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Original Article

Optimizing Rail Track Maintenance by Integrating Geometry Data with Cloud Data Lake and IoT

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Abstract *- This paper explores the real-time integration of the IBM Maximo Application Suite with Track Geometry Car (TGC) defect inspection systems. It integrates the data streaming of IoT systems by leveraging AWS Cloud Data Lake for capturing and storing data. The integration aims to enhance railway maintenance operations through advanced data analytics and asset management capabilities. By combining TGC's precise track monitoring and defect detection with Maximo's robust asset management platform, railway operators can implement more effective and proactive maintenance strategies. This integration facilitates real-time data processing, immediate defect reporting, and streamlined maintenance workflows, ultimately improving the safety and reliability of railway networks.*

Keywords *- IBM Maximo, Track Geometry Car, Railway Maintenance, Real-time Integration, AWS Cloud Data Lake, IoT, Defect Inspection, Asset Management.*

1. Introduction

A track geometry car, also known as a track inspection car or track recording car, is a specialized rail vehicle used to measure the geometry of railway tracks. These cars are equipped with various sensors, cameras, and other instruments to assess the condition and alignment of the tracks. The data collected helps in maintaining the safety and efficiency of railway operations. Here are some key aspects of track geometry cars:

1.1. Measurement Parameters

- Track Gauge: The distance between the inner faces of the two rails [3][4].
- Alignment: The horizontal position of the track [3].
- Cant/Superelevation: The difference in height between the two rails [3][4].
- Cross Level: The difference in elevation of the two rails [3][4].
- Curvature: The degree of curve in the track [3][4].
- Gradient: The slope of the track [3][4].

1.2. Technology and Equipment

- Laser Systems: Used to measure the track geometry accurately [3][4].
- Inertial Systems: Measure the accelerations and movements of the car to detect track irregularities [3][4].
- Cameras: Capture images and videos of the track for visual inspection [3][4].
- GPS: Provides precise location data to correlate measurements with specific track sections [3][4].
- Ultrasonic Systems: Detect internal flaws in the rail [3][4].

1.2. Purpose and Benefits

- Safety: Identifies potential issues that could lead to derailments or other accidents [5].
- Maintenance Planning: Helps in scheduling and prioritizing track maintenance activities [5].
- Efficiency: Ensures smooth and efficient train operations by maintaining proper track alignment and condition [5].
- Regulatory Compliance: Helps rail operators comply with safety standards and regulations [6].

1.3. Operation

- Track geometry cars can be self-propelled or can be towed by another locomotive [7].
- They can operate at various speeds, including high speeds, to simulate real operating conditions.
- Data collected is often transmitted in real-time to monitoring centres for immediate analysis and response [8].

Track geometry cars play a crucial role in the ongoing maintenance and safety assurance of railway networks [7][8].

Currently, the technology and equipment in track geometry cars don't fully integrate with other systems in real-time, nor do they fully utilize advanced data analytics or predictive maintenance. Incorporating these elements would greatly improve our ability to identify and track issues effectively and optimize maintenance schedules. To address this, current research deals with implementing a platform that collects data from track geometry car equipment and delivers real-time insights. This enables our users to make informed decisions about managing and maintaining track schedules, ensuring timely alerts and updates [7][8][9].

2. Background and Related Work

The concept of track geometry measurement dates back to the early days of railroads. Early methods involved manual inspection using simple tools like gauges, levels, and straight edges [9]. With the advancement of technology and the increasing demand for rail transportation, more sophisticated methods were developed [9][10].

2.1. Evolution of Track Geometry Measurement

2.1.1. Manual Inspections

- Early railway maintenance relied on manual inspections. Track workers would walk along the tracks with basic tools to measure parameters such as track gauge and alignment [11][12].
- This method was labour-intensive, time-consuming, and prone to human error [11][12].

