CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Railway Level Crossing System

Railway level crossings are designated points where rail tracks intersect roads or pedestrian pathways at the same grade. These intersections are common in many countries and play a pivotal role in linking rail and road networks. However, their presence also poses significant safety challenges, especially in developing countries like Nigeria where infrastructure maintenance and safety mechanisms are often inadequate. Traditionally, most level crossings have been manually operated, relying on human attendants to lower or raise gates based on train movement. While this system has worked for decades, its limitations are becoming increasingly evident with growing traffic volumes (Eze et al., 2018).

Manual operations are susceptible to human errors such as fatigue, distraction, negligence, and delayed responses. These factors increase the risk of accidents at crossings. According to Afolabi and Gbadamosi (2017), many train-vehicle collisions in Nigeria occur due to late gate closures and the absence of warning systems. Additionally, the lack of standard signaling devices and poor visibility further compound the risks at such junctions.

Globally, many countries have modernized their railway crossing infrastructure by adopting automated systems that reduce or eliminate the need for human intervention. These systems not only improve operational efficiency but also drastically reduce accident rates. They incorporate real-time monitoring and faster gate responses, significantly improving road safety (Nwachukwu & Okonkwo, 2019).

In the Nigerian context, where the railway network is undergoing revitalization, the modernization of level crossings is essential. With new trains operating at higher speeds and increased road traffic in urban centers, traditional manual gate systems are no longer sufficient. There is a clear need for the integration of smart, automated systems to manage railway crossings more effectively and safely. This research contributes to this need by proposing a functional prototype for an automated railway crossing.

2.2 Automation and Sensor-Based System

Automation in railway level crossing systems involves the use of sensor technologies and programmed logic to control crossing gates, lights, and alarms without human intervention. The objective is to ensure timely gate operations and real-time alerts for vehicles and pedestrians, thereby minimizing accidents. The system typically includes train-detecting sensors, microcontrollers for processing data, and output components such as servo motors and buzzers for barrier control and alerts (Singh & Raj, 2020).

Sensor-based systems are pivotal to the automation process. Infrared (IR) sensors, ultrasonic sensors, and magnetic field detectors are among the most widely used technologies. These sensors detect the presence and speed of approaching trains at a distance and send signals to the microcontroller. Based on programmed logic, the system initiates the warning phase—activating visual (LEDs) and auditory (buzzers) alarms—before closing the gate via motorized arms (Ahmed et al., 2021).

One of the key advantages of automation is the reduction of human error, a leading cause of accidents at manually operated crossings. Automated systems also enhance operational speed and reliability, which is particularly beneficial in areas with high train frequency. Moreover, automated crossings can operate continuously and uniformly, making them ideal for remote or rural areas where personnel may not be available at all times (Umar & Babalola, 2020).

In many parts of the world, such as India and parts of Europe, sensor-based automated level crossings have proven effective in significantly lowering accident rates (Okonkwo et al., 2021). Despite their proven efficacy, the adoption of these technologies in Nigeria remains limited, largely due to cost, technical expertise, and infrastructure challenges. However, with the increasing availability of low-cost components and open-source platforms, such as Arduino, the development of affordable, sensor-based railway crossing systems is now more achievable than ever.

2.3 Microcontroller-Based Control System

Microcontrollers are compact, programmable computing devices that are widely used in embedded systems. In the context of railway automation, microcontrollers act as the brain of the system, processing input from sensors and executing programmed responses, such as closing or opening a railway gate. Commonly used microcontrollers include Arduino Uno, Raspberry Pi, and PIC controllers. Their affordability, programmability, and flexibility make them ideal for developing smart transportation solutions (Singh & Raj, 2020).

In an automated railway crossing setup, sensors detect the approach of a train and send signals to the microcontroller. The microcontroller, based on the logic written in its firmware (e.g., Arduino IDE), triggers a sequence of actions: activating LED lights, sounding alarms, and operating gate barriers using servo or DC motors. After the train passes, it receives a departure signal and automatically reopens the gate, completing the cycle (Ahmed et al., 2021).

The use of microcontrollers in such systems offers multiple advantages. First, they allow real-time processing and decision-making, crucial for time-sensitive operations like gate control. Second, microcontrollers can be integrated with various input and output peripherals, enabling more sophisticated operations such as GSM alerts, traffic signal synchronization, and remote diagnostics. Third, their power-efficient nature makes them suitable for installations in off-grid or rural areas with limited electricity access (Okonkwo et al., 2021).

Microcontroller-based systems are also modular and scalable. If required, they can be easily updated or expanded with additional features, such as IoT-based communication, solar power integration, or artificial intelligence-based predictive controls (Umar & Babalola, 2020). For developing nations like Nigeria, microcontrollers offer a low-cost entry point into transport automation. This study explores the potential of Arduino Uno in building a simplified yet functional automated railway crossing system for local application and education.

2.4 Integration of Traffic Signals and Safety Features

The successful deployment of automated railway level crossing systems depends not only on mechanical gate operations but also on the effective integration of traffic signals and safety features. These additions ensure that all road users—motorists, pedestrians, and cyclists—are adequately warned and guided during train crossings. Visual signals, including red, yellow, and green LEDs, play a critical role in conveying system status. Red lights typically signal that a train is approaching and the gate is about to close, while green lights indicate it is safe to proceed (Nwachukwu & Okonkwo, 2019).

