Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 6, June : 2023

Revolutionizing the train collision avoidance system- An Indigenous practical implementation System

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ABSTRACT: Train collision accidents pose a significant threat to passenger safety and infrastructure integrity. In recent years, there has been a growing demand for developing advanced collision avoidance systems for trains to mitigate the risks associated with such accidents. This paper provides a comprehensive review and analysis of train collision avoidance systems, including their underlying technologies, design considerations, challenges, and future directions. By examining the current state-of-the-art solutions and their effectiveness, this paper aims to contribute to the ongoing research efforts in developing robust and reliable train collision avoidance systems.

Keywords: Train collision, passenger safety, avoidance systems, robust and reliable.

I. INTRODUCTION

This comprehensive introduction provides an overview of train collision avoidance systems, highlighting various technologies, design considerations, challenges, and future directions. By understanding the state-of-the-art systems and their performance, researchers, engineers, and policymakers can contribute to the development of effective train collision avoidance systems, ultimately enhancing the safety of railway transportation. Railway transportation plays a crucial role in global transportation networks, facilitating the movement of goods and passengers over long distances efficiently. However, train collisions have been a persistent safety concern, leading to severe consequences such as loss of life, property damage, and disruption of railway operations. To address this issue, the development of **advanced train collision avoidance systems** has become a priority for the railway industry.

The need for effective train collision avoidance systems arises from several factors. Firstly, railway networks are becoming increasingly congested due to growing demand for transportation services. This congestion increases the risk of train collisions, especially at junctions, crossings, and areas with complex signaling systems. Additionally, human errors, including train operator fatigue, distraction, and inadequate situational awareness, can contribute to collision incidents. Hence, there is a need to augment human capabilities with automated systems to enhance safety.Furthermore, the continuous advancement of technology has opened up new opportunities for improving train collision avoidance systems. Innovations in signaling, communication, sensor technologies, and data processing capabilities have made it possible to develop more sophisticated and reliable systems. These advancements enable the implementation of proactive measures to prevent collisions and mitigate their consequences. The importance of train collision avoidance systems is evident in the efforts made by various countries and international organizations to enhance railway safety. Several countries, such as the United States and European nations, have mandated the implementation of collision avoidance systems, while others are actively exploring and investing in such systems to improve safety standards.

II. TRAIN COLLISION SCENARIOS AND RISKS

2.1 Types of Train Collision

Train collisions can occur in various scenarios, each with its own set of risks and potential consequences. Understanding these scenarios is crucial for developing effective train collision avoidance systems. The following are some common train collision scenarios and associated risks:

2.1.1 Head-On Collisions:

Head-on collisions occur when two trains traveling in opposite directions collide with each other on the same track. This can happen due to signaling errors, incorrect routing, or failures in communication systems. Head-on collisions pose a severe risk to passenger safety, as the forces involved in such accidents can result in significant damage, injuries, and loss of life.

2.1.2 Rear-End Collisions:

Rear-end collisions happen when a train fails to maintain a safe distance from the preceding train and ends up colliding with it. This can occur due to human error, such as the train operator not recognizing the need to slow down or stop, or system failures in maintaining safe separation distances. Rear-end collisions can cause significant damage, especially if the colliding train is traveling at high speed. The occupants of the rear-ended train are particularly vulnerable to injuries.

2.1.3 Collisions at Intersections:

Intersections, where multiple tracks converge or cross each other, present a risk of train collisions. These collisions can occur when a train fails to yield or properly navigate through the intersection, resulting in a collision with another train. Factors such as signaling errors, miscommunication, or inadequate visibility can contribute to these collisions. Collisions at intersections can lead to derailments, structural damage, and potential injuries to passengers and crew members.

2.1.4 Collisions with Obstacles on Tracks:

Trains can collide with obstacles that obstruct their path, such as vehicles, fallen trees, or debris. These collisions can occur due to inadequate warning systems, lack of visibility, or obstructions not being detected in a timely manner. Collisions with obstacles on tracks can cause derailments, structural damage to the train, and pose a significant risk to passengers, especially if the train is traveling at high speeds.