2.1.2. Mechanical Devices

- By the late 19th and early 20th centuries, mechanical devices were developed to automate some aspects of track measurement [12].
- These devices often used wheels and levers to measure track geometry, providing more consistent and reliable data than manual methods.

2.1.3. Electronic Measurement Systems

- In the mid-20th century, electronic systems began to be incorporated into track geometry measurement [13].
- These systems used sensors and electronic recording equipment to capture data more accurately and efficiently [13].

2.1.4. Modern Track Geometry Cars:

- Today, track geometry cars are equipped with advanced technologies such as lasers, Inertial Measurement Units (IMUs), GPS, and high-speed data acquisition systems [14].
- These cars can measure a wide range of parameters with high precision at high speeds, allowing for comprehensive and efficient track inspections [14].

2.2. Related Work

2.2.1. Research and Development

- Ongoing research focuses on improving the accuracy and reliability of track geometry measurement systems.
- Innovations include the use of machine learning and artificial intelligence to analyze, track data, and predict maintenance needs.

2.2.2. Standards and Regulations

- Regulatory bodies such as the Federal Railroad Administration (FRA) in the United States and the International Union of Railways (UIC) set standards for track geometry measurement [15][16].
- Compliance with these standards is crucial for ensuring the safety and reliability of rail networks.

2.2.3. Data Integration and Analysis

- Modern track geometry cars generate large volumes of data. Integrating this data with other railway systems, such as asset management and maintenance planning systems, enhances decision-making [17][18].
- Advanced data analytics tools help identify trends and patterns, enabling proactive maintenance strategies.

2.2.4. International Collaboration

- Railways around the world share best practices and technologies related to track geometry measurement.
- International conferences, workshops and collaborative projects contribute to the global advancement of track geometry inspection techniques.

2.3. Key Contribution to the Field

2.3.1. Laser-Based Systems

- The development of laser-based systems revolutionized track geometry measurement by providing high-precision measurements of track parameters [20].
- These systems can detect even minor deviations in track geometry, enhancing the safety and efficiency of rail operations [20].

2.3.2. Inertial Measurement Units (IMUs)

- IMUs use accelerometers and gyroscopes to measure the motion and orientation of the track geometry car.
- This technology helps detect irregular track alignment and curvature irregularities, especially in dynamic conditions [19].

2.3.3. Real-Time Data Transmission

- The ability to transmit data in real-time from track geometry cars to central monitoring centres allows for immediate analysis and response.
- This capability addresses urgent maintenance needs and prevents potential safety issues.

2.4. Future Directions

2.4.1. Automation and Robotics

- The use of autonomous track geometry cars and drones for track inspection is an emerging area of interest [21].
- These technologies have the potential to further improve the efficiency and safety of track inspections [21].

2.4.2. Enhanced Data Analytics

- Advances in big data and machine learning are expected to enhance the analysis of track geometry data.
- Predictive maintenance models will become more accurate, reducing maintenance costs and improving rail network reliability.

2.4.3. Integration with Other Rail Systems

- Integrating track geometry data with other rail systems, such as signalling and train control systems, will provide a more holistic view of rail operations.
- This integration will support more effective decision-making and resource allocation [17].

3. Methodology

The focus of this paper is on managing and integrating track geometry inspection data with Asset Management Systems (IBM Maximo) from AWS Data Lake using service pipelines to cleanse the humongous volume of data that's being generated from IoT (Internet of things) to enhance the safety of train operations.

