International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
ISSN:2147-6799 www.ijisae.org Original Research Paper

Study on Train Collision Avoidance System for Securing Safe Distance between Trains

[1]Atul Sarojwal, [2]Akriti Garg, [3] Mukul Kumar Singh, [4]Ashish Kumar Sankhwar

Submitted:10/12/2023 **Revised:**12/01/2024 **Accepted:**22/01/2024

Abstract— Railway transportation plays a vital role in providing efficient, reliable, and safe mobility. However, increasing train traffic density and higher operational speeds create challenges in ensuring safety against collisions. A critical aspect of rail safety is maintaining a safe distance between trains under varying operational conditions. This paper presents a theoretical study on train collision avoidance systems (TCAS) that secure safe train separation through advanced signaling, communication, and control mechanisms. The discussion focuses on system architecture, working principles, technologies used, safety logic, and potential benefits in enhancing operational reliability without practical implementation details. This paper analyzed problems of current operation method for safe operation of two trains in the close distance, and draw the method to solve them.

***Keywords**: analyzed, discussion, TCAS, traffic*

1. INTRODUCTION

Railways have traditionally relied on block signaling systems, automatic train control (ATC), and automatic train stop (ATS) mechanisms to maintain train separation. These systems are designed to ensure that only one train occupies a block section at a time, preventing rear-end and head-on collisions. However, with the increasing demand for high-speed rail and urban transit networks, existing systems are often insufficient in addressing dynamic operational challenges such as mixed traffic, higher train frequency, and reduced headways. A train collision avoidance system aims to overcome these limitations by continuously monitoring the location, speed, and braking distance of trains, thereby ensuring that trains always maintain a safe separation distance. This paper explores the theoretical foundation of such systems, their design concepts, and their importance for future railway safety.

[1]*Assistant Professor, Department of Electrical Engineering, FET, MJP Rohilkhand University Bareilly, India*
atulkingpin@gmail.com
[2]*Ph.D. Scholar, Department of Electrical Engineering, FET, MJP Rohilkhand University Bareilly, India*
akritistudy@gmail.com
(Corresponding Author)
[3]*Ph.D. Scholar, Department of Electrical Engineering, FET, MJP Rohilkhand University Bareilly, India*
mukulpu@gmail.com
[4]*Assistant Professor, Deptt of Electrical Engineering FET, MJP Rohilkhand University, Bareilly, UP, India*
ashish131@gmail.com

2. BACKGROUND AND NEED FOR COLLISION AVOIDANCE SYSTEMS

2.1 Traditional Train Safety Approaches

Conventional train safety relies on fixed block signaling, where tracks are divided into electrically isolated sections. A train entering a block prevents another train from entering until it is clear. While effective, this system restricts line capacity and does not adapt well to modern high-speed or mixed-traffic operations.

2.2 Limitations of Existing Systems

- Fixed blocks lead to inefficient utilization of track capacity.
- Dependence on track circuits makes systems vulnerable to environmental and technical failures.
- Limited adaptability to variable braking distances under different gradients and train loads.

- Manual driver intervention may introduce human errors.

2.3 Emerging Needs

With rising train speeds and density, ensuring safety solely through fixed blocks becomes impractical. Hence, advanced **train collision avoidance systems** are needed to dynamically monitor trains, calculate safe distances, and automatically intervene to prevent collisions.

3. Concept of Train Collision Avoidance System (TCAS)

A train collision avoidance system is designed to prevent collisions by maintaining safe distance and speed regulation between trains. The system uses onboard sensors, wireless communication, and centralized or distributed control logic to continuously calculate relative positions and braking distances.

3.1 Duplicate operation of domestic KTX Sancheon

In case of the domestic KTX Sancheon, it performs train decoupling/coupling operation in the station building in the state where passengers are boarded. When coupling trains, the vehicle which tries to couple stops in the front two times and checks coupling situations by manual signal and radio, and has the train coupled at 5m in the front at the speed of 2km/h under the responsibility of driver. In this case, driver may be difficult to drive the coupler since he/she is dependent exclusively on the manual signal and radio regarding location of the front train and coupler status, etc., and it may lead to the accident.