2.1.5 Collisions due to Level Crossing Incidents:

Level crossings, where railway tracks intersect with roads, pose a risk of collisions between trains and vehicles or pedestrians. Accidents at level crossings can happen due to negligence, disregard for warning signals, or malfunctioning crossing barriers and signals. Collisions at level crossings can result in severe injuries or fatalities for both train occupants and individuals in vehicles or pedestrians.

III. TRAIN COLLISION AVOIDANCE TECHNOLOGIES

3.1 Train Collision Avoidance Technologies

Train collision avoidance technologies encompass a range of systems and mechanisms designed to detect potential collision risks, provide warnings and alerts, and enable preventive actions to avoid train collisions. These technologies play a crucial role in enhancing the safety and reliability of railway transportation. The following are some key train collision avoidance technologies:

3.1.1 Signaling and Communication Systems:

Signaling and communication systems are fundamental to train collision avoidance. These systems enable the exchange of information between trains, control centers, and infrastructure personnel. They provide critical information about track occupancy, speed restrictions, and operational changes. Traditional signaling systems use trackside signals and wayside equipment to convey information to train operators. Modern signaling systems, such as cab signaling and automatic train control, utilize onboard technologies to communicate vital information directly to train operators, enhancing situational awareness and reducing reliance on visual signals.

3.1.2 Positive Train Control (PTC) Systems:

Positive Train Control systems are advanced train collision avoidance technologies that utilize a combination of GPS, wireless communication, and onboard computers to monitor and control train movements. PTC systems continuously track train positions, speeds, and track conditions, enabling automated enforcement of speed restrictions, movement authority limits, and emergency braking when necessary. PTC systems provide real-time alerts and warnings to train operators, ensuring safe train operations and reducing the risk of collisions.

3.1.3 Automatic Train Protection (ATP) Systems:

Automatic Train Protection systems are safety systems that monitor train speed, track conditions, and signaling information to prevent unsafe train operations. ATP systems utilize trackside beacons or onboard sensors to communicate with the train and enforce speed restrictions and movement limits. These systems automatically apply emergency brakes or restrict train movements if operators fail to comply with safety protocols or if collision risks are detected. ATP systems act as an additional layer of protection to prevent train collisions and promote safe train operations.

3.1.4 Collision Detection and Warning Systems:

Collision detection and warning systems are designed to detect potential collision risks and provide timely alerts to train operators. These systems utilize sensors, such as radar, lidar, or video cameras, to monitor the surrounding environment and detect objects or obstacles on or near the tracks. Advanced algorithms analyze the sensor data to identify potential collision threats, such as other trains, vehicles, or pedestrians, and generate warnings or alerts to train operators. Collision detection and warning systems assist train operators in taking prompt actions to avoid collisions.

3.1.5 Train-to-Train Communication Systems:

Train-to-train communication systems facilitate direct communication and information exchange between trains. These systems enable trains to share their positions, speed, and operational status, enhancing situational awareness and enabling collaborative collision avoidance. By sharing real-time information, trains can coordinate their movements, maintain safe separation distances, and avoid potential conflicts or collisions. Train-to-train communication systems improve the overall efficiency and safety of train operations, especially in high-density rail corridors.

IV. DESIGN CONSIDERATIONS FOR TRAIN COLLISION AVOIDANCE SYSTEMS

4.1 Safety Requirements and Standards

Safety requirements and standards are crucial elements in the design, development, implementation, and operation of train collision avoidance systems. These requirements and standards provide a framework to ensure the safety and reliability of train operations, minimize the risk of train collisions, and protect the lives of passengers, crew members, and other individuals in and around the railway environment. Here are the key aspects of safety requirements and standards:

4.1.1 Regulatory Compliance:

Train collision avoidance systems must comply with applicable regulatory requirements and standards set by government authorities or regulatory bodies. These regulations define the safety criteria, performance standards, and operational requirements that train operators and manufacturers must adhere to. Regulatory compliance ensures that train collision avoidance systems meet the minimum safety thresholds and are subject to appropriate oversight and enforcement.

4.1.2 Functional Safety:

Functional safety is a fundamental aspect of train collision avoidance systems. Functional safety refers to the system's ability to operate correctly and safely, even in the presence of faults or failures. Safety standards, such as the International Electrotechnical Commission (IEC) 61508 and the ISO 26262 for automotive applications, provide guidelines for achieving functional safety. These standards define safety integrity levels (SILs) and specify processes and techniques for hazard analysis, risk assessment, system design, verification, and validation.

