



# Train Collision Avoidance System (TCAS) for Safety Enhancement in Indian Railways

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**Abstract :** The Train Collision Avoidance System (TCAS) is a critical advancement in ensuring safety within the extensive Indian Railways network. This paper presents a comprehensive examination of TCAS, emphasizing its pivotal role in preventing collisions and enhancing operational efficiency contributing to smart city initiative. It integrates hardware like GPS, RFID tags and software components to monitor train movements in real-time. It provides precise movement authority and activates automatic braking when unsafe situations are detected. The potential of TCAS to collaborate with autonomous trains integrating artificial intelligence for proactive collision avoidance measures. The challenges include integration, maintenance, budget constraints and cybersecurity.

**Index Terms -** TCAS, Indian Railway & Safety, GPS, RFID tags, AI integration, Cybersecurity

## I. INTRODUCTION

Indian Railway is the world's fourth largest national railway network, spanning a total of 68,043 km, facilitating a daily operation of 13,169 passenger trains on long-haul and suburban tracks. This extensive network links about 7,325 stations across India transporting 9.5 million passengers and 4 million tons of freight traffic per day. Instances of collisions are due to human errors (or) technical deficiencies because of insufficient maintenance [1]. A brief ideology on evolution of train safety systems, from the earliest railway technology such as the Auxiliary Warning System, Train Protection and Warning System (TPWS) [2] to an Anti-collision Device (ACD). TCAS [3] main features are Automatic Train Protection (ATP) for inter-locomotive communication to prevent collisions and SOS (Save our Souls) either when trains are in same tracks (or) when the train exceeds the speeding limit, Automatic braking system (ABS), cab-based indications, LC gate audio-visual alerts and dynamic Movement Authority updates. Radio modem Antenna for Radio Communication, GPS for tracking, GSM for messages, ultra-high frequency radio communication and an auto braking unit [4].

## II. LITERATURE SURVEY

Urban rail transportation safety is a critical concern, especially in scenarios where the Automatic Train Protection (ATP) system may be ineffective. Several researchers have explored innovative approaches to address this challenge. An approach, proposed by Yang Gao and colleagues [5], combines Symmetrical Double-Sided Two-Way Ranging (SDS-TWR) for precise long-distance measurement and RFID labels for equitable communication channel access. SDS-TWR, effective in GPS-limited areas, provides accurate wireless train location modeling. This system also tackles signal collisions in multi-train scenarios using the CSMA/CA method and a range of hardware components, including STM32 and Nanopan5375. Another significant addition stems from T Dhanabalu's team [6], introducing the Train Tracking Chip (TTC) and Train Identification Chip (TIC) modules. These modules detect nearby trains and transmit signals via GSM networks to assess collision risks. Their system leverages an Android platform, ultrasonic and MEMS sensors, and traditional Walkie-Talkies to maintain safe distances between trains. It also employs a 'scratch pad' sensor for precise train position detection, with LabVIEW, a graphical programming environment, facilitating data analysis at Train Traffic Control Stations (TTCS). Kangmi Lee and collaborators propose a vision-based collision avoidance system [7], which relies on image recognition, sensors (radar, Lidar, ultrasonic), and radio-based systems. The system distinguishes between normal and special mode operations to prevent close proximity collisions effectively. Smita S. Bhavsar's work addresses the need for cost-effective solutions in implementing an Automatic Collision Detection (ACD) system on Indian Railways tracks [8]. The system utilizes GPS for tracking and detection and RFID tags on track segments. ARM Controllers and GSM communication ensure real-time collision prevention. Unmanned crossings are equipped with Light Dependent Resistor (LDR) sensors to detect obstacles and alert the base station through GSM, contributing to safer rail operations. Shreya Patil introduces a novel train safety system utilizing UV and IR sensors, GSM technology, and an LPC2148 processor to detect obstacles and track cracks [9]. This system communicates wirelessly with Train Traffic Control Stations (TTCS) and sends SMS alerts in case of issues, promising all-weather operation and potential train collision prevention. In comparison to these innovative solutions, the TCAS integrates hardware and software components, including GPS and RFID tags and excels in safety measures, fail-safe communication, and centralized monitoring, ensuring real-time speed and location display.

### III. METHODOLOGY OF TCAS

The Train Collision Avoidance System (TCAS) is an Automatic Train Protection (ATP) system designed to enhance railway safety by preventing Signal Passing at Danger (SPAD), excessive speeds, and collisions. TCAS operates by updating the Movement Authority, indicating the safe distance for train travel. It relies on a combination of hardware and software components, real-time communication networks and sophisticated algorithms to ensure safety and transportation efficiency. Figure 1 illustrates the block diagram of TCAS system interfaces, providing an overview of the system's hardware and software elements.