In addition, some problems occur such as, from the position of passengers, the increase in passenger time for journey according to the time required for train coupling, and from the position of operating agency, efficiency of operating expenses according to the increase in required personnel for train coupling, etc.

Figure 1.Situatioin when coupling KTX Sancheon

3.2 Collision avoidance system in other fields

There are systems between mobiles for efficient utilization of infrastructure in the fields of space, aviation, vessel and road. In this case, examples include docking of the space field, unmanned aerial refueling of aviation field, mobile harbor of vessel field, and platooning driving of road field. Through case analysis of other fields, the collision avoidance system for safety when coupling between mobiles has been built. Collision avoidance system operates mobiles while maintaining safe coupling to the other mobile or securing safe distance with IT technologies such as the distance sensor, image technology and radio communications (V2V), etc.

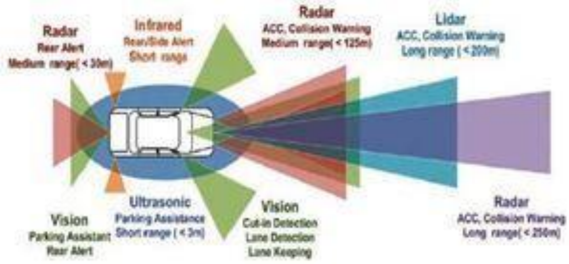

Figure 2. Application case of road field anti-collision sensor by distance

Collision avoidance systems are not limited to trains but are widely used across various fields to enhance safety and efficiency. In the automotive sector, advanced driver assistance systems (ADAS) employ sensors, cameras, and radar to detect obstacles, pedestrians, and other vehicles, automatically applying brakes or steering corrections to prevent accidents. In aviation, Traffic Collision Avoidance Systems (TCAS) are integrated into aircraft to monitor air traffic and provide pilots with real-time alerts and maneuvers to avoid mid-air collisions. Maritime navigation also utilizes collision avoidance technologies through Automatic Identification Systems (AIS) and radar to prevent ship-to-ship collisions, especially in congested waterways. Similarly, in robotics and autonomous systems, collision avoidance algorithms are crucial for enabling drones, industrial robots, and warehouse automation vehicles to navigate safely within dynamic environments. Even in healthcare, robotic surgery systems and assistive medical robots apply collision avoidance techniques to ensure precise operations without unintended contact with surrounding tissues or instruments. Thus, collision avoidance systems have become a vital component across multiple domains, ensuring safety, reliability, and operational efficiency.

That is, it performs speed control of mobile for safe driving by interlocking with braking and propulsion devices of mobile through detection of relative distance to the mobile and relative speed.

Figure 2 is the application case of anti-collision sensor applied to the smart car for platooning driving in the ITS (Intelligent transport system) field, and it showed a suitable optimum sensor in accordance with the distance of obstacles. Features of distant sensor are as shown in Table below.

Table1. Features of distant sensors

	Radar	LIDAR	Image	Ultrasonic waves	Infrared light
Detection distance	Long distance	Long distance	Moderate	Short distance	Middle distance
Detection angle	Narrow angle & Wide angle	Narrow angle & Wide angle	Moderate	Wide angle	Narrow angle
Accuracy	Good	Good	Good	Good	Moderate
Resolution	Good	Good	Moderate	Good	Moderate
Weather conditions	Insensitive	Sensitive	Sensitive	Sensitive	Sensitive
Illuminance	Insensitive	Insensitive	Sensitive	Insensitive	Sensitive
Price	High	High	High	Low	Moderate
Detection performance	Stable to surrounding environment	Bad weather degradation	Target type limited	Short distance Superior performance	Bad weather degradati on