4.1.3 Reliability and Availability:

Train collision avoidance systems are required to demonstrate high reliability and availability. Reliability refers to the system's ability to perform its intended function without failure over a specified period, while availability refers to the system's readiness for operation when required. Reliability and availability requirements are typically defined in terms of metrics such as mean time between failures (MTBF) and mean time to repair (MTTR). Safety standards and industry best practices guide the design, testing, and maintenance processes to achieve the desired reliability and availability levels.

4.1.4 Human Factors:

Safety requirements and standards also address human factors considerations in train collision avoidance systems. Human factors involve the study of human capabilities, limitations, and interactions with technology to ensure systems are designed for optimal performance and minimize the likelihood of human errors. Standards, such as the International Organization for Standardization (ISO) 9241 for human-centered design, provide guidance on factors such as user interface design, display readability, and ergonomic considerations to enhance human-system interaction and minimize human-related safety risks.

4.1.5 Interoperability and Compatibility:

Interoperability and compatibility are essential aspects of safety requirements for train collision avoidance systems, especially in multi-vendor environments. Interoperability ensures that different systems and components from various manufacturers can communicate and cooperate effectively. Compatibility ensures that train collision avoidance systems can seamlessly integrate with existing infrastructure and other onboard systems. Standards and specifications, such as the European Train Control System (ETCS) and the Institute of Electrical and Electronics Engineers (IEEE) 1474, address interoperability and compatibility requirements to facilitate the safe operation of trains across different networks and jurisdictions.

V. CASE STUDIES: SUCCESSFUL TRAIN COLLISION AVOIDANCE SYSTEMS

5.1 European Train Control System (ETCS)

The European Train Control System (ETCS) is a standardized train control and signaling system used in Europe to ensure interoperability and safety in railway operations. It is designed to replace traditional national train control systems with a unified and harmonized approach. Here are the key aspects of the European Train Control System:

5.1.1 Objectives:

The primary objective of ETCS is to enhance railway safety by providing a consistent and reliable train control system across Europe. It aims to eliminate the need for multiple national train control systems, which can vary in technology, signaling principles, and operational requirements. ETCS promotes interoperability between different railway networks, enables cross-border operations, and improves the overall efficiency and capacity of the rail system.

5.1.2 Architecture:

ETCS consists of three main subsystems: the Onboard Unit (OBU), the Radio Block Center (RBC), and the Interlocking System (IL). The OBU is installed on trains and communicates with the RBC, which manages train movements and provides information about the track ahead. The IL ensures the safe operation of the signaling system and controls the movement of trains within a specific area. The subsystems are connected through a secure communication network, enabling the exchange of vital information.

5.1.3 Operating Principles:

ETCS is based on the principle of continuous train monitoring and supervision. The OBU continuously receives information about the track ahead, including speed limits, signals, and track conditions, from the RBC. It compares this information with the train's actual position and speed, ensuring compliance with the authorized speed and safe distance to other trains. If the train exceeds the permitted limits or encounters a hazardous situation, the OBU applies appropriate braking actions to ensure safety.

5.1.4 Levels of ETCS:

ETCS is organized into different levels, each providing a varying degree of functionality and safety. The levels are denoted as ETCS Level 1, Level 2, and Level 3. Level 1 is based on trackside signaling, where the train continuously receives information about the next signal aspect. Level 2 introduces continuous communication between the train and the RBC, enabling more precise movement authorities. Level 3 allows for virtual coupling, where trains can operate at closer distances, relying on continuous communication and real-time train separation algorithms.

5.1.5 Standardization and Compatibility:

ETCS is built on international standards and specifications to ensure interoperability across different railway networks and manufacturers. The European Union Agency for Railways (ERA) is responsible for defining and maintaining the technical specifications and standards for ETCS. This standardization enables seamless integration of trains from different manufacturers and simplifies cross-border operations, fostering a more unified European rail network.