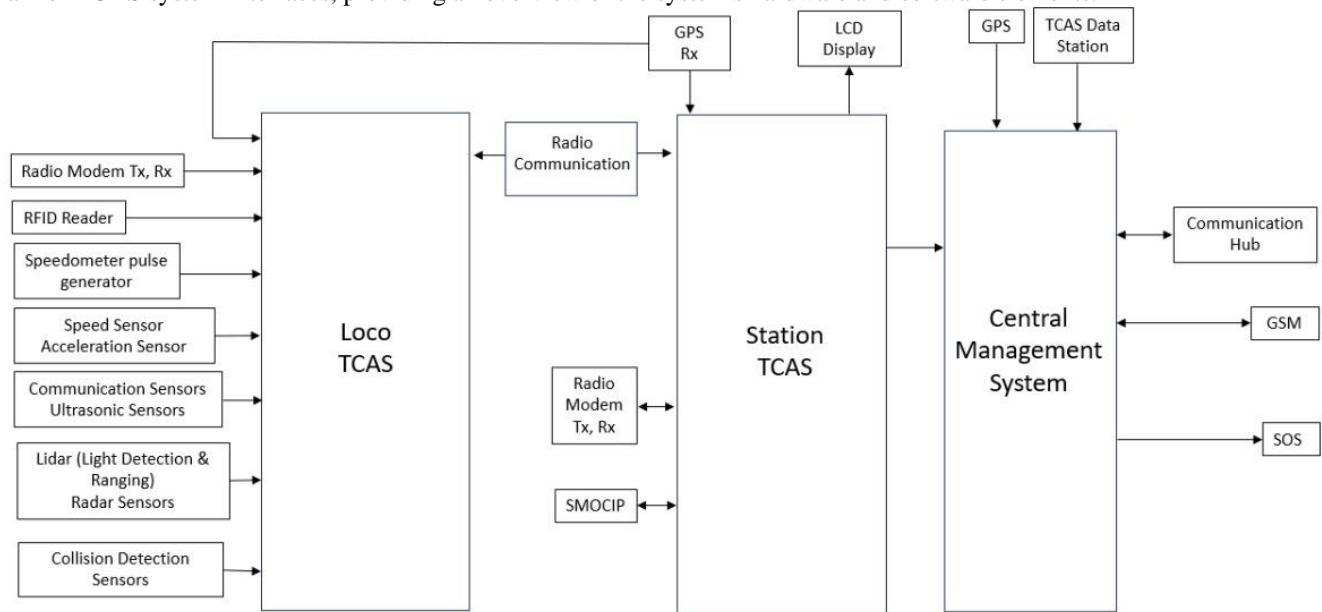


Figure 1: TCAS block diagram

#### 3.1 Communication Protocols

TCAS employs various communication protocols for seamless data exchange between a locomotive and control center. Full Duplex Ultra-High Frequency (UHF) Radio Communication, operating in the UHF band (frequency range of 300 MHz to 3 GHz), enabling simultaneous two-way communication and GSM/GPRS employed to transmit failures, securely exchange keys, ensuring time synchronization and any redundancy measures to prevent failures while providing reliable voice and data communication through GSM, enhancing data transmission capabilities through GPRS.

#### 3.2 Onboard Equipment

Critical onboard equipment has a GPS receiver for precise positioning, Radio Modem Antenna for real-time communication transmitting train status updates, receiving commands from a control center, or communicating with other trains on the track to ensure safe and efficient operation, Brake Control Unit to initiate a halt in unsafe situations, preventing SPAD incidents.

#### 3.3 Onboard Sensors

Onboard sensors continuously monitor parameters like speed (to measure velocity) and acceleration (to measure and detect motion) during to ensure safe distances, prevent excessive speeds, activate automatic braking when necessary, enabling effective message exchange with train stations, swift SOS alert initiation during emergencies. GPS positioning data maintains accurate train location tracking, using ultrasonic, Lidar (or) Radar technologies collision detection sensors identify obstacles and collisions and gives timely braking (or) warnings to prevent accidents.

