# SMART INDIA HACKATHON 2025

## TEAM NIRMAAN

- **Problem Statement ID-** SIH25020
- **Problem Statement Title-** Development of indigenous contactless Integrated Track Monitoring Systems (ITMS) for Track Recording on Indian Railways
- **Theme-** Smart Automation
- **PS Category-** Hardware
- **Team ID-**
- **Team Name-** NIRMAAN

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# IDEA TITLE

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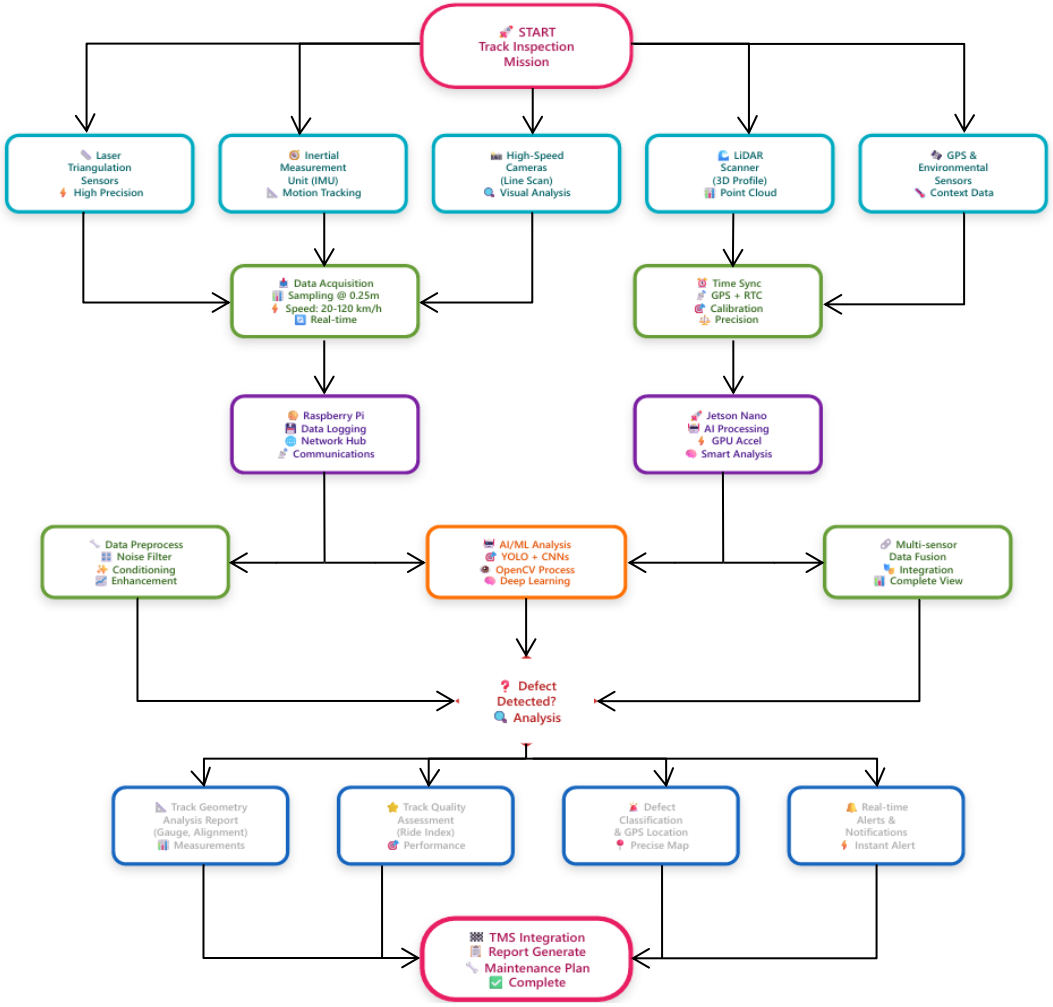
- **Overview:** The **Integrated Track Monitoring System (ITMS**) project was initiated by the **Indian Railways** to provide the most up-to-date **diagnostic tools for the accurate assessment of the network condition** and ensure the availability of the actual data required to perform **proper operation and maintenance** of the track.
- **Compact Contactless ITMS Kit:** A hardware kit that **mounts under any coach** and **performs continuous and real-time track-health monitoring** using multi-modal sensing, GNSS tagging, on-edge preprocessing, hybrid communications cloud AI for **anomaly detection and prediction,** and a web/app dashboard for maintenance teams.
- **Early detection: Multi-sensor fusion** detects surface cracks, misalignment, fastener defects, missing bolts, hotspots, and **abrupt vibration** events before they escalate.
- **Retrofit Philosophy:** A small bolt-on unit **(Mini-TRC)** that turns **any coach into a track recorder, no special TRC required**. Unlike bulky TRCs, this is **a portable kit** that can be **fitted under any coach** for trach monitoring.
- **Data Integration and Analytics:** A centralized database integrates **ITMS data with existing Indian Railways maintenance systems** and provides **historical trend analysis** for decision-making.
- **Solution:** An IoT + AI-based low-cost retrofit system **for both broad-gauge and narrow-gauge,** and the goal is to **provide real-time, comprehensive track-health data** for maintenance, including gauge-alignment, wear, cracks, fasteners, etc.