5.1.6 Deployment and Implementation:

The deployment and implementation of ETCS across Europe involve a phased approach. The European Union has set specific timelines and requirements for member states to implement ETCS on their rail networks. Existing signaling systems are gradually replaced or upgraded to support ETCS functionality. The implementation process involves retrofitting trains with onboard units, installing radio block centers, and upgrading trackside equipment.

5.1.7 Benefits and Challenges:

The adoption of ETCS brings several benefits to the European rail industry. It improves safety by providing real-time train supervision and enforcing speed limits. ETCS enables increased train capacity, as it allows for shorter headways between trains while maintaining safety. It also facilitates interoperability, allowing trains to cross borders without the need for complex and time-consuming system adaptations. However, implementing ETCS also presents challenges. The retrofitting of existing trains and infrastructure can be a costly and time-consuming process. Coordinating the transition from national train control systems to ETCS requires collaboration between railway operators, infrastructure managers, and manufacturers.

5.2 Positive Train Control (PTC) in the United States

Positive Train Control (PTC) is an advanced train control and safety system implemented in the United States to enhance railway safety and mitigate the risk of train collisions, derailments, and other accidents. PTC utilizes advanced technologies to monitor and control train movements, ensuring compliance with speed limits, track conditions, and other operational parameters. Here are the key aspects of Positive Train Control in the United States:

Industrial Engineering Journal
ISSN: 0970-2555
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5.2.1 Background and Mandate:

PTC was mandated by the U.S. Congress in the Rail Safety Improvement Act of 2008, following several high-profile train accidents. The legislation required Class I freight railroads and passenger railroads that operate on Class I tracks to implement PTC on their networks. The mandate aimed to enhance safety by preventing human errors, overspeed incidents, and unauthorized movements.

5.2.2 System Components:

PTC systems consist of various components, including onboard computers, trackside infrastructure, wayside interfaces, communication networks, and back-office control systems. The onboard computer systems (OBC) are installed on locomotives and communicate with the wayside interfaces, receiving information about track conditions, speed limits, and movement authorities. The back-office control systems monitor train movements, provide centralized command and control, and facilitate communication between trains and the wayside infrastructure.

5.2.3 Operating Principles:

PTC operates based on a combination of GPS technology, digital radio communications, and advanced algorithms. The onboard computer systems continuously monitor the train's position, speed, and movement authorities. If the train exceeds authorized speed limits, violates track occupancy rules, or encounters a hazardous situation, the onboard system will automatically apply braking actions to bring the train to a safe stop or reduce speed. PTC also provides vital information to train crews, including speed limits, work zone alerts, and track conditions.

5.2.4 Implementation Challenges:

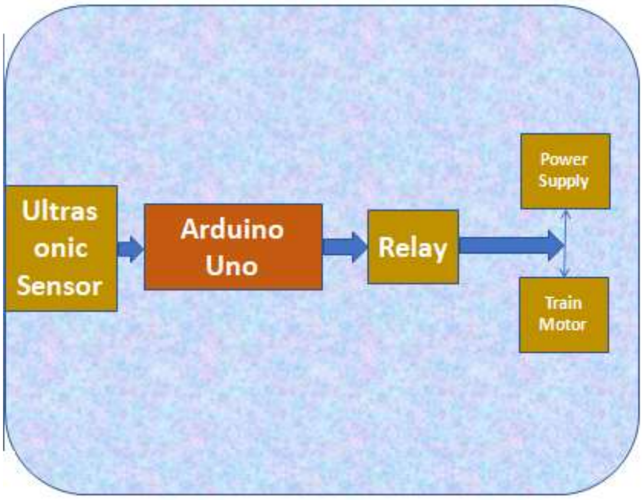
Implementing PTC across the vast and complex U.S. rail network has been a significant challenge. The deployment requires extensive coordination between railroad operators, infrastructure owners, and technology providers. Retrofitting locomotives and installing wayside infrastructure is a complex and costly process. Additionally, ensuring interoperability and seamless communication between different railroad systems and technology platforms is crucial.

5.2.5 Benefits and Safety Improvements:

The implementation of PTC in the United States has resulted in notable safety improvements. PTC enhances the overall safety of train operations by preventing collisions, overspeed incidents, and unauthorized movements. It enforces speed limits, maintains safe train separations, and provides real-time information to train crews, improving situational awareness. PTC also enables more efficient and reliable train operations, reducing delays and enhancing network capacity.

