satisfactory, calling for a more comprehensive training approach to help students form a holistic understanding of railway operations and management.

Existing railway courses predominantly rely on theoretical instruction, presenting a vast amount of knowledge in a theoretical manner. Students lack close contact with practical work, making it challenging for them to develop a macroscopic sensory understanding of railway transportation equipment, let alone master the complex control, management, and maintenance of such equipment in a short timeframe. Therefore, establishing railway transportation experimental training resources to improve the quality and level of experimental training in related courses has become an unavoidable issue in the current development of railway transportation professions.

To address this issue, a solution lies in adopting simulation environment teaching methods. Simulation environment teaching has found extensive applications in various industries such as medicine, animation arts, university education, power engineering, environmental engineering, database technology, and applications. It combines multimedia,

simulation, perception, and artificial intelligence technologies to construct a multidimensional, multisensory, interactive, and highly immersive virtual simulation experimental teaching space, enhancing students' innovation and engineering skills.

For example, Zhang et al. integrated multimedia, simulation, perception, and artificial intelligence technologies to create a multidimensional, multisensory, interactive, and highly immersive "VR Virtual Simulation Experimental Teaching Space". Using examples from medical, animation arts, university education, and power engineering, they demonstrated the application methods and effects of virtual reality technology in different experimental teachings [1]. Zhang et al. simulated power teaching and training tasks using virtual reality technology, proving that simulation environment teaching can improve the effectiveness and quality of teaching and training [2]. Molina et al. introduced the use of a digital sand table, displayed through touch screens and 3D views, allowing students to design and simulate environmental engineering on the digital sand table, effectively enhancing students' innovation and engineering skills, and improving the effectiveness of teaching [3] Li et al. combined virtual experimental technology with database technology and application teaching, creating an innovative teaching method based on virtual environment construction for database technology and applications [4]. Chandramouli et al. investigated the use of desktop VR and CAVE technology to provide an interactive virtual learning environment for geographic information systems (GIS) education. Their research indicates that simulation and immersive techniques can enhance students' learning interest and motivation, strengthen their spatial thinking and problem-solving abilities, and promote their active and collaborative learning [5]. These teaching cases effectively demonstrate the enhancement of teaching effectiveness through simulation environment teaching.

Given the diverse physical environments and equipment involved in railway production, along with the need for collaborative work across multiple job types, trainers must have a profound understanding of the field. Additionally, safety is a fundamental principle in railway operation, making it difficult for trainees to directly engage in on-site learning. Therefore, in railway training and teaching, the use of simulation sand tables, typically with a focus on the virtual, is crucial for relevant research and practical application. Simulation sand tables can simulate various aspects of railway transportation, such as train driving, station management, transport organization, power supply systems, and operational systems, enabling students to practice operations and interactive learning on the sand table, thereby enhancing their professional knowledge and practical skills. Yang introduced a subway vehicle driving training method based on an expert-assisted system, utilizing a vehicle driving simulation platform to provide students with various driving scenarios and expert guidance, improving students' driving skills and theoretical knowledge [6].

There are two main methods for constructing railway sand tables: one is the digital sand table based on virtual reality technology, and the other is the hybrid sand table based on semi-physical simulation technology. The digital sand table can be displayed through touch screens, 3D views, VR panoramas, and other means, achieving visualization, interaction, and immersion, thus improving the realism and enjoyment of the sand table. It reduces development costs and maintenance difficulties, making it suitable for simulating railway systems of various scales and complexities.

Chen et al. proposed a simulation model construction method based on multi-agent simulation technology and virtual reality systems. This method comprehensively, accurately, efficiently, and intelligently demonstrates the behavioral processes of urban rail transit operating in real environments. It establishes a computer simulation model with stations as scenes, validates the simulation model through data collection, explores the application of virtual reality technology in urban rail transit operation simulation, and enhances simulation effects while reducing development costs [7]. Wang et al. designed a virtual reality-based railway sand table, simulating various aspects of railway transportation, such as train driving, station management, and transport organization, allowing students to practice operations and interactive learning on the sand table to improve their professional knowledge and practical skills [8]. Zeng et al. constructed a "VR Virtual

Simulation Experimental Teaching Space", designing and implementing a series of virtual simulation experiments covering various aspects of railway engineering. Using virtual reality technology to simulate different aspects and tasks of railway engineering, it achieved visualization, interaction, and immersion, improving the effectiveness and quality of experimental teaching and enhancing students' practical and innovative abilities [9]. Yang et al. designed and implemented a series of VR panoramic simulation experiments covering various aspects of urban rail transit vehicle engineering. Using VR technology to simulate different aspects and tasks of urban rail transit vehicle engineering, it improved students' practical abilities and theoretical knowledge. The application effects of VR panoramic technology in the simulation system for urban rail transit vehicle engineering demonstrated its effectiveness in improving construction safety management efficiency [10]. López et al. proposed a simulation and control framework for traffic transportation systems based on automated guided vehicles (AGVs). This framework utilizes event simulators to statistically simulate the behavior of AGVs, while using Petri net models to describe and validate the execution process of tasks, thus improving the efficiency and flexibility of simulation and control [11]. Mishra et al. summarized various simulation methods and technologies in the field of public transportation, including micro, macro, and hybrid simulations, as well as different simulation software and tools. These provide inspiration for the construction of simulation sandbox frameworks [12].

On the other hand, the hybrid sand table combines semi-physical simulation of train operation with digital simulation of power supply and operational systems. This integration achieves comprehensive, accurate, efficient, and intelligent sand table performance, enhancing reliability and precision. It is suitable for simulating high-demand railway systems such as high-speed railways.

Zhang et al. built a hybrid real-time simulation system consisting of semi-physical simulation of trains and digital simulation of power supply and operational systems. It comprehensively, accurately, efficiently, and intelligently demonstrates the behavioral processes of urban rail transit systems throughout their real environment and entire lifecycle, providing a new technical means and method for the design and operation of urban rail transit [13]. Luo et al. constructed a sand table virtual simulation experimental platform based on the construction of the Beijing–Shanghai–Hangzhou high-speed railway network. It integrated subsystems such as train operation control, power supply, signal systems, and operational management, simulating the entire lifecycle of high-speed railways. It achieved comprehensive simulation and optimization support for high-speed railway dispatch control systems, providing a new technical means and method for the education, research, and development of high-speed railways [14].

In summary, the application of sand tables in teaching and training is a feasible technological route. It effectively improves the effectiveness and quality of railway teaching and training, providing a new technical means and method for the education, research, and development of railways. In this context, the railway education and popularization industry requires a more comprehensive training sand table to undertake macro training tasks, assisting students in forming a better overall impression of railway operations and management. This allows students to experience and solve various problems in railway transportation through sand table operations, enhancing students' professional competence and comprehensive abilities.

The effectiveness of sand tables in engineering training depends not only on the design and functionality of the sand table itself but also on the methods of use and evaluation. To effectively use and evaluate sand tables, several aspects need consideration: (1) the goals and content of the sand table, ensuring it aligns with training objectives and reflects training needs, emphasizing training focus and challenges; (2) the form and scale of the sand table, ensuring it fits the training format and scale, meets training conditions and requirements, and adapts to training scenarios and environments; (3) the process and methods of the sand table, following training processes and methods, implementing training steps and stages, and using training modes and means; and (4) the feedback and evaluation of the sand table,

providing training feedback and evaluation, collecting training data and information, and analyzing training effects and issues.

Different engineering sand tables may have different design goals and teaching requirements. Therefore, rational sand table evaluation methods and standards should be established based on specific engineering fields and course content to ensure the quality and effectiveness of sand table teaching. Generally, sand table evaluation methods can be categorized as qualitative and quantitative. Qualitative methods involve surveys, interviews, observations, etc., to collect students' and teachers' feelings and feedback on sand table teaching. Quantitative methods involve testing, grades, indicators, etc., to analyze students' performance and progress in sand table teaching. The selection and application of sand table evaluation methods and standards should be adjusted and optimized according to the characteristics and purposes of the sand table, as well as the goals and processes of teaching, to improve the scientific and effective evaluation of sand tables [3].

In railway management, the railway sand table can be used for researching and analyzing the efficiency and reliability of railway operations, providing reference and guidance for improving railway operations. In the training field, the railway sand table can be used for basic training and skills training for railway operation personnel, helping them better grasp knowledge and skills related to railway operations.

However, the current stage of railway sand tables is generally tailored for specific purposes, and standardized development is limited. The proportion of standardized usage is relatively low, with specifications ranging from private standards to widely used international standards such as the O scale (1:48, 1:45, 1:43.5, and 1:43) and HO scale (half of O scale, 1:87). The related control systems are typically developed by manufacturers alone, leading to generally high construction costs and a lack of excellent systems. The applicability of sand tables themselves is generally poor, resulting in relatively high construction costs due to low shipment volumes. Additionally, there is limited development of additional modules, low expansibility, low academic development levels, and a limited impact on training and research, necessitating specialized development. Constructing such a system poses challenges, requiring substantial coordination of numerous motion modules, the design of a refined interactive communication system, and the effective communication of data and the linkage of equipment.

