A Modular Track and Signaling Simulation Trainer for Railway Technology Program

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Abstract
The modular railway track and signaling simulation trainer research project was developed to provide an enjoyable and educational tool to train railway students and professionals upon recognizing the need for effective training in traffic and signaling safety-critical areas. It provides a miniature model that accurately replicates railway switch points and signaling systems with modules depicting track layouts and signaling conditions created using Programmable Logic Controller (PLC) and Human-Machine Interface (HMI). The prototype's accurate and efficient miniature railway model showed that the simulation trainer was very effective. The survey demonstrated that railway students and professionals were satisfied with the trainer's performance and various use and educational potential for students. This simulation trainer design successfully changes railway training programs because it offers a relatively safe and exciting environment that allows learners to get practical experience and understanding of railway operations. The modular design of the trainer will facilitate future expansion and customization, making it adaptable to railway training needs and technology. The simulation trainer should include level crossings, track circuits, and train detection systems for further investigation. This would provide an improvement in the comprehensiveness and flexibility of the trainer, therefore helping with providing skilled railway workers.

1. Introduction

In the railway industry, 'control, command, and signaling' (CCS) refers to onboard and trackside systems and equipment providing train safety, train traffic management, and train separation (Pachl, 2021). The system includes over 40,000 lineside signals and a variety of technology to control train movements. Trains are 'rolling stock'. It includes many service and track maintenance trucks. Britain has over 16,000 rail trucks. The majority are passenger units, carriages, locomotives, freight wagons, and locomotives. Cranes and maintenance trucks are used for engineering, freight, and accident recovery. Ding et al. (2023) emphasize the need to proficiently manage and sustain this varied rolling stock to guarantee railway operations' overall efficiency and dependability.

Different methods have been suggested to promote students' logical thinking in problem-based learning (Raiyn, 2016). Visual learners employing advanced instructional approaches can benefit from this in explaining railway operations. Insufficient instructional resources may affect students' learning and performance. Students do not understand railway operations since there are no instructional materials. The proposed prototype would allow inspection, and training materials would familiarize railway students with operating procedures. It can facilitate and help students identify railway issues, provide solutions, and propose enhancements. The instructional model shows how switch points, signaling, and controllers work. The goal is to explain the importance of railway activities to railway and non-railway technical students.

The College of Industrial Technology, which offers the Railway Technology Program, lacks teaching resources for railway operations, so the researchers created a scale model. The railway curriculum lacks teaching resources for railway operations, affecting students' understanding of the process and sometimes resulting in ineptitude in industry. The perceived solution is the "Development of Modular Track and Signaling Simulation Trainer." The simulation of railway operations will assist and facilitate the student's learning of the modular track and signaling processes.

1.1 Literature Review

1.1.1 Simulation and Signaling Systems in Railway Operations

Railways are constantly innovating to improve efficiency, safety, and reliability. In their comprehensive review of railway control systems, Ding et al. (2023) highlight simulation for training and robust signaling system development as essential subjects. Railway workers need simulations, notably operator training simulators, to understand and navigate the railway system. They provide a safe, controlled learning space for training in system principles, reacting to various situations, and making critical decisions to enhance operational safety and efficiency. Signaling systems are vital to train safety and efficiency. Huang et al. (2021) discuss railway signaling and control technology development, emphasizing the importance of automation and intelligence for increased capacity, decreased delays, and safety improvement.

Rail operators need operator training simulators to comprehend and control operational challenges. According to Cielo et al. (2018), simulation-based rail training offers a safe and controlled learning environment where students may learn by doing and acquire some key abilities without the risks involved in real operations. Learning to behave when crises and emergencies unfold requires fast and accurate decision-making.

Modern simulators can simulate routine operations, equipment failures, bad weather, and passenger emergencies. This exposure to numerous situations helps learners gain confidence and skills. Trainees may learn and make mistakes without consequences. Active learning and many problem-solving methods are encouraged. Simulations give quick feedback on student performance, enabling concentrated improvement and skill development. Although simulator technology may be expensive, the long-term benefits of increased safety, fewer accidents, and better operational efficiency generally outweigh it.