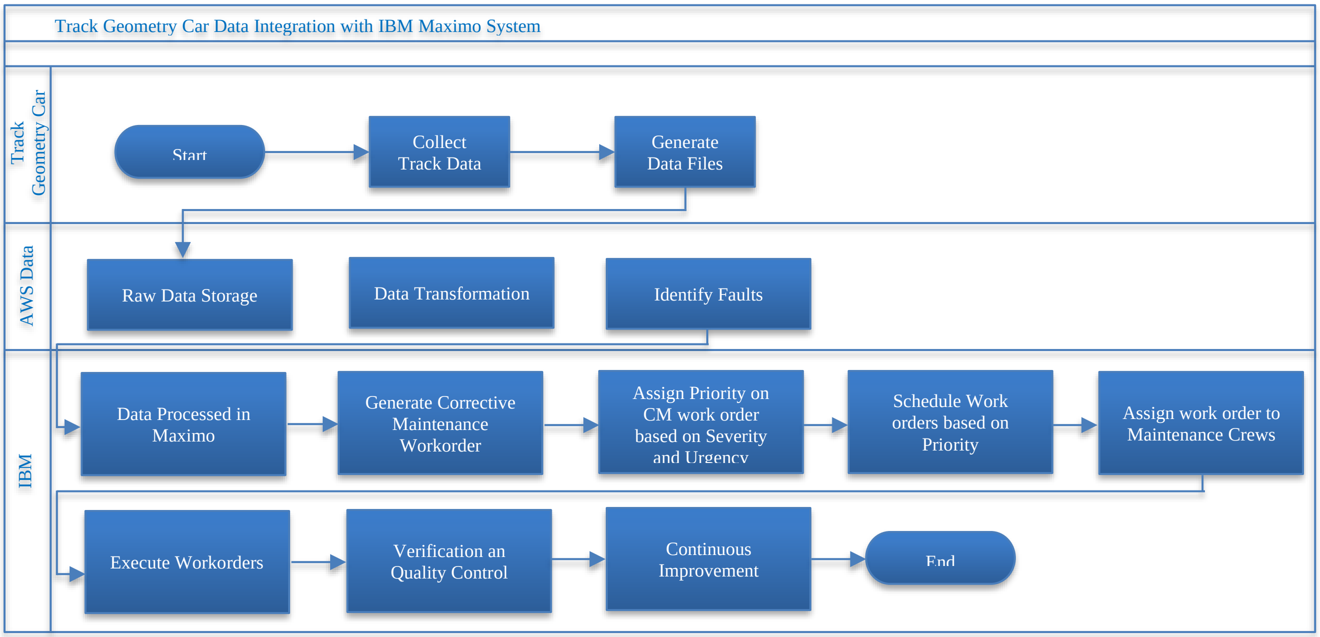

Fig. 1 Process flow of Integrating Track Geometry data with a cloud data lake and IoT