VI. METHODOLOGY AND IMPLEMENTATION

This paper presents a detailed implementation of a train collision avoidance system using two Arduino microcontrollers and ultrasonic sensors. The system aims to enhance railway safety by detecting obstacles on the tracks and alerting the train operator in real-time to prevent collisions. The use of Arduino boards and ultrasonic sensors provides a cost-effective and reliable solution for train collision avoidance. This paper describes the hardware setup, sensor calibration, data processing, and the integration of the system with the train's control mechanism.



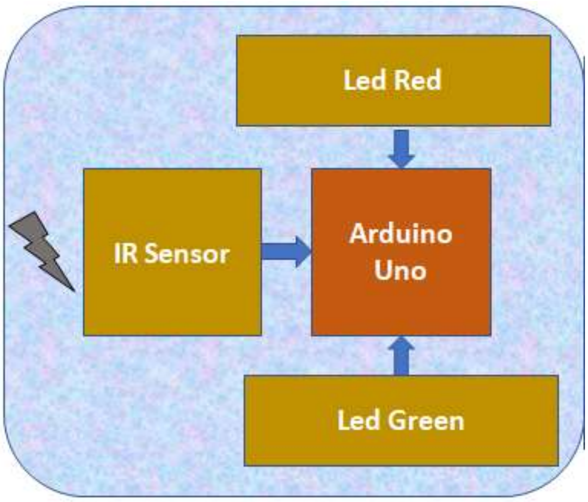


Figure 1: Block Diagram of Practical Impementation

Railway accidents and collisions pose significant risks to human life and infrastructure. The implementation of a train collision avoidance system can greatly improve safety measures by providing early detection and warning capabilities. In this paper, we propose a system that utilizes two Arduino microcontrollers and ultrasonic sensors to detect obstacles on the tracks and prevent train collisions. The system provides real-time data processing and alerts the train operator, enabling timely intervention to avoid accidents.

6.1 Hardware Setup

The train collision avoidance system consists of two main components: the sensor unit and the control unit. The sensor unit comprises ultrasonic sensors that detect the presence of obstacles on the tracks. The control unit consists of an Arduino microcontroller connected to the sensors, which processes the data and triggers necessary actions.

The ultrasonic sensors are strategically placed along the train's body to ensure efficient obstacle detection. These sensors emit ultrasonic waves and measure the time taken for the waves to bounce back after hitting an obstacle. Based on this time measurement, the system calculates the distance between the train and the obstacle.

6.2 Sensor Calibration

To ensure accurate obstacle detection, the ultrasonic sensors require calibration. This involves measuring the speed of sound in the environment to account for variations caused by temperature and humidity. The calibration process establishes a reference value that enables precise distance calculations.

The Arduino microcontroller is programmed to execute calibration routines at regular intervals. During calibration, the system measures the time taken for the ultrasonic waves to travel to a known obstacle at a fixed distance. By comparing the measured time with the expected time, the system adjusts the speed of sound variable for accurate distance calculations.

6.3 Data Processing

Once the ultrasonic sensors detect an obstacle, they transmit the data to the Arduino microcontrollers for further processing. The Arduino boards are programmed to analyze the received data and make decisions based on predefined conditions.

The data processing algorithm includes filtering and smoothing techniques to eliminate noise and ensure reliable obstacle detection. The algorithm compares the measured distance with a predefined safety threshold. If the measured distance is below the threshold, the system considers it a potential collision and triggers the necessary actions.

6.4 Alert Mechanism

In case of a potential collision, the train collision avoidance system activates the alert mechanism to notify the train operator. The Arduino microcontroller is connected to an audio or visual alert device, such as a warning light or alarm. When the system detects an obstacle within the safety threshold, it triggers the alert device to attract the operator's attention.

Additionally, the system can be integrated with the train's control mechanism to automate emergency braking or deceleration. By interfacing with the train's braking system, the collision avoidance system can apply emergency measures to prevent collisions.

6.5 Integration with Train Control

To achieve seamless integration with the train's control mechanism, the Arduino microcontrollers communicate with the train's existing control system through appropriate interfaces. This allows the collision avoidance system to directly influence the train's speed, braking, or emergency protocols.