With continuous technological advancement, railway sand tables are also undergoing continuous improvement and upgrading. Currently, railway sand tables have the potential to support technologies such as virtual reality, artificial intelligence, and big data, which can better simulate the real situation of railway operation and develop more modules on a well-established sand table. This enhances the practicality and effectiveness of railway sand tables.

One of the technologies that can be applied to railway sand tables is drone technology. Drones are unmanned aerial vehicles that can obtain geospatial information by carrying sensors. They have the advantages of high mobility, fast data acquisition, and high data accuracy. Drone technology has been widely used in civil fields, especially in railway inspection. It can achieve rapid, efficient, accurate, and low-cost railway inspection, including geotechnical surveying, settlement monitoring, damage detection, intrusion inspection, and other tasks. It can provide reference and support for railway management, operation, and maintenance.

The design of this sand table aims to expand the foundation of the simulation training platform, integrate various training equipment and methods, construct a virtual–real integrated framework, further enrich the simulation training sand table, establish mutual mappings and correlations between various modules, further refine and improve, add more functions and intelligent modules, demonstrate more experimental tasks, and provide a more powerful auxiliary role. This design aims to utilize advanced technology and intelligent devices, based on the comprehensive practical training platform for train automatic control, to construct an integrated virtual and real framework, enriching the simulation training sand table and providing powerful auxiliary functions.

Simultaneously, the development and deployment of a drone detection module is undertaken to demonstrate the basic application within the simulation platform. We apply drone railway environment detection to the dispatching work and try to simulate the drone railway environment detection work on the simulation sand table platform. We use image recognition technology to detect the scaled-down models for teaching and scientific research simulation. In addition, we also use the drone perspective to replace the trainee's binocular perspective on the micro sand table, which can provide the trainee with a broader vision, a more realistic simulation, a more efficient detection, and richer data, further expanding the trainee's cognitive range and spatial sense.

Ultimately, we will construct a simulation training sand table platform that integrates training, demonstration, testing, experimentation, and evaluation functions.

The structure of this article (see Figure 1) is organized as follows: Section 2 introduces the equipment architecture, Section 3 outlines the training experimental process for the sand table framework design, Section 4 conducts an analysis and evaluation of the framework, Section 5 presents conclusions and future work, and finally, a list of references concludes the article.

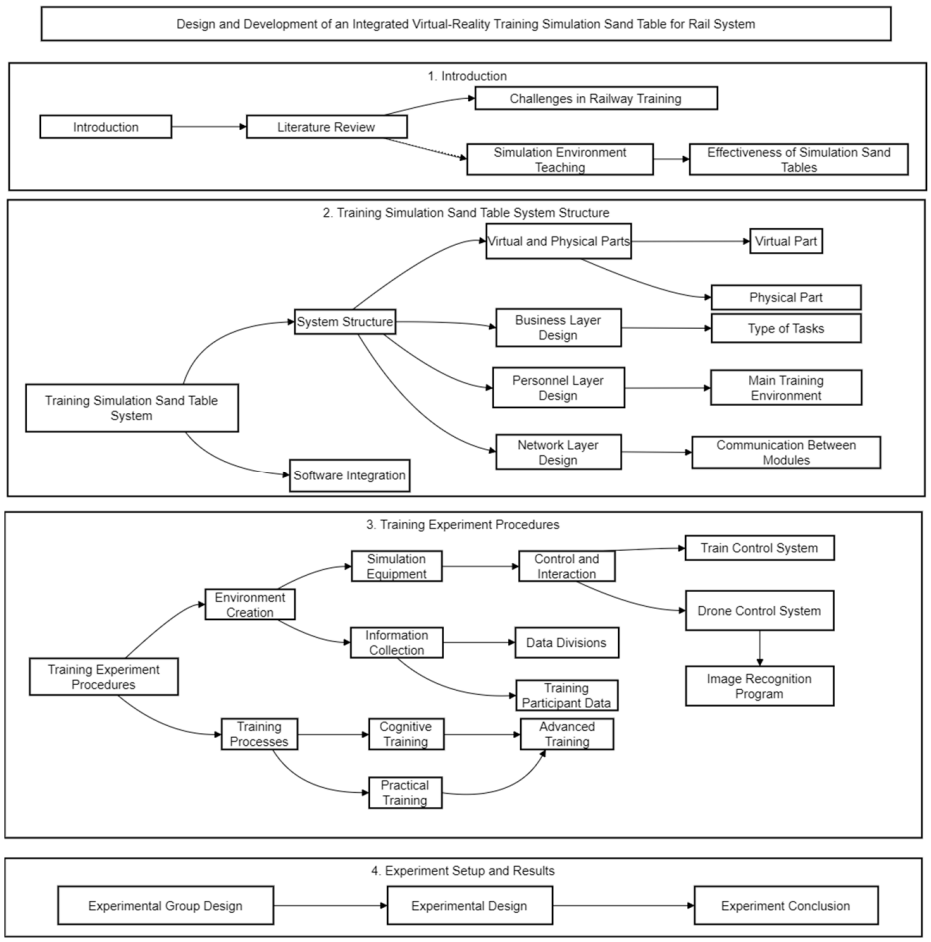


Figure 1. Article structure block diagram.

2. Training Simulation Sand Table's System Structure

2.1. System Structure

The design of this educational simulation sand table consists of two main parts with seven hierarchical levels, as shown in the Figure 2 below. The two parts are the virtual part and the physical part. The virtual–physical part can be mainly divided into four levels: the control layer, function layer, data layer, and terminal layer, based on their respective functions. The virtual part, which is based on software and data, involves experiments and

exploration. The physical part, which is based on physical models and equipment facilities, emphasizes display and interaction.

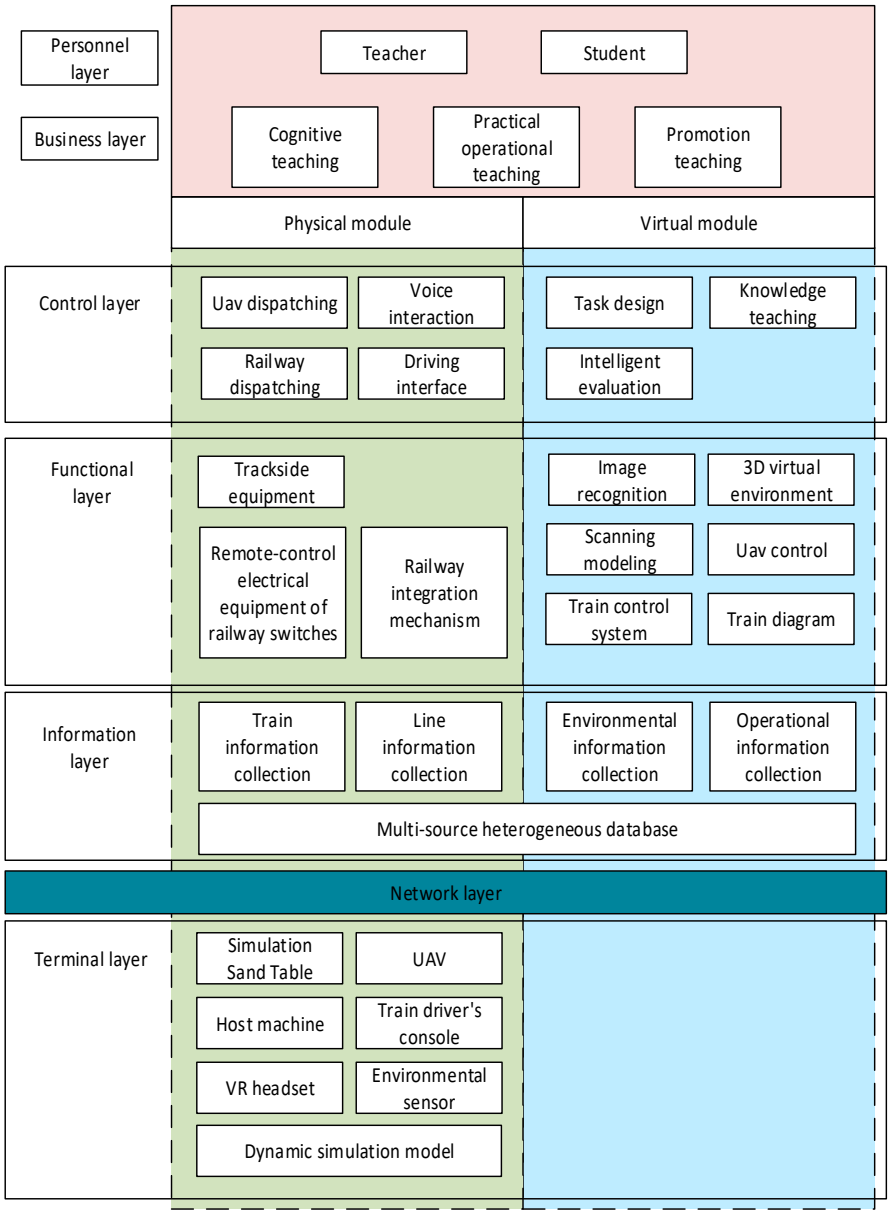


Figure 2. Architecture diagram of virtual and real integrated training.

