

# Predictive Maintenance in Metro Train

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## Abstract :

The dependability and effectiveness of metro systems are crucial in a time when urban transportation networks are the lifeblood of cities. This paper provides a thorough review of the ideas, applications, and impact of predictive maintenance in these systems in order to explore its revolutionary power.

Traditional maintenance methods are being redefined by predictive maintenance as a proactive strategy. Predictive maintenance enables metro operators to foresee equipment breakdowns before they happen by utilizing cutting-edge technologies like machine learning algorithms.

Predictive maintenance in metro systems has broad implications. Most importantly, it reduces downtime to guarantee continuous service for millions of commuters. Anomalies and possible failures are quickly identified by the real-time analysis of enormous information, enabling precise, just-in-time responses. This avoids both revenue losses brought on by service interruptions and operating costs related to emergency repairs. The financial effects of

predictive maintenance are significant, with metro systems saving a lot of money thanks to better resource allocation, lower maintenance costs, and extended asset lifespans.

Predictive maintenance dramatically improves safety, a key concern in public transportation. The early detection of safety-critical issues helps to avoid accidents and ensures the wellbeing of both personnel and customers. Additionally, increased safety helps foster public confidence, promote greater ridership, and promote economic development in metropolitan areas.

This study also offers a thorough examination of the technology supporting predictive maintenance. Smartly placed Internet of Things (IoT) sensors in metro systems gather real-time data on a range of characteristics, including temperature, vibration, and wear and tear. These data points are then analysed using complex algorithms that may accurately forecast equipment failures. Additional benefits come from combining smart technologies and predictive maintenance. Predictive maintenance makes metro systems into intelligent, adaptable entities when used in conjunction with smart city efforts. By minimizing environmental damage and maximizing energy use, this synergy promotes sustainable urban growth.

## **Introduction :**

The term "predictive maintenance," or simply "PdM," refers to a maintenance methodology that has developed through time in response to the shortcomings of conventional maintenance methods. There are generally two types of conventional maintenance techniques:

**Reactive Maintenance:** Also referred to as "breakdown maintenance" or "run-to-failure maintenance," this method entails only fixing or replacing tools and resources when they malfunction or experience a failure. Reactive maintenance can be expensive because of unplanned downtime, urgent repairs, and the possibility of more serious damage.

**Preventive maintenance :** is a technique that entails planned maintenance tasks, such as routine inspections, component replacements, and overhauls, based on predetermined time intervals or usage levels. While preventive maintenance seeks to lessen the likelihood of failures, it might result in unneeded maintenance and increased expenses when components break.

In response to these conventional approaches' shortcomings, predictive maintenance was developed. It makes use of technological developments in data analytics, machine learning, and real-time or almost real-time monitoring of the health and performance of infrastructure and equipment. Predictive algorithms, data gathering systems, and sensors are frequently used in this monitoring.

Predictive maintenance's historical context includes the following key components such as data gathering, condition monitoring, predictive algorithms, cost savings and efficiency and technological advancements.

Due to the special operating problems and crucial function that these transit networks provide in urban areas, metro systems place a high priority on predictive maintenance. The importance of preventive maintenance for metro systems is highlighted by the following points such as :

**Minimized Service Disruptions:** In heavily populated urban regions, metro systems are crucial forms of transportation. Any downtime or service interruptions can have a huge negative impact on commuters' daily lives and the economy as a whole. Predictive maintenance identifies and addresses maintenance needs before they develop into significant failures, hence reducing service interruptions.

**Reduced costs:** Unplanned maintenance can put a strain on the limited financial resources available to metro systems. Through the use of resources that are concentrated on the regions that require attention most immediately, predictive maintenance enables metro operators to maximize their maintenance budgets.

**Enhanced Safety:** Metro systems place a high priority on safety. By identifying and resolving possible problems before they become serious problems that could result in mishaps or operational failures, predictive maintenance contributes to the protection of both personnel and passengers. A critical incident can be avoided and the public's confidence in the dependability of the system can be preserved with this proactive approach.

**Extended Asset Lifespan:** The metro infrastructure, which consists of tracks, tunnels, stations, and rolling stock, is a significant investment. By locating and fixing problems as soon as they arise, predictive maintenance increases the lifespan of these assets. By doing so, the need for pricey replacements is diminished and the return on investment is increased.

**Operational Effectiveness:** The effectiveness of metro systems as a whole is enhanced through predictive maintenance. Metro operators may deliver more dependable and efficient services by limiting disruptions, cutting down on maintenance downtime, and optimizing maintenance schedules.

**Data-Driven Decision Making:** Predictive maintenance programs provide a ton of data that can be used to make wise choices. This information can be used by metro operators to make adjustments to their maintenance plans, schedule equipment upgrades, and allocate long-term funds for system upgrades.

**Sustainability:** The environmental impact of metro systems is decreased by effective maintenance procedures. Predictive maintenance supports sustainability objectives by prolonging asset lifespans and maximizing energy use, which helps lessen the environmental impact of metro transit.

**Regulations and Compliance:** Strict safety and compliance requirements apply to metro systems. By ensuring that infrastructure and equipment are in excellent working order and lowering the likelihood of non-compliance and the resulting fines, predictive maintenance helps operators fulfil these criteria.

**Experience for passengers:** A well-maintained metro system gives users a more reliable and pleasant ride. By eliminating delays, cutting down on problems, and guaranteeing a smooth and secure ride, predictive maintenance helps passengers feel satisfied.

To sum up, in order for metro systems to play the vital role they play in urban transportation, predictive maintenance is necessary. Predictive maintenance makes ensuring that metro systems continue to be dependable and sustainable forms of public transportation in expanding cities all over the world by minimizing downtime, cutting costs, raising safety, and boosting overall efficiency.