Auditory alerts, such as buzzers or sirens, provide an additional layer of safety, especially useful for visually impaired users or in low-visibility conditions. More advanced systems may include countdown timers, flashing signs, and illuminated barrier arms to improve visibility during nighttime operations. Integration of these components ensures clear, consistent communication between the system and road users (Singh & Raj, 2020).

The design of safety features also considers fail-safe mechanisms. For example, in the event of a power outage, the system should either revert to a default safe position (e.g., barrier closed) or have a manual override mechanism. Some modern implementations include battery backups or solar-powered components to maintain operations during blackouts (Ahmed et al., 2021).

Synchronization of traffic lights with the barrier system is another crucial aspect. If the gate is about to close, traffic lights must turn red to halt oncoming vehicles. These coordinated responses minimize confusion and ensure orderly conduct during train passage (Okonkwo et al., 2021).

Despite the technological advances, many crossings in Nigeria still lack basic safety integrations. This underscores the need for low-cost, locally adaptable systems that incorporate visual and auditory alerts. This study includes the development of such features using buzzers and LED lights integrated with a microcontroller platform for real-time signaling.

2.5 Gaps in Existing Research

Despite ongoing research in railway automation, many studies focus primarily on high-cost or urban-specific technologies, leaving rural and underdeveloped areas underserved. Furthermore, research on local adaptation of automation in Nigeria is limited, with few works addressing the affordability, scalability, and maintenance challenges of such systems in low-resource environments. Additionally, most existing studies do not integrate user-friendly features or alternative energy sources like solar. Communication capabilities like GSM alerts are also underexplored in microcontroller-based prototypes. This project addresses these gaps by proposing a low-cost, Arduino-based automated railway crossing system equipped with basic sensors, traffic signals, and safety features for local use.

2.6 Summary of Literature Insights

S/N	Author(s) & Year	Study Focus	Key Findings	Contribution to Current Study	Identified Research Gap
1	Eze et al. (2018)	Assessment of safety at Nigerian railway crossings	Revealed that the majority of railway crossings in Nigeria remain manually operated, making them susceptible to human error and frequent accidents.	Highlights the necessity of replacing manual operations with automated crossing systems for enhanced safety.	Did not propose or test a specific automated solution or prototype.
2	Afolabi & Gbadamosi (2017)	Railway transport risks and incidents in Nigeria	Identified delayed gate closures and the absence of visual and auditory warnings as leading causes of train-vehicle collisions.	Justifies the inclusion of LEDs and buzzer-based alert systems in the proposed design.	Focused mainly on risk analysis without presenting a technological intervention.
3	Singh & Raj (2020)	Arduino-based automated railway crossing	Developed a functional prototype	Provides a technical benchmark for	Did not consider adaptability or constraints in

			employing IR sensors, servo motors, and buzzers to automate railway gate control.	implementing Arduino and sensor technology in this project.	rural/sub-Saharan African settings.
4	Ahmed et al. (2021)	Design of microcontroller-based railway crossing prototype	Demonstrated successful real-time train detection and automatic gate control using Arduino, significantly reducing reliance on manual input.	Validates Arduino's suitability for cost-effective, real-time automation in developing countries.	Lacked a focus on community-level deployment or localization in Nigerian infrastructure.
5	Okonkwo et al. (2021)	Embedded systems in rail transport automation	Highlighted the scalability and flexibility of microcontroller-based systems in smart infrastructure applications.	Supports the modular and expandable system design adopted in this study.	The study was theoretical with no prototype implementation or contextual adaptation.
6	Umar & Babalola (2020)	Railway safety challenges in Nigeria	Pointed out infrastructural gaps and limited technical skills in rural areas, hindering the adoption of advanced safety technologies.	Emphasizes the importance of developing simple, affordable, and locally adaptable solutions.	Did not suggest practical, low-cost solutions for bridging the infrastructure gap.
7	Nwachukwu & Okonkwo (2019)	Technological upgrade of railway systems in Africa	Called for the use of low-cost technologies and safety enhancements to reduce accidents and improve efficiency in African rail systems.	Aligns with the broader objective of this study to contribute to railway modernization in Nigeria.	Provided policy-level recommendations without a practical prototype or pilot implementation.

References

Afolabi, A., & Gbadamosi, A. (2017). *Railway level crossing accidents and safety interventions in Nigeria*. Nigerian Journal of Transport and Logistics, 5(2), 42–50.

Ahmed, M. T., Yusuf, A. A., & Oke, A. R. (2021). *Development of an automatic railway crossing system using Arduino*. International Journal of Engineering and Emerging Technology, 6(1), 60–67.

Eze, C. C., Onuoha, J. O., & Okafor, N. E. (2018). *Assessment of safety issues at Nigerian railway crossings*. Journal of Transportation Safety, 9(1), 27–34.

Nwachukwu, I. E., & Okonkwo, C. (2019). *Rail transportation safety and the need for technological advancement in Nigeria*. Journal of Applied Sciences and Engineering, 7(3), 55–64.

Okonkwo, M. O., Usman, A., & Bello, T. (2021). *Design and implementation of an automated level crossing using embedded systems*. Journal of Innovative Engineering Technologies, 4(2), 89–95.

Singh, R., & Raj, A. (2020). *Arduino based automatic railway gate control system*. International Journal of Advanced Research in Electronics and Communication Engineering, 9(4), 112–117.

Umar, I. A., & Babalola, R. (2020). *Challenges and prospects of railway transport in Nigeria: A safety perspective*. Journal of Engineering Research and Reports, 12(3), 1–8.