#### 3.4 Runway Edge Equipment

TCAS integrates railway signals and signs to determine the train's location and route accurately. Sensors nearby (or) at LC gates provide data verification, enhancing system accuracy. RFID (Radio-Frequency Identification) is a crucial component of TCAS and RFID tags are placed at 1-kilometer intervals along railway tracks, enabling precise train tracking, direction detection and collision avoidance. As train passes through an RFID tag, it sends a unique identifier to TCAS, ensuring accurate positioning, timely brake activation and SOS commands in any scenario of collision. RFID ranges, signifying the effective distances between onboard RFID readers and track tags, guarantee system reliability and accuracy.

#### 3.5 Control Center Hardware

TCAS network relies on a central management unit (CMU), responsible for overseeing system monitoring and control which continuously collects data from various sources - onboard sensors, GPS, RFID tags on the tracks. It communicates maintaining real-time contact between the control center and TCAS-equipped trains, allowing movement authorities and coordinate emergency responses.

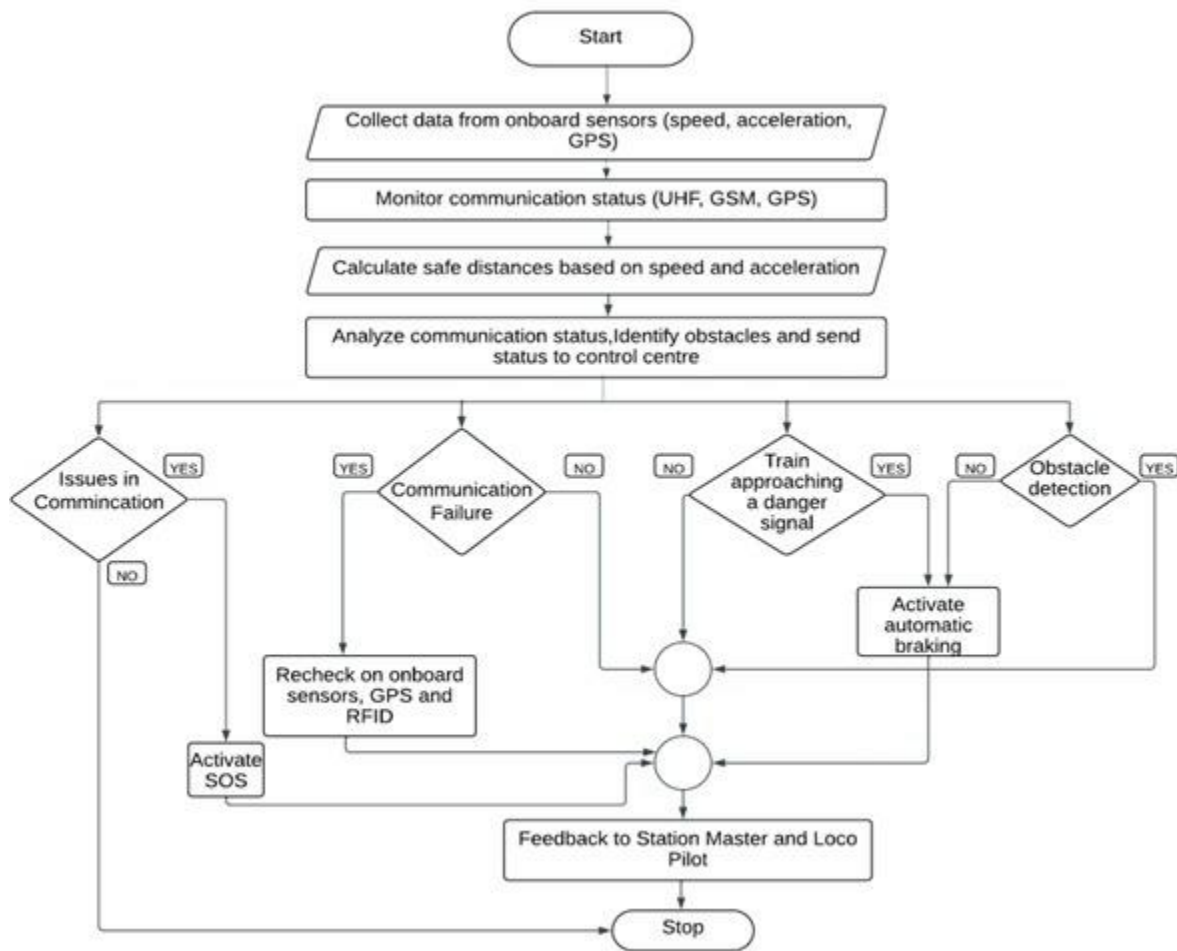


Figure 2: flow chart of TCAS

As indicated in Figure 2 in the initial phase, system acquires data from sensors onboard trains, and communicates status to the processing phase and enters the Data Processing Phase, where it calculates safe distances and identifies obstacles and gives real time updates to authorities so that swift responses can be achieved. Safety Check evaluates whether the train is approaching danger signals or if obstacles. Additionally, the system offers SOS activation during emergencies, enhancing its emergency response capabilities. The Control Center plays a pivotal role in receiving and analyzing train data, issuing movement authorities, and closely monitoring the system's overall status. In passenger trains, it may also facilitate public communication during critical situations enhancing overall passenger safety.