In addition to the virtual and physical modules, the sand table system also includes the business layer design, the personnel layer design for training participation, and the network layer design. The business layer determines the type of tasks, the personnel layer provides the main training environment, and the network layer facilitates communication between various modules. All of the above ensure the implementation of the experimental process, collectively simulating the production process of the railway production site on the educational simulation sand table.

The Figure 3 mainly describes the interrelationship between the three major objectives and two main modules in the sand table design, consisting of six individual components. The virtual part includes the dispatching module, interlocking module, timetable module, 3D virtual module, line environment perception module, and virtual classroom module. The environment perception module provides more information from a data perspective, thereby providing strong support for the realism and credibility of the sand table model.

The virtual classroom module provides guidance from a training perspective, assisting students in their operations. The physical part includes the sand table, dynamic model, interactive equipment, drone, data sensor, and intelligent interaction module, all working together to enhance the interactive experience and optimize training effectiveness, in conjunction with the intelligent interaction module.

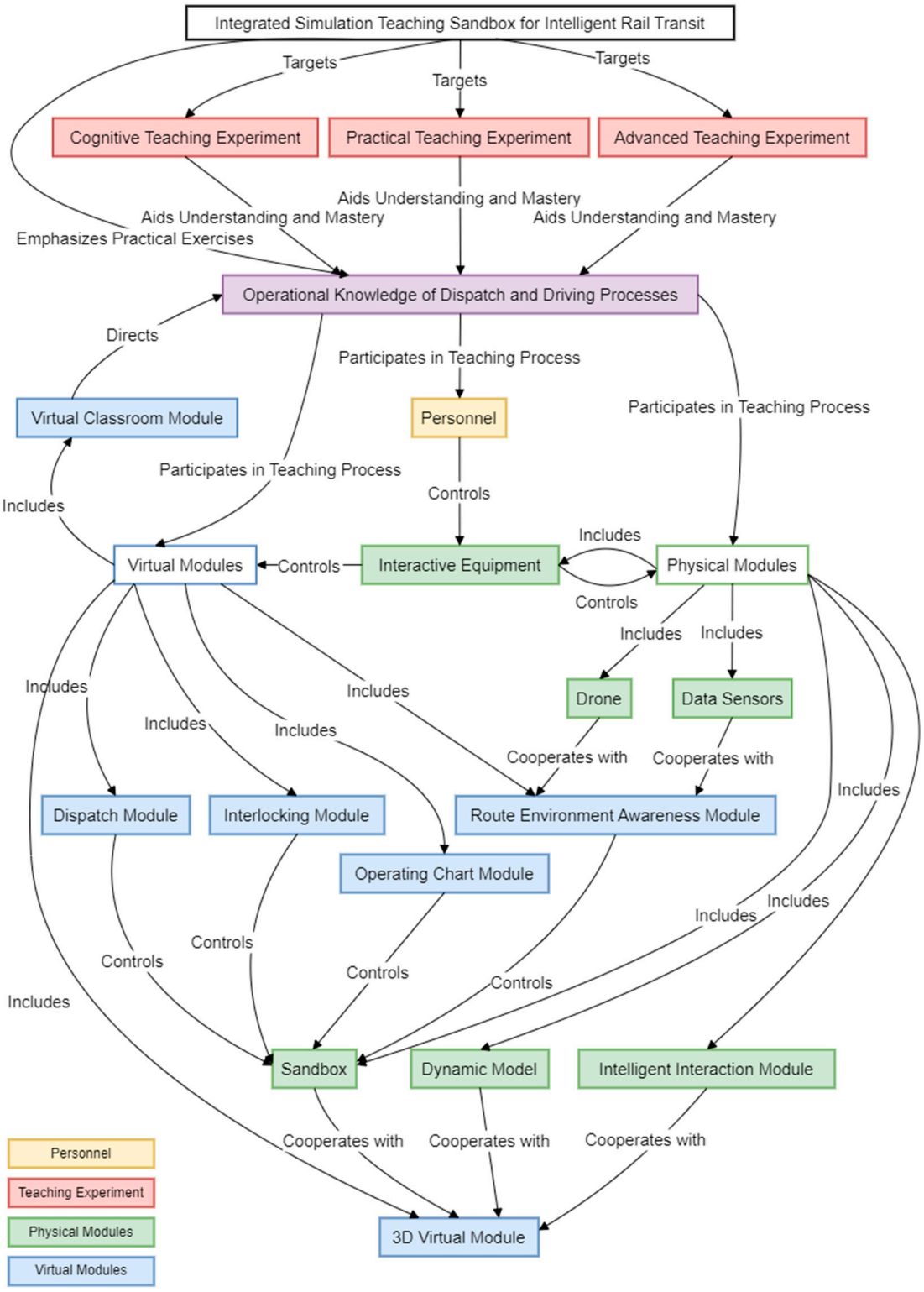
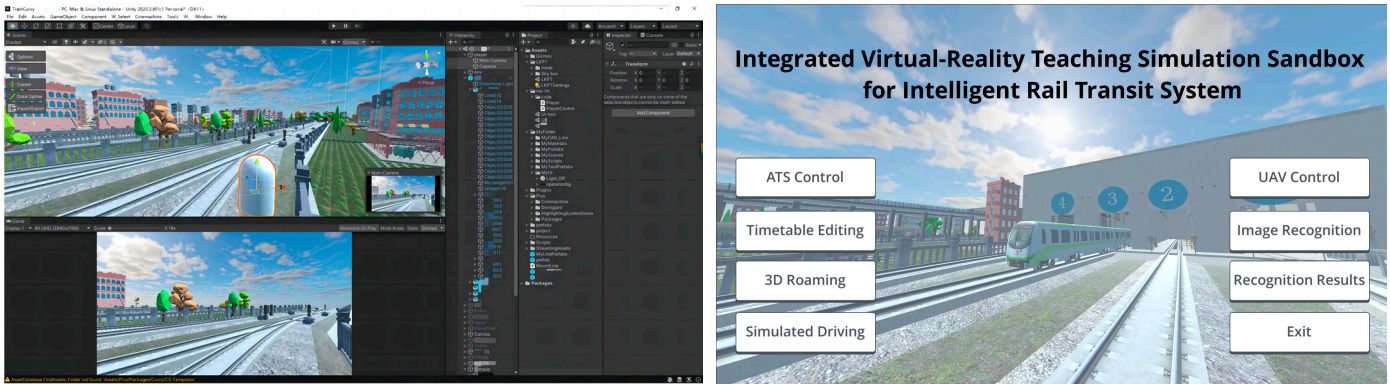


Figure 3. Practical operation training structure diagram.

2.2. Software Integration

The project utilizes Blender for creating 3D models, U3D (as shown in Figure 4a) using the C# language for building the virtual 3D environment and the basic infrastructure system's main page (as shown in Figure 4b), which serves as the sand table startup interface. The page contains eight buttons, each with distinct functions: (1) control ATS interface, (2) activate timetable editing interface, (3) activate 3D roaming interface, (4) activate train driving interface, (5) activate drone control module, (6) activate image recognition interface, (7) activate image recognition results, (8) exit the program.



(**a**) Unity project interface (**b**) System main interface

Figure 4. Virtual 3D environment and UI window interface.

2.3. Drone and Image Recognition Technology

In the current system design, this scheme uses the DJI RoboMaster TT drone (Figure 5) as a demonstration sample. This drone is the second-generation product of the DJI education series drone module. It has a maximum flight time of 13 min and a maximum flight distance of 100 m. It is equipped with a five-megapixel high-definition camera that can capture smooth flight images. Moreover, the drone supports Python3 programming and uses the RoboMaster SDK provided by DJI for application development. The application can easily control the drone's actions such as take-off, landing, turning, and six-axis movement. The application is set in the image detection window. Under the premise of ensuring controllable noise, the drone has an excellent display effect. It can fully demonstrate the application value and advantages of the railway sand table drone detection simulation in the existing environment and conditions, thereby enhancing the attractiveness and persuasiveness of the project presentation.



Figure 5. DJI RoboMaster TT.

The drone's track foreign object intrusion recognition module employs YOLOv5 image recognition technology, a high-performance real-time object detection network based on

PyTorch. Based on YOLOv5 v6.1, YOLOv5 is a high-performance real-time object detection network based on PyTorch 1.6 [15]. It features faster speed and higher accuracy compared to YOLOv4. It is more compact, faster, occupies less space, and provides higher precision. This enables efficient detection of railway environments within video images. An interactive window is designed to define regions for detecting images transmitted by the drone. The detection results are shown in Figure 6. The window allows adjustment of IoU and confidence settings, enabling control over the start, pause, or stop of detection, and limiting the frame rate to avoid lag.