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# TECHNICAL APPROACH

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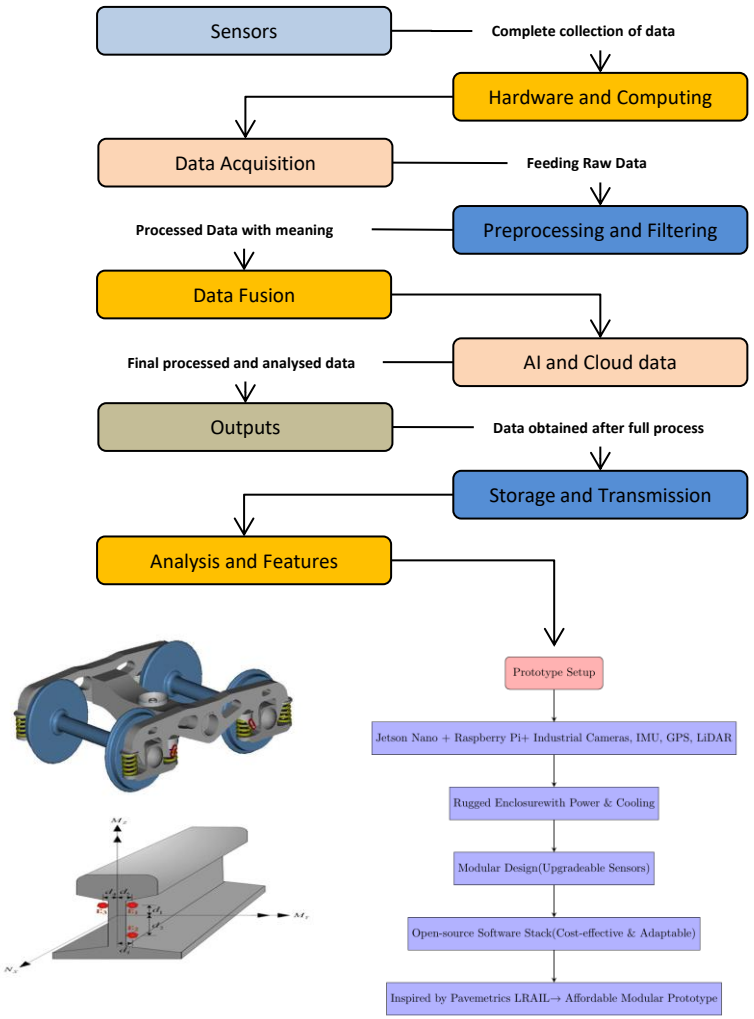
**Sensor Suite:** Dual laser triangulation sensors to check alignments and twists.
Inertial sensors for vertical as well as horizontal unevenness.
High-speed cameras for track inspection, such as missing clips, bolts, fasteners, and ballast.
Inertial references for ride quality.
LiDAR for safe operating distance from structures.
Defect detection by AI-based vision, IMUs, optical sensors, GPS, and temperature-humidity sensors.

**Hardware and Compute Platform:** Jetson Nano for on-board AI interface.
Raspberry Pi to log data and networking.
A strong EMI-shielded enclosure, TRC auxiliary supply or battery, cooling fans, and vibration isolation mounts ensure the smooth operation of the prototype.

**Data Acquisition and Processing:** Sampling is performed at ~0.25 m per 25 cm, covering speeds ranging from 20 km/h to 120 km/h.
On-board computation using Pi and Jetson for time synchronization for GPS with RTC.
Preprocessing and noise filtering.
Real-time extraction of geometry, wear, and vibration features.
Data fusion is done by combining lasers, IMUs, cameras, and LiDAR for comprehensive defect mapping.

**Software and AI:** YOLO, custom CNNs, and OpenCV for preprocessing.
Ride quality from accelerometer data.
Rail wear profiles from LiDAR/laser scanners.
Python and ROS for integration.
Dataset labelling with Roboflow.