Simulators improve individual and team abilities, fostering communication and collaboration among operational people. Dispatchers and signal operators must work together for railway safety and efficiency. Simulation technology in railway training can provide a highly trained and capable workforce to meet modern railway operations.

1.1.2 Signaling Systems and Intelligent Traffic Control

Signaling systems underpin safe and efficient railway operations. Sun et al. (2023) note that train control systems communicate between train operators and track infrastructure, controlling train movements, maintaining safe distances, and preventing accidents.

Technology is vital in signaling systems. Ahlstrom et al. (2012) study how train operators perceive and interpret signal information and create ways to decrease human error and improve human-machine interaction. Vinayagam et al. 2023 Signaling network failures may be severe. Thus, considerable research focuses on designing reliable systems with redundancy, fault tolerance, and strict testing processes.

Modern signaling systems, such as moveable block and Communication-Based Train Control, are replacing fixed-block systems. Train detection sensors, wireless connectivity, and computer-based interlocking increase modern systems' capacity, operational flexibility, and safety (Liu et al. 2022; Pachl 2021). Modern signaling systems have auxiliary systems like Automatic Train Protection (ATP) and Automatic Train Operation (ATO) to have a holistic train control system. This link improves railway safety, efficiency, and automation.

Railway networks require signalling systems to operate safety and effectively. Current research and development are attempting to improve the capability, reliability, and integration of signaling systems and other systems in accordance with modern railway requirements.

Advance systems such as moving blocks can utilize the development of intelligent signaling systems so that higher transportation capacities along with optimized train operations are achieved. These systems need to reduce the train headway and minimize the delays through prediction control and through improvement of the train operating curves. Such advanced systems, while they necessitate the replacement of already laid-out infrastructure, bring long-term efficiency and capacity benefits justifying the investment.

1.1.3 Technology in Railway Maintenance

Technology is supporting railway maintenance shift from reactive to proactive and predictive procedures. According to the review of Almeida et al. (2023), an AI and machine learning application in railway maintenance, integrating these technologies into the system enables railway companies to adopt condition-based monitoring and predictive maintenance, improving fleet reliability, operational efficiency, and safety.

CBM sensors and data-collecting devices continuously observe rails, rolling stock, and signaling equipment. Real-time data helps unveil irregularities and probable failures so that maintenance can occur before turning into costly breakdowns or safety hazards. Khan & Ahmed, 2024.

Artificial intelligence and machine learning algorithms predict component and system lifespans using maintenance data, sensor readings, and operational parameters. This optimizes maintenance schedules to reduce downtime and optimize asset utilization (Liu et al., 2022). Predictive maintenance improves scheduling, reducing unnecessary maintenance and downtime. This significantly reduces human, material, and operational disruption costs (Zhao et al., 2023).

The AI-driven maintenance system prevents failure and accidents by proactively identifying and managing potential issues. AI-driven maintenance solutions improve efficiency and service reliability in operations by preventing downtime, thereby ensuring the proper functioning of railway equipment (Sharma et al., 2023).

1.2 Objective of the Study

The main objective of this study is to construct an instructional mini-model that clearly explains the working mechanism of switch points and signaling in railway systems. This mini-model should help students understand these crucial railway operations both within and outside the classroom.

Specifically, the study aims to:

1. Design the Instructional Miniature Model with the following controls:
    1. Rocker switch that supplies the track's power
    2. Toggle switch to control the switching position of the turnouts that is integrated with the wayside signal's status
    3. Controller for the train's speed
    4. Human Machine Interface (HMI) that selects the mode of operation (manual/automatic)
2. Construct an Instructional Miniature Model with the following features:
    1. Electric train tracks that power the train with speed regulation

    2. Functional switch point for signaling that is controlled by a toggle switch
    3. Automated wayside signal for the "GO and STOP" operation of the train
    4. Provide a Human Machine Interface (HMI)
    5. Provide an instructional manual
3. Test the usability of the Instructional Miniature Model by:
    1. Conducting a test with the help of professors and railway expert
    2. Create a scenario and provide materials to test the functionality of the features
4. Evaluate the prototype's performance in terms of Functionality, Aesthetics, Workability, Durability, Economy and Safety.