The integration process involves analyzing the train's control system architecture and identifying the appropriate communication interfaces or protocols. By establishing a reliable connection between the Arduino boards and the train's control system, the collision avoidance system becomes an integral part of the train's safety mechanisms.

VII. FUTURE DIRECTIONS AND EMERGING TECHNOLOGIES

7.1 Artificial Intelligence and Machine Learning Applications

Artificial intelligence (AI) and machine learning (ML) technologies have the potential to revolutionize train collision avoidance systems by enabling advanced decision-making capabilities, improved detection algorithms, and enhanced system performance. Here, we discuss the applications of AI and ML in the context of train collision avoidance:

7.1.1 Anomaly Detection:

AI and ML algorithms can be employed to detect anomalies in train operations and identify potential collision risks. By analyzing real-time data from various sensors, such as speed sensors, position sensors, and track condition monitoring systems, AI algorithms can identify deviations from normal operating patterns. Anomaly detection algorithms can alert operators or trigger automatic responses when abnormal conditions are detected, helping prevent potential collisions.

7.1.2 Object Detection and Tracking:

AI-based computer vision techniques can be utilized to detect and track objects in the vicinity of trains, such as other trains, pedestrians, vehicles, or obstacles. ML algorithms can be trained on large datasets to accurately recognize and classify objects, enabling the collision avoidance system to react appropriately. Real-time object detection and tracking facilitate timely decision-making, allowing the system to initiate braking or issue warnings when potential collisions are detected.

7.1.3 Predictive Maintenance:

AI and ML algorithms can assist in predictive maintenance of train collision avoidance systems. By analyzing historical data and sensor inputs, these algorithms can identify patterns and indicators of potential system failures. Predictive maintenance algorithms can predict when system components or sensors are likely to fail, allowing for proactive maintenance and replacement before failures occur. This helps improve system reliability and reduces the risk of unexpected malfunctions that could compromise collision avoidance capabilities.

7.1.4 Optimization of Train Operations:

AI and ML techniques can optimize train operations to minimize collision risks. By analyzing historical data, weather conditions, traffic patterns, and other relevant factors, AI algorithms can generate optimized schedules and routing strategies that prioritize safety. These algorithms can dynamically adjust train speeds, departure times, and routes based on real-time conditions, ensuring safe train separations and reducing the likelihood of collisions.