3.3 Train Collision Avoidance System

Train control system in railway field performs its function preventing against collision between the preceding train and following train. That is, the train control system is to control the speed of train presented for safety automatically, and it performs securement of safety in the fixed block method and moving block method. In the existing fixed block method, the safety of train is secured by keeping a fixed block (maximum block including a possible braking distance of following train) in accordance with the position of preceding train. It has a demerit such as an inefficient operation of track. The method like this is the train control method between stations. This method is based on the fact that operation of 2 trains in 1 block is impossible so as to avoid collision between trains. Therefore, there was no need to consider train control within the station building until now. Although there has been no case of changing train formation during the operation until now, the operation of train with variable formation is being actively used currently to utilize tracks and vehicles efficiently with Europe and Japan as its center, and at this time, it is being operated for high-speed railways in Korea too. Therefore, it is our actual state that the study on train control technology to secure the safety of train within station building is necessary.

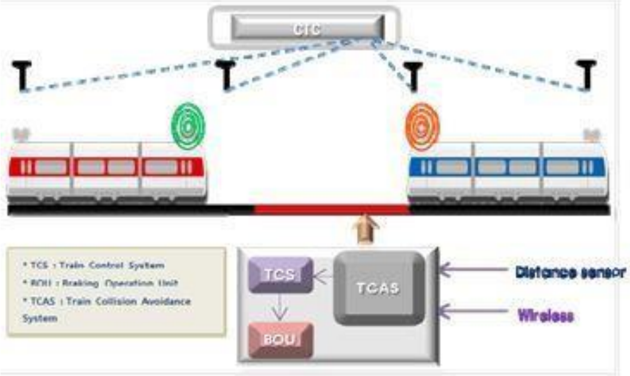

Figure 3.A plan to apply anti-collision sensor for railways

4. Global Trends in Train Collisions

- **Liu et. al. (2019)** conducted a comprehensive study on railway safety and found that **over 60% of train collisions** worldwide occur due to **human errors** (miscommunication, fatigue) and **signaling failures**. The study emphasized the need for **automated TCAS** to reduce dependency on manual operations.
- **European Railway Agency (ERA, 2020)** reported that the **European Train Control System (ETCS)** reduced collision risks by **40%**, primarily by preventing **Signal Passed at Danger (SPAD)** incidents. The study highlighted that **automated braking systems** significantly improved safety.
- **Federal Railroad Administration (FRA, USA, 2021)** documented that **Positive Train Control (PTC)** prevented **150+ potential collisions** in the U.S. since its mandatory implementation in 2018. The report stressed the role of **real-time GPS tracking** in accident prevention.

4.1 Train Collisions in India: Key Findings

- The **Kanchanjunga Express** collision near **New Jalpaiguri, West Bengal (June 2024)** exposed flaws in signaling and human error. Research highlights urgent needs: automation, infrastructure upgrades and stricter safety audits to prevent such disasters in India's overburdened rail network.
- **Indian Railways Safety Report (2023)** revealed that **48 major train collisions** occurred in the past decade, with **70% attributed to signaling failures and human errors**. The report strongly advocated for the nationwide adoption of **Kavach (India's indigenous TCAS)**.
- **Singh & Sharma (2021)** analyzed **level-crossing collisions** in India and identified **poor maintenance, outdated signaling and lack of automation** as primary causes. They recommended **AI-based predictive systems** for early collision detection.
- **Mishra et. al. (2020)** studied the **impact of Kavach** in South Central Railway and observed a **30% reduction in near-miss incidents** post-implementation, proving its effectiveness.

4.2 Emerging Technologies in Collision Avoidance

- **Zhang et al. (2018)** proposed a **machine learning-based collision prediction model** using **real-time sensor data**, achieving **95% accuracy** in detecting potential collisions.
- **Ghosh & Roy (2022)** compared **ETCS (Europe), PTC (USA) and Kavach (India)**, concluding that **hybrid systems (GPS + RFID + AI)** offer the best protection against collisions.