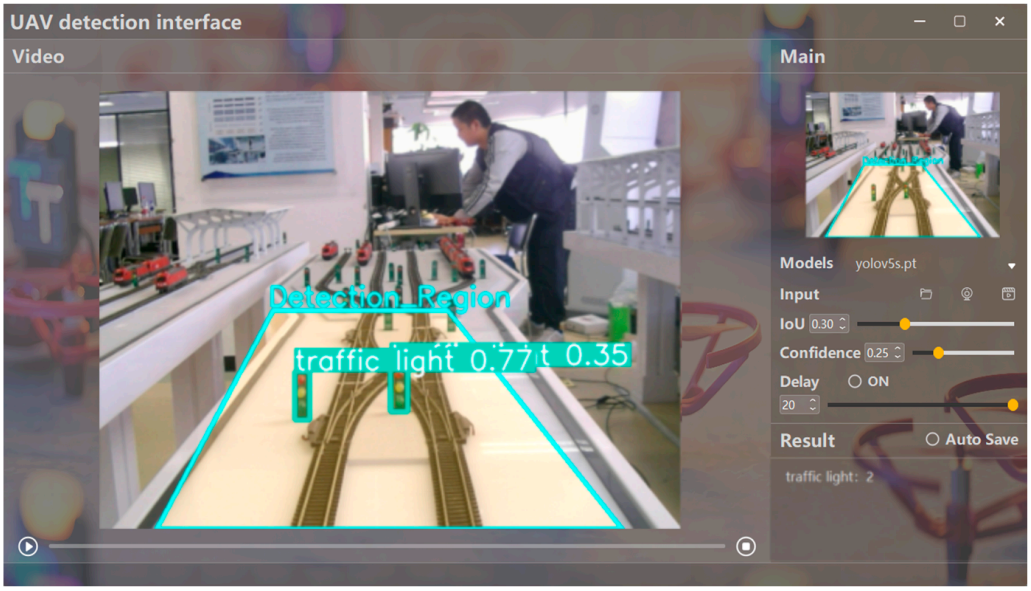


Figure 6. Interactive window based on YOLO v5.

The architecture of YOLOv5 consists of four components: Input, Backbone, Neck, and Prediction [16].

1. The Input component involves feeding image data into the network [17].

It employs the Mosaic technique to reduce computations while retaining image information. YOLOv5 mainly utilizes mosaic data augmentation, which combines four different images into a new image, thereby enhancing data diversity and complexity.

2. The Backbone is responsible for extracting features from the images.

It employs CSPNet as the main network, which is a cross-stage partial network that effectively reduces redundancy in feature maps and improves computational efficiency. CSPNet divides the input feature map into two parts, one directly passing through transformers and dense connection layers to the output, and the other part is added to the previous part after feature extraction, as depicted in the following formula:

$$\mathrm{CSP}(x) = x_1 + \mathrm{ResBlock}(x_2) \text{ where } x_1, x_2 = \mathrm{Split}(x)$$

Here, x represents the input feature map, Split denotes the segmentation operation, ResBlock is the residual block, and $\mathrm{CSP}(x)$ is the output feature map.

3. The Neck fuses features from different levels extracted by the Backbone.

It uses SPP and PAN modules to enhance feature diversity and expression capability.

The PANet layer includes a feature pyramid network (FPN) module and a path aggregation network (PAN) module. The FPN module works by upsampling, downsampling, and merging feature maps of different scales in a top–down and bottom–up manner to obtain multi-scale and high-quality feature maps. The PAN module further fuses and

optimizes the feature maps obtained from the FPN module in a top–down and bottom–up manner, thereby improving detection accuracy and speed. The formulas for the FPN module and the PAN module are as follows:

$$\mathrm{FPN}(x_1, x_2, x_3) = (y_1, y_2, y_3) \text{ where } \begin{aligned} y_3 &= x_3 \\ y_2 &= \mathrm{Upsample}(y_3) + x_2 \\ y_1 &= \mathrm{Upsample}(y_2) + x_1 \end{aligned}$$

$$\mathrm{PAN}(y_1, y_2, y_3) = (z_1, z_2, z_3) \text{ where } \begin{aligned} z_1 &= y_1 \\ z_2 &= \mathrm{Downsample}(z_1) + y_2 \\ z_3 &= \mathrm{Downsample}(z_2) + y_3 \end{aligned}$$

Here, x_i are feature maps of different scales obtained from the CSPNet layer, y_i are feature maps of different scales obtained from the FPN module, z_i are feature maps of different scales obtained from the PAN module, Upsample is the upsampling operation, and Downsample is the downsampling operation.

The SPP layer includes a spatial pyramid pooling (SPP) module [18]. The SPP module performs maximum pooling at different scales on the input feature map and then concatenates them together. This increases the multi-scale information and receptive field of the feature map while keeping the size of the output feature map unchanged. The authors of YOLOv5 improved upon SPP to create SPPF, which is faster while maintaining the same output.

4. Prediction is responsible for outputting detection results.

It employs an anchor-free method, directly predicting the target's center point and dimensions, thereby enhancing detection flexibility.

The CIoU loss function is an improved bounding box regression loss function. It considers not only the IoU (intersection over union) between the predicted box and the ground truth box but also their distance and aspect ratio. The CIoU loss function effectively addresses some problems in bounding box regression, such as excessive convergence, instability, and local optima. The formula for the CIoU loss function is as follows:

$$L_{CIoU} = 1 - IoU + \frac{\rho^2(b, b_{gt})}{c^2} + \alpha v$$

Here, b_{gt} and b_{gt} represent the predicted box and the ground truth box, $\rho^2(b, b_{gt})$ represents the Euclidean distance between their centers, c represents the diagonal length of the smallest enclosing rectangle containing them, v represents their aspect ratio consistency, and α represents the balance coefficient.

3. Training Experiment Procedures

This simulation training sand table creates a scaled-down environment using an HO scale of 1:87. Relevant buildings and landscapes are proportionally scaled down, allowing for rich details within limited space. The simulation equipment, driven by miniature chips and motors, possesses autonomous capabilities, simulating the operation principles of actual railway equipment within the scaled-down environment. This enables the replication of railway workflows on the sand table platform, playing a crucial role in various training activities related to railway courses.

As shown in Figure 7, in this sand table, the control window can exchange data with the sand table, train control system, and UAVs, issuing driving commands. The train control system can control the speed and direction of vehicles on the sand table and is connected to the simulation driving system, facilitating interaction between train operation and simulated driving data. This enables linkage between sand table train operations and simulated driving operations. The drone transmits images to the image recognition program for analysis, allowing for the retrieval of route information.

Moussa ISSA et al. proposed updating the digital twin of railway infrastructure by integrating data from various sources, such as sensors, images, geographic information systems, maintenance records, etc., into a unified data structure. We learned from their ideas and applied them to the design of the sandbox [19]. The design of training participants and network layers is also part of the sand table system. The information collection process of this sand table system includes space, air, ground, and training. Space refers to satellites providing flat two-dimensional information, air refers to drones providing one-dimensional information of the routes and three-dimensional information of buildings, ground refers to ground equipment providing key location information and system status data. The data are divided into vehicle data, route segments, and point information. training information collection targets participant behavior data, including data sets of various types such as instruction issuance speed and instruction execution speed, to assist participants in analyzing and judging route conditions, executing reasonable operations, and summarizing participant behavior information. It provides data evaluation and analysis procedures for behavior appropriateness and execution efficiency analysis, achieving training and learning effectiveness evaluation. The overall structure is shown in Figure 8.