3.1. Data Collection and Analysis

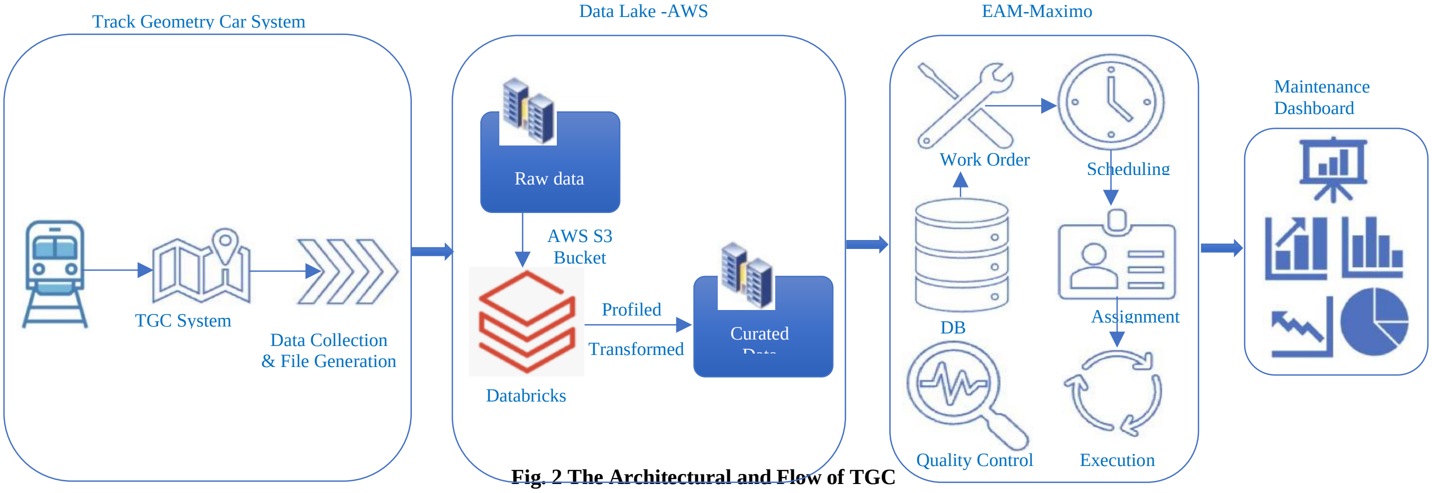

Fig. 2 The Architectural and Flow of TGC

3.1.1. Data Acquisition

- As the track geometry car travels, it collects data on various track parameters using sensors and measurement tools [23].

3.1.2. Data Processing

- Raw data is processed to filter out the noise and irrelevant information, ensuring that only accurate and relevant data is analyzed [23].

3.1.3. Defect Identification

- Algorithms and software analyze the processed data to identify defects such as misalignments, gauge variations, surface irregularities, and internal rail flaws [24].

3.2. Prioritization of Defects (Sampling and prioritization)

3.2.1. Severity Assessment

- Each identified defect is assessed for its severity and potential impact on safety and operations [24].

3.2.2. Urgency Determination

- Based on severity, defects are categorized by urgency as per the rule base, determining which issues need immediate attention and which can be scheduled for later [24].

3.3. Work Order Generation

3.3.1. Defect Documentation

- Detailed documentation for each defect is created, including the type of defect, its location, severity, and any additional relevant information.

3.3.2. Work Order Generation

- Using a computerized maintenance management system (CMMS) or similar software, work orders are generated for each identified defect [28].
- Each work order includes [30]:
    - Defect Description
    - Location Details
    - Severity and Urgency
    - Recommended Actions
    - Resource Requirements

3.4. Scheduling and Assignment

- Work orders are reviewed and scheduled based on priority and available resources. High-priority defects are scheduled for immediate action, while less critical issues are planned for regular maintenance as per SLA's defined [28].
- Maintenance teams or contractors are assigned to each work order based on their expertise, availability, and the specific requirements of the task [28].

3.5. Execution of Work Orders

- Maintenance teams carry out the necessary repairs or adjustments as specified in the work orders [28].
- Teams document the completion of each task, including any deviations from the work order, additional findings, and the outcomes of the repairs [28].

3.6. Verification and Quality Control

- After maintenance work is completed, follow-up inspections are conducted to ensure that the defects have been properly addressed and that the track meets safety and operational standards.
- Results of the repairs and inspections are fed back into the data system to update the condition records and improve future defect detection and maintenance planning.

3.7. Continuous Improvements

- Analyzing the effectiveness of the completed work orders and overall maintenance strategy to identify areas for improvement.
- Refining maintenance procedures, work order processes and defect detection algorithms based on insights gained from completed work orders and follow-up inspections.

By following these steps, rail operators can efficiently convert track geometry car data into actionable work orders, ensuring timely maintenance and repairs that enhance the safety and reliability of the rail network.

3.8. Sample Track Geometry data and trend lines

Table 1. Various track geometry measurements

Measurement Point	Gauge (mm)	Alignment (mm)	Elevation (mm)	Curvature (1/R)	Cross-Level (mm)
1	1435	2	10	0.0005	5
2	1436	3	12	0.0006	4
3	1434	1	8	0.0004	6
4	1435	2	11	0.0005	5
5	1436	3	13	0.0007	4
6	1435	2	9	0.0006	5
7	1434	1	10	0.0005	6
8	1435	2	12	0.0006	5
9	1436	3	14	0.0007	4
10	1435	2	11	0.0005	5

3.8.1. Explanation of Columns

- Measurement Point: Sequential point number where the measurements are taken.
- Gauge (mm): The distance between the inner sides of the two rails.
- Alignment (mm): Horizontal deviation of the track from the ideal centerline.
- Elevation (mm): The vertical position of the track relative to a reference level.