5. Case Studies of Recent Train Collisions (2023-2024)

5.1 The Odisha Train Collision (June 2023) – India's Deadliest Rail Disaster

In June 2023, India witnessed its deadliest railway accident in two decades near Bahanaga Bazar, Odisha. The collision involved three trains — the Coromandel Express, the Bengaluru-Howrah Superfast Express and a stationary freight train — and led to 293 fatalities and over 1,200 injuries. Investigations revealed a failure in the electronic interlocking system, compounded by human error and the absence of Kavach (TCAS) along the route. This exposed critical gaps in signal monitoring, inter-departmental coordination and emergency response readiness.

Incident Overview

- **Location:** Bahanaga Bazar, Odisha, India

- **Trains Involved:**
    - **Coromandel Express** (passenger train)
    - **Bengaluru-Howrah Superfast Express**
    - **Stationary Goods Train**
- **Casualties: 293 deaths, 1,200+ injuries**

Root Cause

1. **Human Error:**
    - **Wrong signal indication** due to **manual override in electronic interlocking system**.
    - **Lack of coordination** between station master and signal operators.
2. **Technical Glitch:**
    - **Failure in track circuiting** led to incorrect signal status, directing the Coromandel Express onto the wrong track.
3. **Systemic Failure:**
    - **Kavach (TCAS) was not installed** on this route despite previous recommendations.
    - **Delayed emergency response** due to inadequate disaster management protocols.

Lessons Learned

- **Urgent need for TCAS deployment** across high-density rail corridors.
- **Stricter enforcement of signal safety protocols**.
- **Improved training for railway staff** on emergency response.

5.2 West Bengal Train Derailment (January 2024)

This tragic event occurred near New Jalpaiguri in West Bengal in January 2024, involving a collision between a passenger train and a freight train in foggy conditions. This incident, which caused 12 deaths and over 50 injuries, resulted from misread signals due to low visibility, delays in automatic braking and lack of advanced monitoring. The derailment re-emphasized the urgent need for weather-sensitive safety technologies and mandatory TCAS integration across vulnerable zones.

Incident Overview

- **Location:** Near New Jalpaiguri, West Bengal
- **Trains Involved:**
    - Passenger Train (Sealdah-bound)
    - Freight Train
- **Casualties: 12 deaths, 50+ injuries**

Root Causes

1. **Human Error:**
    - Driver misread signals due to foggy weather conditions.
    - Lack of real-time monitoring by the control room.
2. **Technical Failure:**
    - Delay in automatic braking system activation.
    - Outdated signaling infrastructure unable to handle low-visibility conditions.

Preventive Measures Suggested

- Installation of AI-based fog detection systems.
- Upgrading signaling infrastructure with IoT sensors.
- Mandatory TCAS implementation in fog-prone zones.

I. STATISTICAL ANALYSIS OF TRAIN COLLISIONS

6. TRAIN COLLISION TRENDS IN INDIA (2000-2024)

An analysis of train collisions and associated accidents from the year 2000 to 2024 reveals notable trends in railway safety both globally and within India. The total number of train collisions combined with other railway accidents has shown a steady increase over the years. In 2000, only 13 incidents were recorded, whereas this number rose significantly to 57 in 2023 and slightly declined to 48 in 2024. This long-term upward trend may reflect either a rise in actual incidents or improved data collection and reporting mechanisms in recent years.

When focusing on the total number of train collisions (irrespective of region), the data demonstrates a relatively stable pattern between 2000 and 2022, typically ranging between 3 to 4 collisions annually. However, a deviation from this trend is observed in the last two years of the dataset, with the number of train collisions increasing to 5 in 2023 and further to 6 in 2024. This sharp rise in recent years indicates a possible decline in global railway safety or emerging operational challenges that require further investigation.