**Prototype Setup:** Use Jetson Nano with Raspberry Pi with industrial cameras, IMU, GPS, and a low-cost LiDAR, all in a rugged enclosure with power and cooling.
The system is modular, so sensors can be upgraded later for better performance.
Runs on an open-source software stack, making it cost-effective and easy to adapt.
Inspired by Pavemetrics' LRAIL system but built as an affordable, modular prototype for real-time inspection and post-run analysis.



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# FEASIBILITY AND VIABILITY

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## Feasibility (Technical)

- Low-cost, proven sensors like ultrasonic, accelerometers, cameras, and GPS are widely available in India.
- Platforms like ESP32, STM32, Jetson Nano, and Raspberry Pi can handle preprocessing with AI models and the Cloud.
- Real-time communication is feasible using LoRa for Rural areas and Wi-Fi/4G for Urban areas.
- Power independence is possible via the use of solar, provided with battery backup.

## Viability (Operational)

- Works on both Broad-Gauge and Narrow-Gauge lines.
- Rugged modular design, which is suitable for India's extreme weather and vibration conditions.
- Can be scaled from a prototype ~₹80k–100k to a large deployment fleet.

## Use Cases

- Indian Railways Safety Monitoring: Prevent derailments by detecting cracks, weld failures, misalignments, and hot-spots.
- Predictive Maintenance: Railway engineers get early alerts, reducing downtime.
- Urban Metro Systems: Use in metro/rapid transit for high-frequency monitoring.
- Private Rail Corridors / Freight Corridors: Ensures reliability of cargo routes.
- Export Potential: Low-cost monitoring kits for developing countries with large rail networks, like Africa and Southeast Asia.

## Challenges

- Sensor Noise and Reliability: False positives/negatives due to vibration or weather.
- Ruggedization: Dust, rain, heat.
- Real-time Data Transfer: Limited connectivity in rural zones.
- Maintenance of IoT Kits: Regular calibration of sensors.
- Adoption Resistance: Railways may be hesitant to replace established TRCs.

## Solutions to Challenges

- Sensor Noise: Apply digital filtering with multi-sensor fusion for higher accuracy and good results.
- Ruggedization: Use IP65 enclosures, vibration-damping mounts, and industrial-grade components.
- Connectivity Issues: Hybrid approach, LoRa for Rural areas, 4G/Wi-Fi for Urban areas, with local SD card backup.
- Calibration: Automated self-check algorithms and maintenance dashboard.
- Adoption Resistance: Pilot projects with RDSO and demonstrate cost savings along with safety benefits.

## Business Potential

- Indian Railways' safety and maintenance market is worth ₹5,000+ Cr annually.
- Potential to replace or complement TRCs with thousands of retrofit kits.
- Sell kits directly to Indian Railways and Metro corporations (B2G Business).
- Cloud-based dashboard, predictive maintenance reports as a paid service.
- Affordable indigenous kits for developing rail markets abroad.

### Supporting Facts for Feasibility and Viability

- Indian Railways already uses Track Recording Cars (TRCs), but their high cost and limited availability mean low coverage, and there are only 7 (out of which 3 are contactless ITMS) TRC machines available in India right now. Due to this, track monitoring takes place every 4 months. Our ITMS bridges this gap by enabling every train to be a monitoring train.
- India has the 4th largest railway network globally ~68,000 km. Covering this with TRCs alone is impossible; a distributed ITMS model is the only viable alternative.

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# IMPACT AND BENEFITS

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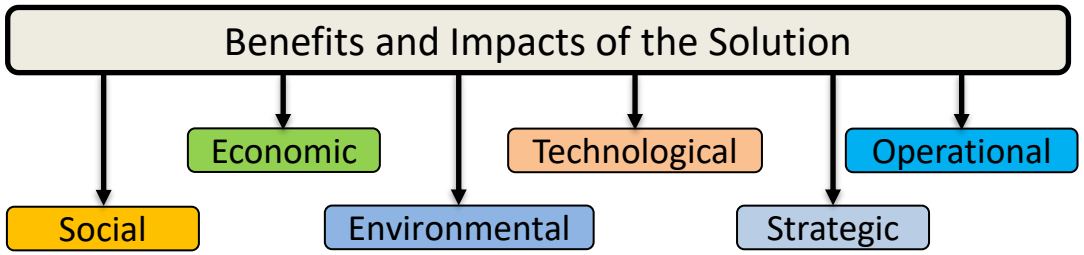


## 1. Social Impacts and Benefits

- **Continuous real-time monitoring: Prevents derailments** by detecting cracks, misalignments, and defects early.
- **Increased Safety:** Saves lives by **avoiding accidents**.
- **Trustworthy:** Builds **public confidence** in railway safety.