## Idea :

Our idea is to develop a **predictive maintenance** system for metro trains that leverages machine learning techniques to proactively identify and address potential issues in metro train components using **Machine Learning Algorithms** to ensuring safe, efficient, and reliable transportation services. The key components of our idea are as follows :

- Data Integration
- Predictive Analytics
- Maintenance Scheduling
- Cost Savings and Safety
- Early Issue Detection

## Approach :

Our approach for Predictive Maintenance in Metro is designed to revolutionize the maintenance practices in metro train systems, ensuring the safety, reliability, and efficiency of the transportation service. By leveraging machine learning algorithms, specifically Random Forest and Gradient Boosting, we aim to proactively detect and address potential issues in metro train components. The following approach outlines the systematic steps to achieve this goal.

**1. Data Collection and Integration:** We have gathered real-time data from metro train onboard systems and infrastructure, including temperature, pressure, speed, track conditions, and power systems. Centralize this data in a structured manner.

**2. Data Preprocessing:** After data integration cleaned and preprocessed the data to handle missing values, outliers, and inconsistencies. Convert timestamps into standardized formats. Aggregate data into suitable time intervals for analysis.

**3. Feature Engineering:** Created relevant features from the data, such as rolling statistics, mean, standard deviation, and trends over time. Engineer domain-specific features that capture the operational context of metro trains, considering passenger load and weather conditions.

**4. Labeling and Anomaly Detection:** Define labels for the data to indicate instances of failures or maintenance events. Implement anomaly detection techniques to identify unusual patterns or outliers in the data, which may indicate potential issues.

**5. Model Selection:** Train Random Forest and Gradient Boosting models on the training data. These ensemble models are selected for their ability to handle non-linearity, complex relationships, and dynamic data patterns.

## **6. Hyperparameter Tuning:**

Hyperparameter tuning to optimize the models' performance. Parameters such as the number of trees, maximum depth, and learning rate for Gradient Boosting are carefully adjusted.

**7. Model Training:** Train the Random Forest and Gradient Boosting models on the entire training dataset using the optimized hyperparameters.

**8. Model Evaluation:** Evaluate the models' performance on the testing dataset using key metrics such as accuracy, precision, recall, F1-score, and ROC-AUC. Ensure that the models can predict maintenance needs within acceptable time frames.

**9. Maintenance Scheduling:** Develop a maintenance scheduling system that prioritizes tasks based on the predictions. This system aims to minimize disruptions to train operations.

**10. Continuous Model Improvement:** Implement regular model updates as new data becomes available and monitor their performance. Retrain the models to adapt to changing operational conditions and evolving maintenance requirements.

**11. Cost-Benefit Analysis:** Conduct a comprehensive cost-benefit analysis to assess the economic impact of the predictive maintenance system. Consider factors such as reduced downtime, improved safety, and extended component lifespan.

This approach is underpinned by the power of machine learning and data-driven decision-making. It aims to bring efficiency, safety, and reliability to metro train operations, making it a pivotal step in modernizing the transportation sector.

## **Current Situation :**

- **Overcrowding:** Many metro systems, especially in densely populated cities, struggled with overcrowded trains during peak hours.
- **Aging Infrastructure:** Older metro systems often faced issues with aging infrastructure, including deteriorating tracks, tunnels, and stations
- **Fare Evasion and Revenue Leakage:** Some metro systems had issues with fare evasion, where passengers avoided paying for their tickets, resulting in revenue losses
- **Operational Delays:** Delays caused by technical issues, track obstructions, or accidents were common and resulted in passenger dissatisfaction and disruptions in service.

These approaches can provide a more comprehensive view of maintenance needs and help ensure that resources are allocated effectively.

## Available Methodologies :

**Condition-Based Monitoring:** Collecting and analyzing data on the condition of various components in real-time & identify potential issues before they occur.

**Reliability-centered maintenance:** Identifying critical components and developing maintenance plans that prioritize these components based on their impact on safety and operational efficiency.

**Hybrid approaches:** Combine elements of both condition-based monitoring and reliability-centered maintenance. These approaches can provide a more comprehensive view of maintenance needs and help ensure that resources are allocated effectively.

## Key benefits of our Solution :

1. **Reduced Downtime:** Predictive maintenance enables maintenance teams to address issues before they lead to system failures or breakdowns. This minimizes downtime and ensures that metro trains remain in service, reducing disruptions to passengers and the overall transportation network.
2. **Enhanced Safety:** By proactively identifying and addressing maintenance needs, predictive maintenance helps prevent safety-critical failures, such as brake malfunctions or track defects. Passengers and metro train staff benefit from a safer commuting experience.
3. **Cost Savings:** Efficient maintenance practices result in cost savings. Predictive maintenance optimizes resource allocation, reduces the need for emergency repairs, and extends the lifespan of components. This ultimately leads to reduced maintenance costs.
4. **Improved Component Lifespan:** Predictive maintenance ensures that metro train components are serviced and replaced at the right time. This extends the lifespan of expensive components like brakes, wheels, and electrical systems, reducing the frequency of replacements.
5. **Sustainability:** Extending the lifespan of components and minimizing waste from replacements aligns with sustainability goals. Predictive maintenance contributes to eco-friendly operations by reducing resource consumption and waste.
6. **Data-Driven Decision-Making:** Predictive maintenance relies on data analysis and machine learning algorithms, promoting data-driven decision-making within the organization. This can lead to better resource allocation and strategic planning.

7. **Safety for Maintenance Teams:** Maintenance personnel benefit from a safer work environment as they can proactively plan and schedule maintenance activities, reducing the need for emergency repairs in potentially hazardous situations.
8. **Operational Continuity:** Predictive maintenance helps ensure the continuity of metro train services, making them more reliable for daily commuters and essential for emergency transportation services.