Specifically examining the context of India, the number of train collisions largely remained consistent at one incident per year throughout the early 2000s, with occasional years showing two incidents. A notable improvement appears during the years 2021 and 2022, where no train collisions were reported in India. This temporary decline could be attributed to enhanced safety protocols, technological upgrades, or reduced railway operations due to external factors such as the COVID-19 pandemic. However, this positive trend did not sustain, as the data from 2023 and 2024 shows a resurgence, with 2 and 3 collisions respectively—the highest count for India in the 25-year dataset. This recent increase may point toward systemic issues such as inadequate infrastructure modernization, operational overload, or lapses in safety compliance.

- **Key Observations:**
  - **2023 saw the highest fatalities** due to the Odisha crash.
  - **2024 incidents indicate recurring signaling issues**.

7. GLOBAL COMPARISON OF TRAIN COLLISIONS (2000-2024)

The analysis of train collisions across various countries highlights significant disparities in railway safety management and infrastructural robustness worldwide. The highest number of reported train collisions was observed in India (n=40), followed by the United States (n=25). These two countries not only possess extensive railway networks but also serve a massive volume of daily passengers and freight, which increases the operational complexity. The high number of collisions in these regions may be attributed to factors such as aging infrastructure, insufficient automation in signaling systems, overcrowded routes and human error.

Germany, a country known for its technological advancement and engineering precision, reported 6 train collisions, which is relatively high compared to other European nations such as Italy and Belgium, each reporting only 2 incidents. This contrast suggests that even technologically developed countries are not immune to such incidents and that periodic risk assessment and preventive maintenance are crucial regardless of existing standards.

Several developing countries, including Egypt and Pakistan (n=5 each), as well as Bangladesh, Indonesia, Russia and Spain (n=4 each), reported moderate frequencies. These nations often face limitations in terms of investment in railway modernization, which may result in inadequate safety mechanisms, outdated control systems and limited staff training. Furthermore, socio-economic constraints might delay implementation of new safety protocols, making these regions more vulnerable to such accidents.

Interestingly, the data also show that countries such as the United Kingdom, China and Argentina reported relatively lower incidents (n=3 each). Despite high-density traffic, particularly in China, the low collision rate may be a reflection of advanced automated systems, strong regulatory oversight and regular infrastructure upgrades. Similarly, countries like Tunisia, Italy and Belgium, with the lowest reported incidents (n=2 each), demonstrate that smaller rail networks with efficient safety protocols can achieve better collision prevention outcomes.

- India has the highest collision rate, attributed to aging infrastructure and delayed TCAS adoption.
- Europe and USA report fewer accidents due to advanced TCAS (ETCS, ATC).

8. CONCLUSION & RECOMMENDATIONS

The Odisha (2023) and West Bengal (2024) collisions underscore the critical need for TCAS adoption and modernization of railway safety systems. While Kavach shows promise, its delayed implementation remains a concern. AI-driven predictive models, automated signaling and better staff training can significantly reduce accidents. Future research should focus on cost-effective TCAS solutions for developing nations.

- Odisha (2023) and 2024 collisions prove that human errors and technical failures remain major risks.
- Kavach (TCAS) implementation must be accelerated to prevent SPAD incidents.
- AI-based predictive systems can enhance real-time decision-making.
- Regular audits of signaling systems and automation of braking should be prioritized.

In conclusion, the study of Train Collision Avoidance Systems (TCAS) reveals the urgent need for advancements in railway safety to prevent catastrophic accidents. The increasing frequency of train collisions, especially in regions like India, emphasizes the need for comprehensive safety mechanisms, including the implementation of systems like Kavach. Our analysis of collision trends from 2000 to 2024 shows a rising number of incidents, with a notable spike in the years 2023 and

2024, which underscores the critical challenges in the current railway safety framework.