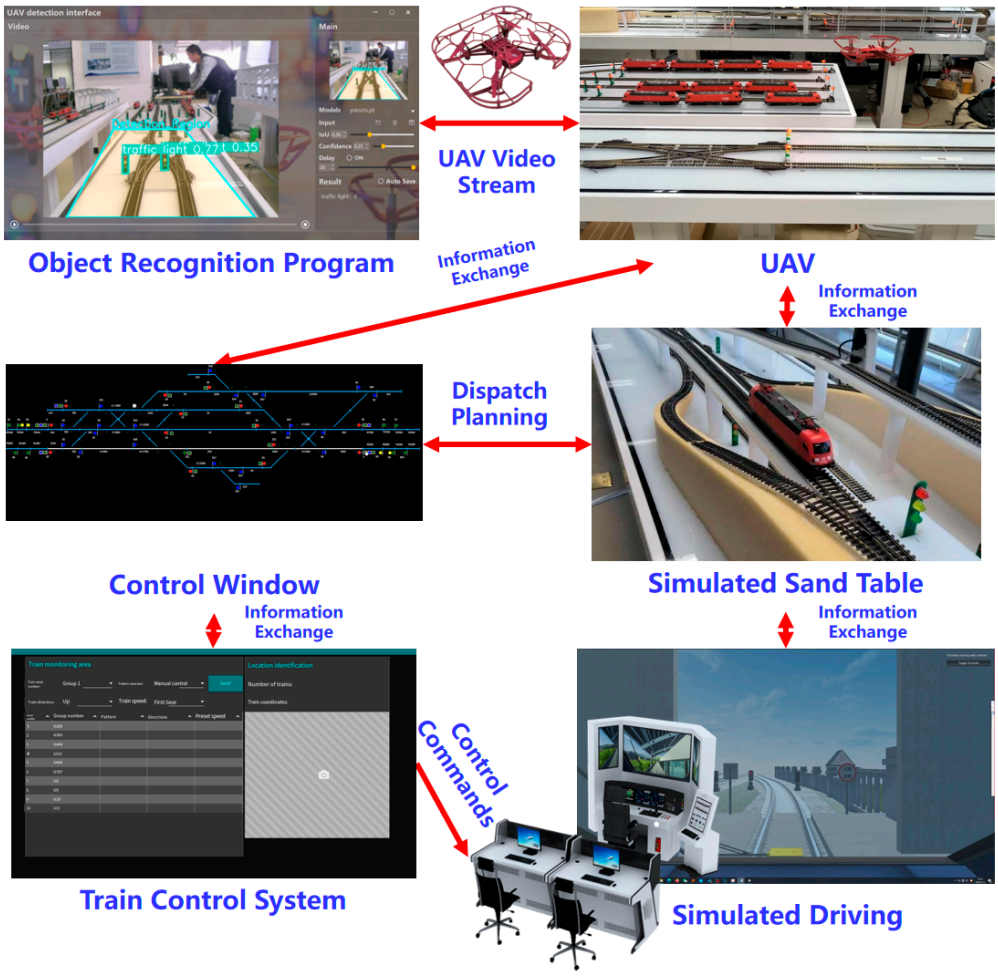


Figure 7. Integrated virtual-reality training simulation sand table.

By designing training content in accordance with real-world operational procedures and systematically invoking different modules, the project has designed three types of training processes: cognitive, practical, and advanced, based on the anticipated construction platform.

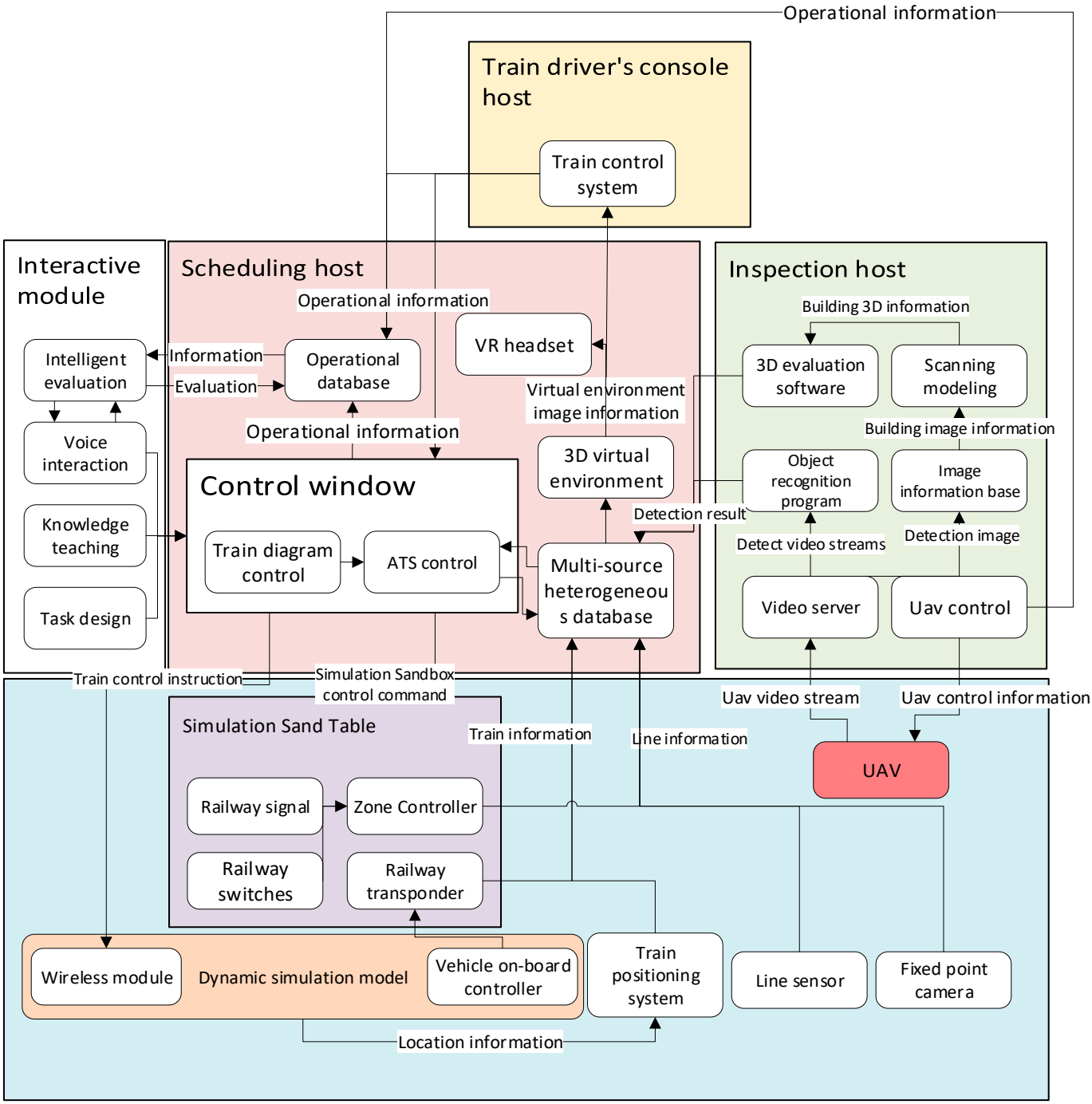


Figure 8. Data transmission structure diagram.

3.1. Cognitive Training Design Principles

The intelligent rail transit virtual and real integrated training simulation sand table can be designed for cognitive training, mainly focusing on training and popularization. The content primarily covers cognitive knowledge about equipment, signals, and operational processes with low human intervention. Five virtual modules and four physical modules are involved in the design of cognitive training processes. This makes the sand table an efficient cognitive training tool for gaining a deeper understanding of rail transit equipment and operational processes (see Figures 9 and 10 for reference). It is designed for individuals, including students, faculty, and visitors, who are new to the field and seek to understand rail transit operations and technology.

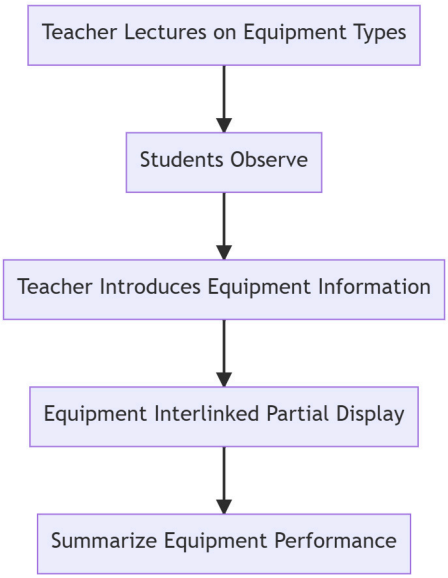


Figure 9. Equipment cognitive training process.

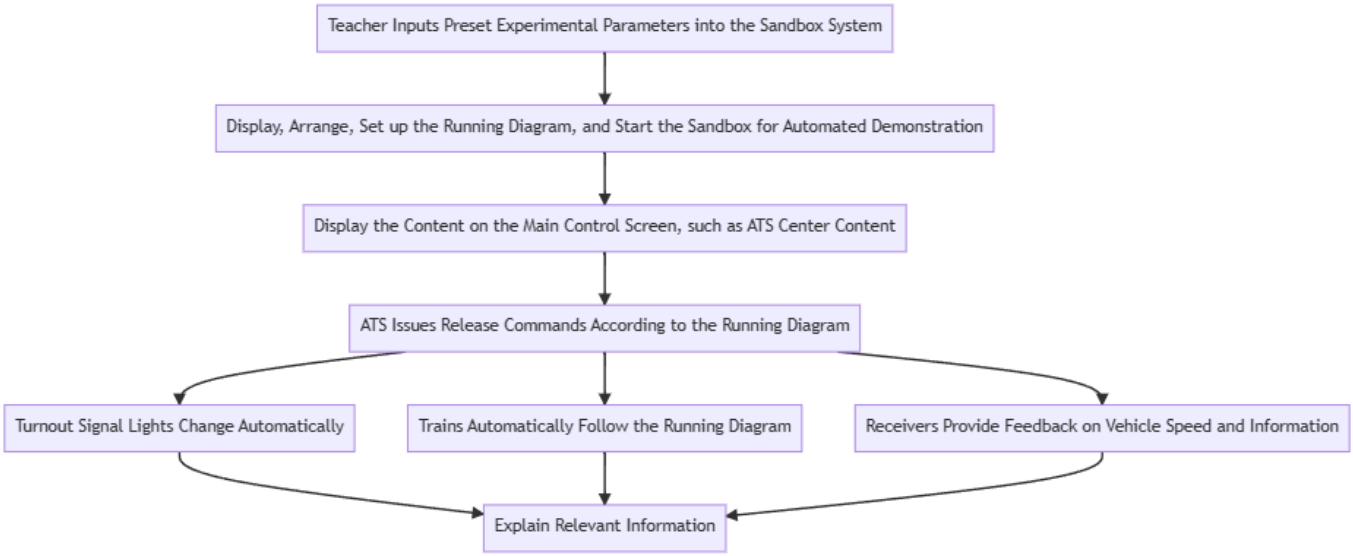


Figure 10. Operation process and cognitive training process.