2. Research Methods

This research aims to develop a modular track and signaling simulation trainer for the railway industry. The study focuses on creating a miniature model that effectively demonstrates the operation of switch points and signaling in railway systems. The methodology encompasses project design, development, operation, and testing procedures, along with an evaluation system to assess the effectiveness and usability of the developed trainer.

2.1 Project Design

The modular track and signaling simulation trainer is designed as an instructional tool for railway personnel, particularly students and trainees. The model incorporates various components of a railway system, including switch points, signals, and a train, to provide a comprehensive understanding of railway operations. The miniature model is controlled by a Programmable Logic Controller (PLC) and a Human Machine Interface (HMI), allowing for both manual and automated operation.

2.2 Project Development

The development of the simulation trainer involves the following key sections:

1. Chassis Section: This section comprises the base structure of the trainer, constructed using plywood and lumber wood.
2. Train Control Section: This section includes a speedometer to control and monitor the train's speed.
3. Railway Track Section: This section consists of different modules representing various track configurations, including straight tracks, single turnouts, and diamond turnouts.
4. Signaling Section: This section incorporates LEDs to simulate wayside signals, providing visual cues for train operation.
5. Human Machine Interface (HMI) Section: This section includes an HMI touchscreen for monitoring and controlling the simulation trainer.

2.3 Fabrication and Assembly Procedure

The fabrication and assembly procedure involves constructing the chassis section, preparing the HMI for the train monitoring system, and setting up the train speed controller.

2.4 Operation and Testing Procedure

The operation procedure includes steps for powering the device, controlling the train's speed, monitoring the system, and ensuring proper functionality of the railway turnouts and signals. The testing procedure involves evaluating the train speed control, the functionality of each module, and the overall performance of the Human Machine Interface (HMI).

2.5 Evaluation Procedure

The evaluation procedure involves a survey to assess the performance of the prototype. The survey was conducted with 30 respondents, including railway students and professionals. The evaluation was based on a

Likert Scale, considering factors such as functionality, aesthetics, workability, durability, economy, and safety.

3. Results and Discussion

Successful development and testing of the modular track and signaling simulation trainer demonstrate its teaching value for railway experts. The little model provides a fascinating understanding of switch locations, signaling systems, and train control. PLC and HMI integration provides human and automated operation, increasing trainer flexibility and training opportunities.

Although it has tremendous potential, the simulation trainer itself has many limitations. Some technical complexities will likely not be completely represented in the miniature model because it is a simplified version of a real railway system. Further study may be possible in the future on integrating additional railway components and services, like level crossings, track circuits, and train detection systems. As such, the current prototype focuses extensively on switch points and signaling.

Building the simulation trainer was quite a test for creative problem-solving and thinking. Introducing a PLC and HMI into such a small model could only be done with a thorough examination of the communication protocols and programming logic. The trainer's modular design adopts a new approach to training, so it can be extended or even modified according to the widening training needs and technological progress in the railway industry.

This research enhances railway training and education by using a simulation trainer as a practice tool that increases the knowledge and skills of railway employees. The simulation trainer creates a controlled environment whereby students may practice what they have learned and improve their analytical abilities, leading to safer and more efficient train operations.

The research thus clearly demonstrates that a substantial tool for railway training and education was successfully developed. Enhanced training of competent railway personnel will lead to safer and more efficient railway operations, and the modular track and signaling simulation trainer is destined to make that happen.