- Curvature (1/R): The inverse of the radius of curvature, indicating the sharpness of the curve.
- Cross-Level (mm): The difference in height between the two rails, also known as “cant”.

This data is typically collected using specialized track geometry cars equipped with a variety of sensors and measurement devices. The data is then analyzed to identify any deviations from standard track geometry, which can indicate areas in need of maintenance or repair.

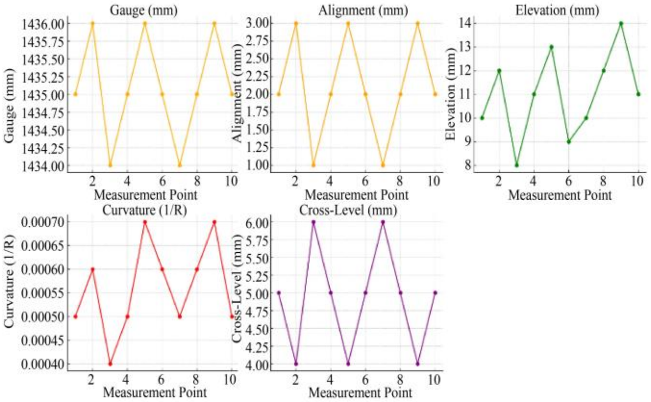

Fig. 3 Visualization of track geometry data (Gauge, Alignment, Elevation, Curvature and Cross-Level) presented in Table 1.

These visualizations can help identify patterns and potential issues in track geometry.

4. Results and Discussion

Integrating a track geometry car with IBM Maximo using an AWS Data Lake can bring several improvements and benefits.

4.1. Improved Data Management

- AWS Data Lake enables centralized storage of all track geometry data, making it easily accessible for various applications, including IBM Maximo.
- AWS Data Lake can handle large volumes of data, allowing for efficient storage and retrieval of extensive track geometry data over time [25].

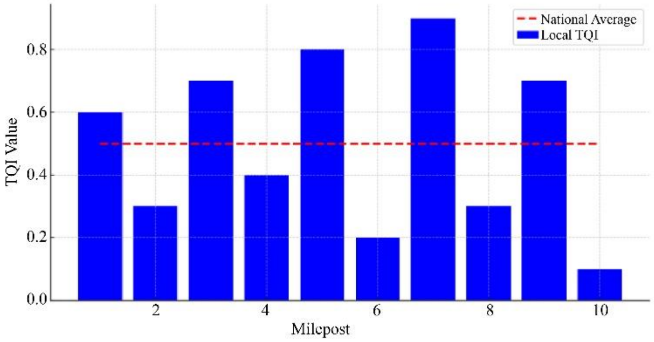

Fig. 4 Track quality indicator

The graph above is a TQI (Track Quality Indicator) Summary Chart for different milepost locations. It displays the local TQI values (blue bars) compared to the national average (red dashed line). Each bar represents a milepost, with its height indicating the relative track quality. Bars above the red line suggest better-than-average track quality, whereas those below indicate poorer conditions, potentially requiring reinspection or maintenance. This visual helps quickly identify segments that deviate significantly from national standards.

4.2. Enhanced Data Analytics

- Leveraging AWS analytics tools like Amazon Athena, Amazon Redshift, and Amazon QuickSight allows for advanced analytics and reporting on track conditions and maintenance needs.
- Combining historical and real-time data can help develop predictive maintenance models and reduce downtime and maintenance costs.

4.3. Integration and Interoperability

- AWS services provide robust APIs and integration capabilities, making it easier to connect track geometry data with IBM Maximo for streamlined maintenance workflows [25].
- Ensuring data consistency and reliability across platforms, leading to more accurate maintenance scheduling and asset management [25][26].