## 2. Economic Impacts and Benefits

- **Low-cost prototype:** The prototype costs around **~₹80k–100k.**
- **Predictive maintenance:** Highly **reduces inspection and repair costs**.
- **Punctuality boost: Improves train punctuality** by minimizing unscheduled downtime.
- **Easy Scalability:** Retrofit on multiple coaches **with minimal investment**.

## 3. Environmental Impacts and Benefits

- **Efficiency: Energy-efficient IoT devices** with battery backup, operate with solar as well, and reduce carbon footprints.
- **Increased Shelf-life:** Extends **rail track life**, reducing the need for frequent replacement of tracks.
- **Reduction in fossil fuel usage**: **Reduces fuel use** compared to heavy Track Recording Cars.

## 4. Technological Benefits

- **Multi-sensor fusion:** Uses various sensors like **ultrasonic, accelerometer, vision, strain, temperature, and GPS** for comprehensive defect detection.
- **AI/ML-based analytics: Anomaly detection, predictive maintenance, and historical defect trends** with enhanced data and higher accuracy.
- **Edge Preprocessing:** Faster **real-time alerts** with cloud backup for large-scale data.

## 5. Strategic Benefits

- **Indigenous system:** Eliminates dependence on costly foreign TRCs as well as spare parts and promotes **Atmanirbhar Bharat and Make in India** initiatives.
- **Model Upgrade:** Easily **modular and upgradable** with newer sensors or AI models.
- **Gauge Flexibility:** Can be deployed on **both Broad Gauge and Narrow Gauge** networks.

## 6. Operational Benefits

- **Continuous Monitoring:** Works continuously as **any train becomes a monitoring train**. No need to run TRC on different tracks for maintenance purposes.
- **Rugged Design:** Compact, strong, and durable **retrofit kit** that withstands harsh railway environments.
- **Seamless Connectivity: Real-time communication** via LoRa for Rural areas and Wi-Fi/4G for Urban areas ensures timely defect alerts.
- **Easy Accessibility: User-friendly dashboard and mobile app** for easy access for railway staff.

In summary, our **proposed ITMS solution is safer, cheaper, indigenous, scalable, efficient, eco-friendly, and smarter** compared to the current solution.

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# RESEARCH AND REFERENCES

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## Video References

- Video Reference 1
- Video Reference 2

| Parameter | Existing Foreign ITMS | Proposed Indigenous ITMS |
|---|---|---|
| **Deployment** | Requires dedicated Track Recording Cars (TRCs), limited availability | Compact modular kit, can be **retrofitted under any train coach for both broad gauge and narrow gauge** |
| **Cost** | **₹15–20 Cr per TRC**, high operating cost | **~₹80k–100k per prototype**, scalable per-coach deployment, low operational cost |
| **Coverage** | Limited runs, **not all tracks are inspected** frequently | **Continuous monitoring every time train runs** on the track |
| **Technology Dependence** | Mostly foreign technology, dependency for maintenance and spares | **Fully indigenous, uses low-cost and efficient sensors** |
| **Sensors** | Limited to geometry, alignment, ultrasonic, bulky hardware | **Multi-sensor fusion**: Ultrasonic, Accelerometer, Camera, GPS, Strain, Temperature |
| **Communication** | **Data collected offline**, requires manual upload and analysis | **Real-time connectivity** via LoRa for Rural areas, Wi-Fi/4G for Urban areas, instant data transfer |
| **Data Analysis** | Offline processing, **delay in anomaly detection** | AI/ML-based cloud analytics, **edge preprocessing** |
| **Power Supply** | Heavy power requirement, dependent on train engine | **Energy efficient, Battery back-up,** along with use of **solar energy** |
| **Scalability** | **Cannot scale easily**, limited to a few TRCs per zone | **Highly scalable**, that is, retrofit kits on multiple trains simultaneously |
| **Maintenance** | **High maintenance** due to complex and imported systems | **Easy maintenance using indigenous components**, railway staff trained locally |
| **Environmental Impact** | High fuel usage, periodic operation only | **Energy-efficient** IoT devices with extended track-life, reduced replacements |
| **Social Impact** | Slow response, derailments possible between TRC runs | Saves lives by **continuous real-time defect detection** and an early warning system |
| **Strategic Value** | Import-dependent, limited tech sovereignty | Indigenous product, **boosts Atmanirbhar Bharat** |