The positive evaluation survey result confirms the trainer's effectiveness and usefulness. The prototype's utility, attractiveness, operability, durability, cost-effectiveness, and safety satisfied the respondents, suggesting it may improve railway training programs.

4. Conclusions

The modular track and signaling simulation trainer serves its functions as a teaching tool for railway students. The little model effectively shows how switch points and signaling work in railway systems, therefore improving trainee knowledge and understanding. Modern technologies like PLC and HMI greatly enhance trainer flexibility and the learning process. The evaluation results confirm the effectiveness and applicability of the produced trainer. The simulation trainer provides a safe, exciting, and comprehensive learning environment, which might improve railway training programs. The trainer's modular architecture guarantees its adaptability to evolving training needs and technological advancements in the railway industry, therefore enabling future expansion and modification. The study shows how successfully a major tool for railway education and training is created. The modular track and signaling simulation trainer is designed and developed to improve the training of qualified railway experts, enhancing railway operations' safety and efficiency.

5. References

Ahlstrom, D., Kirwan, B., & Strayer, D. L. (2012). Effects of simulator practice and real-world experience on train engineers' performance and eye movements in signaling tasks. *Human Factors*, *54*(6), 968-981.

Almeida, D., Cavalcante, L., & Moreno, A. (2023). Artificial intelligence and machine learning applied to railway maintenance: A systematic literature review. *Journal of Intelligent Transportation Systems*, *27*(3), 308-328.

Cielo, J. A., Fawcett, C., & Gibb, R. (2018). Simulation-based training in the rail industry: A review. *Ergonomics*, *61*(5), 618-633.

Ding, Y., Li, S., & Zhang, Y. (2023). A review of railway control systems: From conventional to intelligent. *Transportation Safety and Environment*, *5*(1), 100189.

Huang, K., Li, Z., & Kang, S. (2021). Railway signaling and control technologies: A comprehensive review. *IEEE Transactions on Intelligent Transportation Systems*, *22*(12), 7667-7685.

Khan, M. A., & Ahmed, A. (2024). Condition-based maintenance of railway tracks using IoT and machine learning. *In 2024 International Conference on Electrical, Computer and Energy Technologies (ICECET) (pp. 1-6). IEEE*.

Liu, Y., Zhao, X., & Liu, Z. (2022). A digital twin-driven production logistics synchronization system for smart manufacturing. *Computers & Industrial Engineering*, *172*, 108416. https://doi.org/10.1016/j.cie.2022.108416
Liu, Y., Zhao, X., & Liu, Z. (2022). A digital twin-driven production logistics synchronization system for smart manufacturing. *Computers & Industrial Engineering*, *172*, 108416. https://doi.org/10.1016/j.cie.2022.108416
Pachl, J. (2021). Railway operation and control (2nd ed.). Springer.

Raiyn, J. (2016). The role of visual learning in improving students' high-order thinking skills. *Journal of Education and Practice*, *7*(25), 115-121.

Sharma, S. K., Bhatia, M., & Dhir, S. (2023). Cloud computing for maintenance of railway signalling systems. *FUDinfo*.

Sun, Q., Cai, W., & Zhang, K. (2023). A survey on train control systems: Architectures, technologies, and challenges. *IEEE Transactions on Intelligent Transportation Systems*, *24*(7), 6792-6811.

Vinayagam, S., Shaji, S., & Arun, J. (2023). Reliability analysis of railway signalling system using fault tree analysis. *In 2023 7th International Conference on Computing Methodologies and Communication (ICCMC) (pp. 870-874). IEEE*.
Vinayagam, S., Shaji, S., & Arun, J. (2023). Reliability analysis of railway signalling system using fault tree analysis. *In 2023 7th International Conference on Computing Methodologies and Communication (ICCMC) (pp. 870-874). IEEE*.
Zhao, X., Li, L., & Sun, Y. (2023). Predictive maintenance of high-speed train bogies based on deep learning. *IEEE Transactions on Intelligent Transportation Systems*, *24*(1), 770-780.