Figure 9 illustrates the equipment cognitive training process. Its purpose is to provide a detailed explanation of various fixed rail transit equipment in a combined virtual and real environment, leveraging physical objects or three-dimensional models. This helps students understand the basic overview of railway equipment and the fundamental characteristics of different types of equipment. This training process is primarily intended for visitors and students who have limited prior knowledge of the railway industry, as well as railway employees.

Figure 10 depicts the operation process and cognitive training process for rail transit operations. Compared to the equipment cognitive training, this process includes more detailed instruction on the procedures and business principles of railway production operations, delving deeper into the operational logic of railways. It utilizes a movable and scalable real environment to create a three-dimensional virtual environment, designing parameters based on actual production site logic and using the sand table for semi-physical simulation of train operations. This training process goes further than equipment cognitive training by delving into the systems and software currently in use in the field. It is more closely aligned with the production site compared to purely software-based simulations,

hence yielding better training outcomes. This process is intended for visitors, students, and railway employees who already have some familiarity with railway systems, allowing them to gain a deeper understanding and construct a clearer perception of railway production systems.

Throughout the simulation process, teachers preset operational parameters, automatically conduct demonstrations, provide explanatory analyses, and allow students to observe and ask questions. This enables students to intuitively comprehend the potential outcomes of each operation in railway production, as well as to deepen their awareness of the current production status. Following the conclusion of the training process, an assessment of training effectiveness can be conducted through course internship reports.

3.2. Practical Training Design Principles

The intelligent rail transit virtual and real integrated training simulation sand table is designed for practical training, focusing on practical operations, job processes, and realistic experiences related to dispatching and driving procedures. It has strong advantages in training and popularization. It is targeted at beginners and visitors, allowing for basic simulation and popularization introductions. It has a good appeal for younger visitors. Additionally, it provides further training for those with some related knowledge. Utilizing all modules in the sand table, it simulates train operations and virtual scenarios, replicating train operation states and potential safety incidents for training. This includes dispatching operation simulation training, train driving simulation training, drone information gathering training, and emergency response training, as shown in Figures 11 and 12. It enhances the participants' adaptability and crisis management abilities. The practical training process plays a significant role in railway cognitive internships and related courses, providing a highly realistic environment while also being cost-effective and efficient.

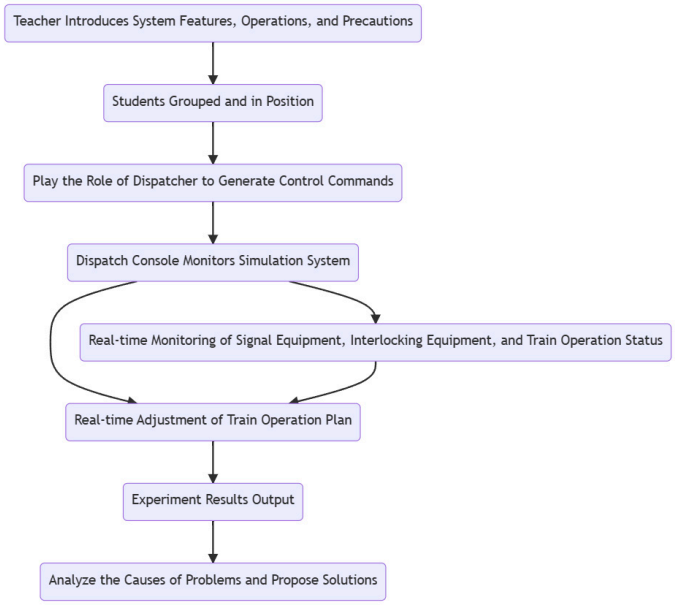


Figure 11. Schedule the job training process.

Figure 11 illustrates a training process designed to enhance students' understanding of train operation patterns, signal systems, train control systems, safety thresholds, and operational efficiency [20]. It simultaneously fosters emergency response capabilities and communication skills. The integrated virtual and real training simulation sand table helps students gain a deep understanding of the principles and necessity of various operations, enabling them to quickly acquire dispatching skills and improve operational efficiency and accuracy. Additionally, this training tool can simulate various situations and anomalies, requiring students to engage in comprehensive dispatching and coordination, thereby

cultivating their overall capabilities and emergency response skills. The integrated virtual and real training simulation sand table not only elevates students' cognitive levels, operational skills, and overall abilities, but also ensures their safety in actual work settings. Therefore, it is an effective training tool that assists students in mastering dispatching skills and enhancing their overall competence.

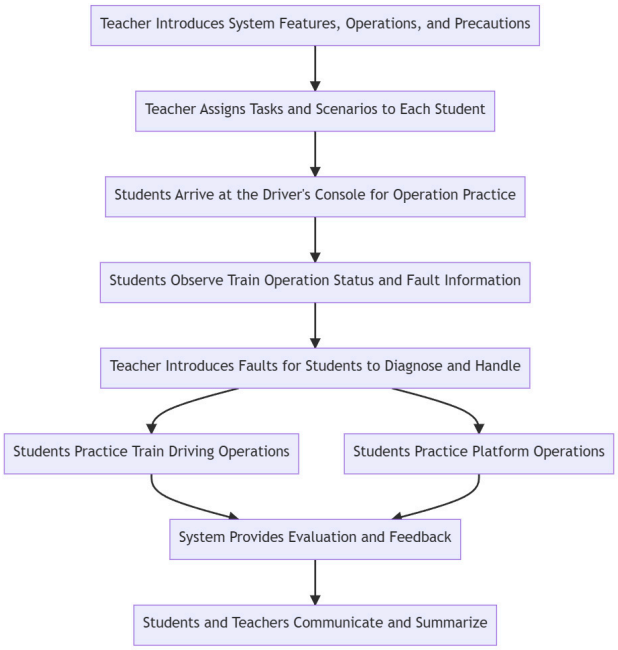


Figure 12. Driving operation training.

Figure 12 presents a training process aimed at enhancing trainees' awareness of operational safety and their adaptability, ultimately elevating their skill levels and operational efficiency in actual driving tasks. The driving operation training within the integrated virtual and real training simulation sand table is an exceedingly effective method for simulating train operation. Students engage in diverse operational exercises in a realistic train driving simulation environment, thereby augmenting their understanding of train driving.

They experience different operational scenarios and tasks under safe and risk-free conditions, cultivating their awareness of train driving safety and adaptability. Simulating emergency train driving procedures aids students in mastering skills for handling urgent situations, fortifying their safety consciousness. Moreover, simulating real train driving operations enhances students' practical capabilities and operational skills, familiarizing them with critical considerations in train driving and heightening their professional competence and driving skills. During platform operations on the simulator, students engage in teamwork, fostering their sense of collaborative effort. In summary, the driving operation training within the integrated virtual and real training simulation sand table is an exceptionally effective method for simulating train driving, improving students' cognitive levels and operational abilities.

3.3. Advanced Training Experiment Design Principles

The intelligent rail transit virtual and real integrated training simulation sand table can be designed for advanced training. This training process mainly focuses on training and research, with a focus on validating results in operations research and practicing engineering. It targets students and faculty members with some participation experience, a certain level of understanding of related system efficiency, and a grasp of some professional knowledge. The platform primarily relies on manual operations and allows for complex and comprehensive simulation experiments. It offers advanced and complex means of input and output. At the same time, the platform uses advanced modules and most

reserved interfaces, allowing for the integration of transportation-related models through interfaces, enabling free modification of content, and facilitating the creation of simulation processes and task designs. This includes setting experimental processes and cases, such as timetable compilation and evaluation (as shown in Figure 13) and drone detection and deployment (as shown in Figure 14).