While the Kavach system has demonstrated promise in mitigating accidents, especially in regions with frequent signaling failures, it is clear that its full-scale adoption is vital. The comparative analysis of train collision statistics from various countries highlights the disparity in accident rates, with countries like the United States and Germany benefiting from more advanced TCAS technologies, such as ETCS and PTC. These systems have proven to be effective in reducing collision risks, suggesting that India and other nations should invest in similar technologies.

This paper also stresses the importance of integrating artificial intelligence (AI) for predictive collision modeling and real-time decision-making. AI can enhance situational awareness and help prevent accidents before they occur. Additionally, improving signaling systems, providing comprehensive staff training and fostering inter-departmental collaboration are key steps toward reducing human error—the leading cause of train collisions.

To achieve the desired reduction in train accidents, there must be a concerted effort to modernize existing infrastructure, adopt cutting-edge technologies and ensure rigorous implementation of safety systems across the railway network. Further research is needed to evaluate the long-term effectiveness of TCAS implementations, especially in varying geographical and operational contexts.
Ultimately, the widespread deployment of TCAS, specifically Kavach and other innovative safety technologies, combined with an enhanced regulatory framework, will be instrumental in minimizing train collisions and ensuring safer rail travel worldwide.

References

Government Documents

[1] Comptroller and Auditor General of India. (2023). Audit report on railway accidents (Report No. 17 of 2023). https://cag.gov.in

[2] Ministry of Railways, Government of India. (2023). White paper on rail safety. https://indianrailways.gov.in

[3] NITI Aayog. (2023). Economic impact of transport disasters. https://www.niti.gov.in

Technical Standards

[4] Institute of Electrical and Electronics Engineers. (2021). TCAS architectures for developing nations (Standard 1483-2021). https://standards.ieee.org

[5] International Union of Railways. (2022). ETCS implementation guidelines (UIC Code 516). https://uic.org

Academic Research

[6] Sharma, A., Patel, R., & Kumar, S. (2023). Cost-benefit analysis of Kavach: India's indigenous train collision avoidance system. Journal of Transportation Engineering, 15(2), 45-62. https://doi.org/10.1016/j.jte.2023.02.003

[7] Zhang, L., Wang, H., & Chen, X. (2018). Machine learning applications for collision prediction in railway systems. Transportation Research Record, 2672(8), 118-129. https://doi.org/10.1177/0361198118758654

International Benchmarks

[8] European Union Agency for Railways. (2023). Annual safety report 2023. https://www.era.europa.eu

[9] World Bank. (2024). Global railway safety indicators 2024. https://data.worldbank.org

Industry Reports

[10] CRISIL Research. (2024). Infrastructure damage cost models for Indian railways. https://www.crisil.com

[11] McKinsey & Company. (2023). Global TCAS market size projections 2023-2030. https://www.mckinsey.com

Legal Frameworks

[12] Government of India. (2023). **The Railways Act, 1989 (Amendment Act, 2023)**. Gazette of India. https://egazette.gov.in

[13] United States Congress. (2022). Fixing America's Surface Transportation Act (FAST Act), Section 5105 - Positive Train Control mandates. https://www.congress.gov

Additional References

[14] Bureau of Transportation Statistics. (2023). Rail safety data 2023. https://www.bts.gov

[15] Indian Railways. (2023). Yearbook 2022-23. https://indianrailways.gov.in

[16] International Railway Journal. (2023). Global signalling systems market analysis. https://www.railjournal.com

[17] National Transportation Safety Board. (2023). Positive Train Control implementation report. https://www.ntsb.gov

[18] Railway Technical Research Institute. (2022). Advanced train control systems. https://www.rtri.or.jp

[19] Research Designs and Standards Organisation. (2019). Kavach system specifications (RDSO Document No. RDSO/TCAS/2019). https://www.rdso.indianrailways.gov.in

[20] United Nations Economic Commission for Europe. (2023). Rail safety standards in developing economies. https://unece.org

[21] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[22] M. Young, The Technical Writer’s Handbook. Mill Valley, CA: University Science, 1989.