#### IV. RESULT

The TCAS demonstration was conducted with the primary objective of showcasing its effectiveness in enhancing safety within the Indian Railways network. The experiment focused on key features such as real-time collision avoidance, automatic braking, and the seamless integration of hardware and software components which included a representative section of the railway track, encompassing GPS, RFID tags, and communication systems. The results demonstrated TCAS's successful real-time monitoring of train movements, prevention of collisions through Automatic Train Protection (ATP), and responsive activation of the Automatic Braking System (ABS) to avert Signal Passing at Danger (SPAD) incidents as shown in Figure 3.



Figure 3: DMI showing over speed

The communication protocols, utilizing Full Duplex Ultra-High Frequency (UHF) Radio Communication and GSM/GPRS systems, showcased seamless data exchange, ensuring reliable voice, data communication and the integration of hardware, including onboard sensors and RFID tags, proved effective in precise train tracking and collision avoidance. In the event of errors or emergencies, an SOS message was received as shown in Figure 4, highlighting the system's robustness and its capacity to swiftly respond to critical situations.

TCAS FIELD DEMO:  
 L:28016  
 SPAD at 13:18:14  
 on 15/07/23  
 Abs Location: 52742.

Figure 4: SOS message



Figure 5: RFID tag fixed on a sleeper

The positive outcomes of the demonstration position TCAS for further integration and widespread adoption to enhance the overall safety and efficiency of the railway system.

**V. CONCLUSION**

The Train Collision Avoidance System (TCAS) represents a critical advancement in enhancing safety within the Indian Railways. This is highlighted by the tragic train collision in Odisha [10], resulting in 275 casualties and over 1,000 injuries, which underscores the urgent need for advanced safety technologies like TCAS in India's extensive railway network. TCAS is a comprehensive solution that incorporates real-time monitoring, automatic braking, and robust communication capabilities. These features could have effectively prevented the catastrophe in Odisha, which was caused by signal faults and human errors. TCAS's fail-safe measures and advanced warning systems are particularly vital in high-speed rail travel scenarios. However, TCAS is not just a technological innovation; it embodies a visionary approach to the future of Indian rail transportation. It promises passengers and cargo an unprecedented level of security and efficiency. As TCAS continues to evolve, its integration of artificial intelligence, collaboration with autonomous trains, and addressing of human factors and public awareness will be instrumental in shaping the future of Indian railways. Through meticulous planning and a steadfast commitment to overcoming obstacles, TCAS has the potential to play a pivotal role in ensuring safer, more efficient, and interconnected rail travel for generations to come, safeguarding lives and the nation's economic interests.

## VI. CHALLENGES OF TCAS

Challenges and limitations of TCAS occur due to adverse weather conditions such as heavy rain, fog, and snow, which can disrupt RFID tags and optical sensors. To counter this, protective measures like weather-resistant equipment like sealed enclosures, waterproofing, corrosion-resistant materials, temperature control systems, vibration and shock resistance, specialized coatings, effective airflow management and real-time weather monitoring can be placed. In high-traffic areas, radio frequency congestion can hinder communication, prompting the use of advanced antenna technology like directional antennas and beamforming. Data security is maintained through robust encryption and access controls, with regular security audits to fend off unauthorized access and cyber threats. A phased integration approach, compatibility testing, and system upgrades ensure seamless integration.

## VII. FUTURE SCOPE

TCAS in Indian Railways holds significant promise, with advancement in technologies the integration of artificial intelligence (AI) and machine learning algorithms can bolster predictive capabilities, leading to more proactive collision avoidance measures. Self-driving trains can help create a super smooth and really effective train system thereby minimizing human errors such as operating and fatigue management, to enhance safety. Evaluating the economic impacts of TCAS, including potential cost savings and efficiency gains, is essential for widespread adoption. Public awareness campaigns can foster trust and acceptance among passengers. The wide-spread integration of TCAS into smart cities and transportation networks offers a comprehensive approach to railway safety and efficiency, ensuring a bright future for TCAS in Indian Railways.

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