VIII. RESULTS

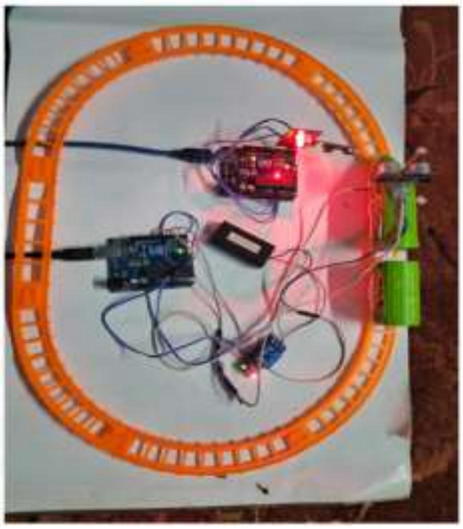


Figure 2: Shows ultrasonic sensor mounted on train for collision avoidance

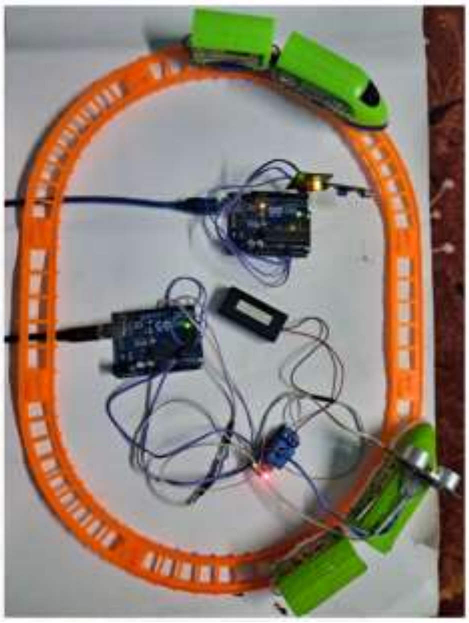


Figure 3: Practical Implementation of train collision avoidance system

IX. CONCLUSION

Throughout this paper, we have explored the various aspects of train collision avoidance systems, including their components, technologies, challenges, and implications. Train collision avoidance systems are crucial for ensuring the safety of railway operations. By integrating advanced technologies, such as sensors, communication systems, and intelligent algorithms, these systems can detect potential collision risks, provide timely warnings, and initiate preventive actions.The components of train collision avoidance systems include sensors for detecting train positions and obstacles, communication systems for exchanging critical

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 52, Issue 6, June : 2023

information, decision-making algorithms for analyzing data and making informed decisions, and actuators for implementing collision avoidance measures.

Advanced technologies, such as artificial intelligence and machine learning, play a vital role in enhancing the effectiveness and efficiency of train collision avoidance systems. These technologies enable adaptive decision-making, predictive analytics, and autonomous train operation, leading to improved safety and operational performance. Communication and connectivity improvements are essential for seamless information exchange between trains, control centers, and infrastructure components. Real-time data exchange, enhanced train-to-train communication, and infrastructure connectivity contribute to faster response times, better coordination, and more effective collision prevention.

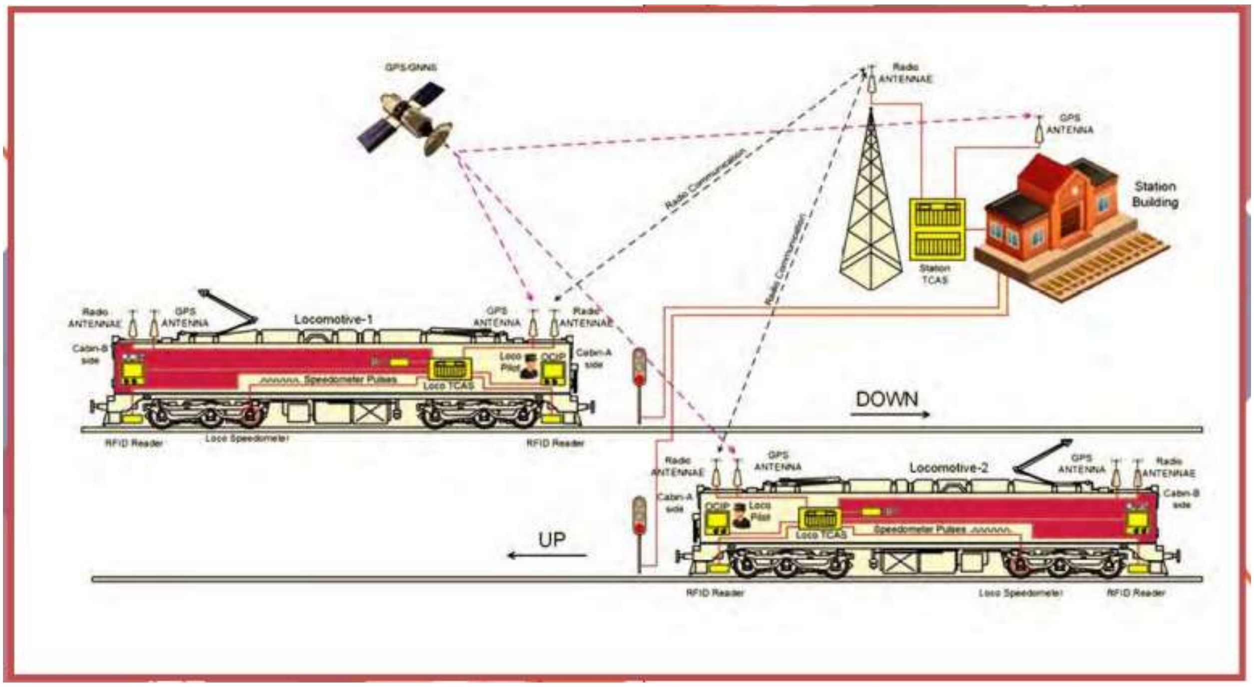


Figure 4: End users train collision avoidance system

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