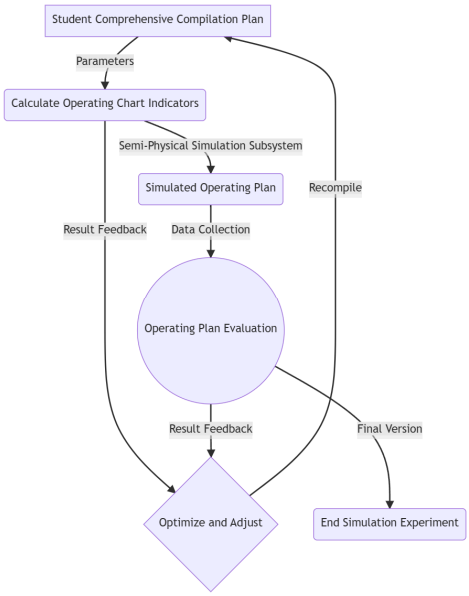


Figure 13. Design the flow of operation parameters independently.

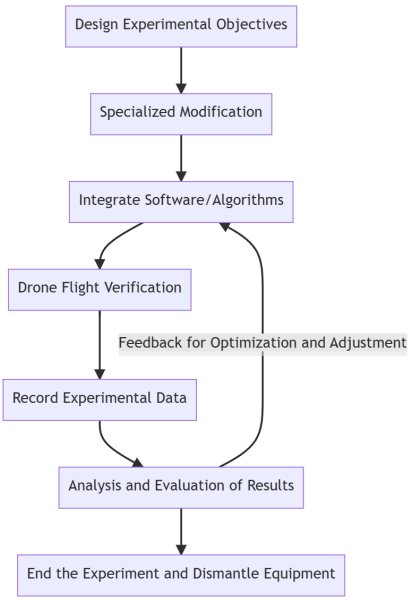


Figure 14. UAV application verification process for intelligent dispatching work.

The enhanced training process builds upon the default training provided by the sand table's basic equipment. Students can adjust preset parameters and schemes to evaluate train operation plans, train schedules, and plan efficiency. They can practically test plan effectiveness, optimize and enhance existing plans, and exercise their innovative capabilities.

The specific process of design the flow of operation parameters independently (as shown in Figure 13) is outlined as follows:

(1) Students compile train operation plans based on experimental objectives and foundational data.

(2) Through the indicator calculation function in the operation compilation module, students analyze and calculate schedule efficiency. They then readjust the plan based on the calculation results.
(3) Using dynamic simulation models on the sand table, students simulate the operation plan, gathering information on equipment occupancy and train operation data. They analyze and calculate relevant data, evaluate it against the indicators, and further optimize it with AI assistance.
(4) Upon completion of the train operation plan design, the simulation experiment concludes.

The specific process of UAV application verification process for intelligent dispatching work (as shown in Figure 14) is outlined as follows:

(1) Students design experimental objectives based on requirements or interests.
(2) Students perform specialized modifications to the sand table equipment or their own devices according to the experimental needs.
(3) Students integrate their independently developed software or algorithms into the platform to drive the sand table for unmanned aerial vehicle (UAV) flight verification, recording target experimental data.
(4) After multiple rounds of data collection, students analyze and evaluate the experimental results, confirming the reliability of the software or algorithm. They then make optimization adjustments based on the feedback from the results.
(5) They compile a comprehensive experimental report, concluding the simulation experiment, and dismantle any externally connected experimental equipment.

4. Experiment Setup and Results

4.1. Experimental Groups

To validate the effectiveness and superiority of the railway transportation training simulation sand table system proposed in this paper, we designed an experiment to compare the effects of different teaching methods on student learning. The experiment involved 60 sophomore students majoring in railway transportation from a certain university, who were randomly assigned to four experimental groups: field teaching group, computer teaching group, classroom teaching group, and experimental system teaching group, as shown in Table 1.

Table 1. Experimental Group Composition and Teaching Methods.

Experimental Group	Relative Knowledge Mastery Level	Relative Operation Skill Level	Relative Learning Satisfaction
Field Teaching Group	90.30%	81.60%	92.40%
Computer Teaching Group	92.10%	86.40%	89.80%
Classroom Teaching Group	88.50%	81.40%	86.40%
Experimental System Teaching Group	95.60%	90.80%	90.60%

Field Teaching Group: Students, under the guidance of teachers, conducted field inspections and operational demonstrations at railway bureaus or stations to observe and experience the actual situation and workflow of railway transportation, but were not able to perform actual operations or practice.

Computer Teaching Group: Students, under the guidance of teachers, conducted experimental operations and practices in the railway transportation laboratory of the school, using the comprehensive training platform for automatic control of trains on computers to carry out actual railway dispatching operations and practices, but without physical demonstrations.

Classroom Teaching Group: Students, under the guidance of teachers, engaged in theoretical teaching and case analysis to learn the basic knowledge and theory of railway transportation, but were not able to perform actual operations or practice, nor experience the actual situation and workflow of railway transportation.

Experimental System Teaching Group: Students, under the guidance of teachers, used the railway transportation training simulation sand table system proposed in this paper for teaching, using computers, sand tables, and UAV equipment to conduct comprehensive simulation operations and practices related to railway transportation, experiencing the actual situation and workflow of railway transportation.

The experiment lasted for two weeks, covering railway equipment teaching, dispatch organization teaching, and train operation planning teaching.

4.2. Experimental Design

Knowledge Mastery Level: Equipment cognitive training (Figure 9) was conducted for students in each experimental group, and after the teaching, a unified theoretical exam was conducted for students in each experimental group, comprising a set of 20 multiple-choice questions and 10 short-answer questions covering basic knowledge related to railway transportation equipment. The exam scores reflected the students' mastery of knowledge.

Operation Skill Level: Schedule the job training (Figure 11) was conducted for students in each experimental group, and after the teaching, a unified practical assessment was conducted for students in each experimental group, involving a comprehensive assessment of basic skills in multiple positions related to railway dispatching. The assessment scores reflected the students' level of skill application.

Learning Satisfaction: After the overall course teaching ended, a questionnaire survey was conducted for students in each experimental group, covering their satisfaction with the teaching methods, including the effectiveness of teaching methods (weighted value 4), satisfaction with teaching effects (weighted value 3), interest in teaching content (weighted value 2), and comfort of teaching environment (weighted value 1). The questionnaire used a five-point scale, with higher scores indicating higher satisfaction.

Learning Financial Cost: During the teaching process, the learning financial cost for students in each experimental group was recorded, including the purchase cost of teaching equipment, the rental cost of teaching venues, the salary cost of teaching personnel, and the cost of teaching materials consumption, etc.

Learning Time Cost: During the teaching process, the learning time cost for students in each experimental group was recorded, including the time spent on course arrangement, experimental operation, and travel time to the course venue, etc.

4.3. Experimental Conclusions

To compare the effects of different teaching methods on students, data tables and graphs were generated (Figures 15 and 16).

From the Table 2. and Figure 15, it can be seen that the Experimental System Teaching Group performed the best in terms of knowledge mastery level and operation skill level, with significantly higher scores than the other three experimental groups. This indicates that the railway transportation training simulation sand table system proposed in this paper can effectively improve students' learning effects on knowledge and skills related to railway transportation. The Computer Teaching Group ranked second in terms of knowledge mastery level and operation skill level, higher than the Field Teaching Group and Classroom Teaching Group, indicating that virtual reality equipment can simulate actual situations and operational scenarios of railway transportation well, enhancing students' interest and learning effects. The Field Teaching Group ranked third in terms of knowledge mastery level and operation skill level, slightly higher than the Classroom Teaching Group, indicating that field teaching can allow students to intuitively experience the working environment and workflow of railway transportation, conducive to knowledge consolidation and application, but limited by the inability to personally operate on-site. The Classroom Teaching Group performed the worst in terms of knowledge mastery level and operation skill level, with scores lower than the other three experimental groups, indicating that the classroom teaching method lacks practical elements, making it difficult to stimulate students' learning motivation and effects.

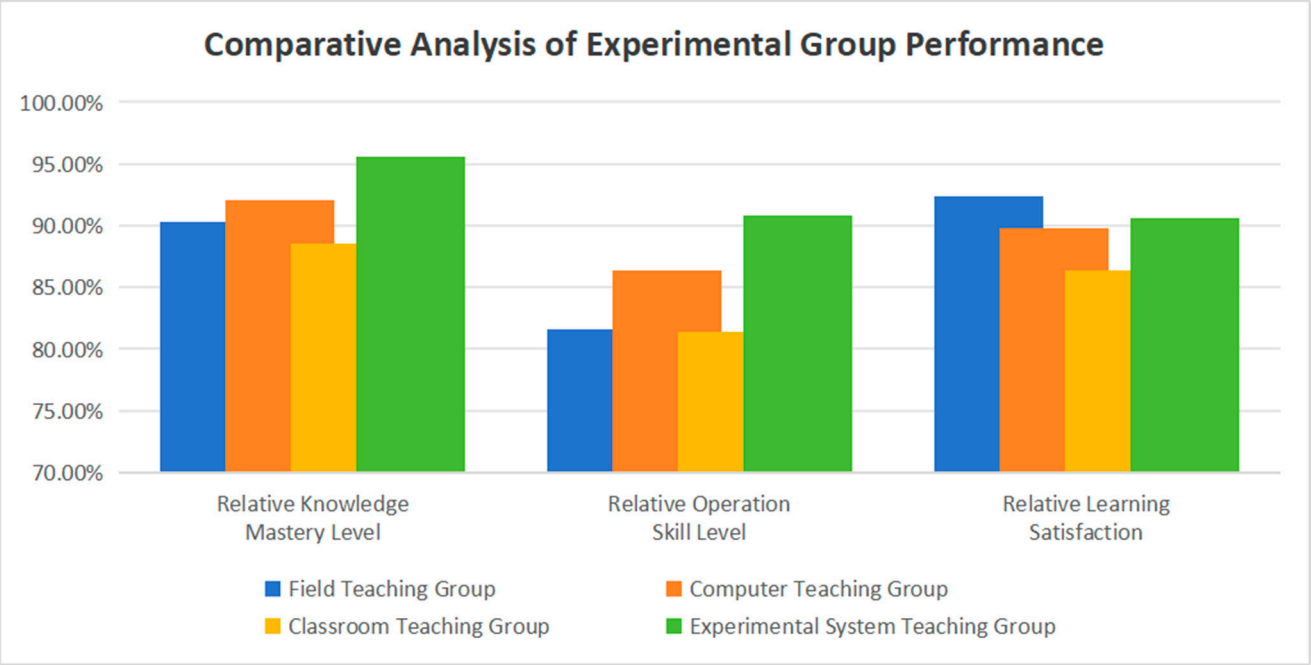


Figure 15. Comparative analysis of experimental group performance.

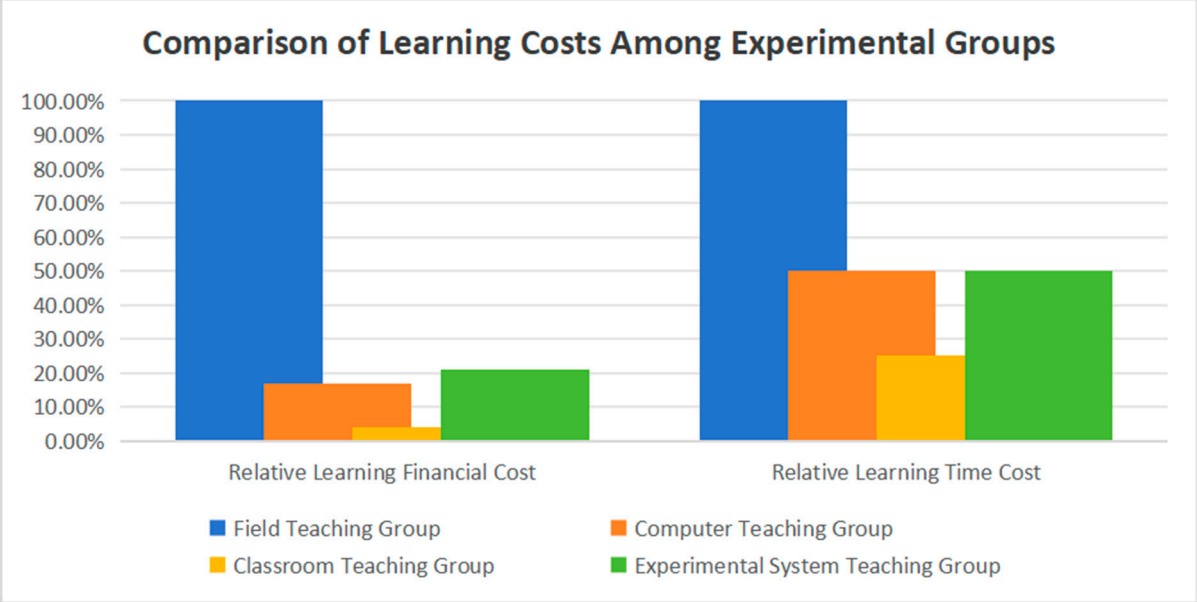


Figure 16. Comparison of learning costs among experimental groups.

Table 2. Comparative Analysis of Experimental Group Performance.

Experimental Group	Relative Knowledge Mastery Level	Relative Operation Skill Level	Relative Learning Satisfaction
Field Teaching Group	90.30%	81.60%	92.40%
Computer Teaching Group	92.10%	86.40%	89.80%
Classroom Teaching Group	88.50%	81.40%	86.40%
Experimental System Teaching Group	95.60%	90.80%	90.60%

In terms of learning satisfaction, the Field Teaching Group scored the highest, followed by the Experimental System Teaching Group, Computer Teaching Group, and Classroom

Teaching Group. This indicates that field teaching methods can provide students with the most satisfying learning experience because they expose students to real railway systems, stimulating their interest and curiosity. The Experimental System Teaching Group and Computer Teaching Group also achieved high scores, indicating that practical operation, compared to classroom teaching, can give students more participation and provide them with a satisfactory learning experience, better meeting students' learning needs and expectations.

From the Table 3 and Figure 16, it is evident that in terms of learning financial cost, the Field Teaching Group had the highest learning financial cost, followed by the Experimental System Teaching Group, Computer Teaching Group, and Classroom Teaching Group. It can be seen that field teaching methods require students to spend the most on learning financial cost because they involve transportation costs and time to railway bureaus or stations, expert salary costs, and production site maintenance costs, etc. The Experimental System Teaching Group and Computer Teaching Group had relatively low learning financial costs because they only need to purchase or lease teaching equipment once for long-term use, and the service life of teaching equipment is long with low maintenance costs, but the time still includes experimental time for actual demonstrations and operations. The Classroom Teaching Group had the lowest learning financial cost because it only required basic teaching resources such as classrooms and teaching materials, but the teaching effect was also the least satisfactory.

Table 3. Comparison of Learning Costs Among Experimental Groups.

Experimental Group	Relative Learning Financial Cost	Relative Learning Time Cost
Field Teaching Group	100.00%	100.00%
Computer Teaching Group	16.84%	50.00%
Classroom Teaching Group	4.21%	25.00%
Experimental System Teaching Group	21.05%	50.00%

Regarding learning time cost, the Field Teaching Group had the highest learning time cost, followed by the Experimental System Teaching Group, Computer Teaching Group, and Classroom Teaching Group. This indicates that field teaching methods require the most time for students due to transportation, expert guidance, and on-site observation. The Experimental System Teaching Group and Computer Teaching Group had relatively lower learning time costs because they mainly involved practical operation and simulation, although they still required time for experiments. The Classroom Teaching Group had the lowest learning time cost because it only involved classroom teaching without practical operations.

In conclusion, the experimental results demonstrated that the railway transportation training simulation sand table system proposed in this paper effectively improved students' learning effects on knowledge and skills related to railway transportation. Practical teaching methods, such as the experimental system teaching group and computer teaching group, achieved better results compared to traditional teaching methods, such as field teaching and classroom teaching. Additionally, the experimental system teaching group showed the highest satisfaction among students, indicating the effectiveness and superiority of the proposed simulation sand table system in railway transportation training.

5. Conclusions

This design, based on the comprehensive practical training platform for train automatic control, incorporates 3D simulation technology and computer technology. It introduces various types of equipment including drones, cameras, and driver's cabins. Developed using C# and Python languages, with Blender and U3D, the design includes multi-terminal data transmission and communication logic. It constructs a composite integrated database. Tailored for training and experimentation, the intelligent rail transit virtual and real in-

tegrated simulation training sand table is comprehensively designed and developed. It can be applied to training in related rail transit professional courses, effectively reducing training costs and improving the practical training quality of railway operation and management talents, meeting the requirements for talent development in the railway and related industries under new circumstances.

In the future, the development of rail transit sand tables should focus on further intelligence, datafication, and informatization. Regarding physical sand tables, it is more suitable to enhance the transformation of dynamic simulation models for railways to obtain more accurate data and adjust control methods more reasonably, thereby enhancing display effectiveness. As for virtual simulation platforms, it is more suitable to develop independent systems in the future, improving user experience, optimizing human–computer interaction effects, adding experimental functions, exploring more task directions, and enhancing the application effectiveness of the sand table.

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Institutional Review Board Statement: The study conducted in this paper primarily focuses on the utilization of a comprehensive simulation training sand table system for railway transportation training purposes. The research involves teaching experiments with four groups of fifteen participants each, aiming to evaluate the system's efficacy in enhancing the practical ability training quality of railway operation management personnel. As the study solely pertains to railway transportation education and does not involve medical experiments or pose any risk of harm to participants, ethical review and approval were deemed unnecessary. Therefore, ethical review and approval were waived for this study.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: The authors declare no conflict of interest.

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