4.4. Operational Efficiency

- Automating data ingestion and processing from the track geometry car to AWS Data Lake and then to IBM Maximo can significantly reduce manual intervention and errors.
- Real-time data processing and analysis can provide immediate insights into track conditions, enabling quick decision-making and response.

4.5. Cost Efficiency

- AWS offers cost-effective storage solutions with various pricing models, allowing for efficient management of storage costs based on usage and data access patterns [27].

- By leveraging cloud resources, organizations can optimize their resource utilization, paying only for what they use [27].

4.6. Improved Decision Making

- Integrating data from the track geometry car with IBM Maximo and AWS Data Lake provides comprehensive reports and dashboards, aiding in better decision-making [27].

- Data-driven insights can help identify trends, anomalies, and areas that need immediate attention, leading to proactive maintenance strategies.

4.7. Enhanced Collaboration

- Data-driven insights can help identify trends, anomalies, and areas that need immediate attention, leading to proactive maintenance strategies.

4.8. Case Studies

4.8.1. North American Freight Rail Network

By integrating real-time track geometry data with their existing asset management systems, this freight rail company achieved significant improvements in maintenance operations, resource allocation and regulatory compliance.

4.8.2. High-Speed Asian Railway Network

By leveraging real-time track measurement data, this railway network was able to safely increase train speeds and enhance service efficiency. Maintenance decisions were informed by a thorough analysis of comprehensive data, ensuring optimal operational performance and reliability.

4.8.3. European Railway Network

The successful integration of Track Geometry data led to substantial operational improvements, including a 20% reduction in unplanned downtime due to proactive maintenance strategies, a 15% decrease in maintenance costs through optimized scheduling, and significant enhancements in safety metrics that resulted in fewer track-related incidents.

This paper significantly advances the novelty of the integration of track geometry car systems by utilizing multiple advanced platforms like IBM Maximo and AWS to collect, store, and analyze data in real time, creating a shift from passive data collection to dynamic management and preventive maintenance planning. It extends beyond merely identifying defects to leveraging cloud-based analytics for immediate maintenance actions, prioritizing defects based on their severity and operational impact. Furthermore, it links predictive maintenance insights directly to an established asset management system, IBM Maximo, facilitating the practical application of predictive models in real operational settings. The use of cloud platforms also enhances scalability and adaptability, opening avenues for future technological enhancements and integration with other systems.

5. Conclusion

The integration of track geometry car data with IBM Maximo via AWS Data Lake significantly enhances track maintenance management by streamlining workflows and utilizing both real-time and historical data for proactive scheduling and predictive maintenance. Leveraging AWS's advanced analytics and IBM Maximo's operational capabilities, this system optimizes resource allocation, reduces downtime, and lowers maintenance costs. Comprehensive data lifecycle management, from collection to actionable maintenance scheduling, supports predictive analytics and improves decision-making and future planning. This approach enables more effective scheduling, prevents downtime, and extends infrastructure lifespan through the identification of patterns and early prediction of issues, leading to proactive maintenance. Ultimately, this integration ensures high operational efficiency and reliability, offering a holistic and cost-effective solution for track maintenance.

5.1. Enhanced Data Utilization

- The workflow efficiently manages the entire data lifecycle—from collection, ingestion and processing to integration and actionable use in maintenance scheduling.
- The processed data is used not just for reactive maintenance but can be leveraged for predictive analytics, enhancing decision-making and future planning.

5.2. Improved Maintenance Efficiency

- By integrating processed data with IBM Maximo, the system can schedule maintenance activities more effectively, preventing downtime and extending the lifespan of the infrastructure.
- The ability to analyze historical and real-time data allows the system to identify patterns and predict potential issues before they become critical, leading to a proactive rather than reactive maintenance approach.

5.3. Cost Reduction

- Predictive maintenance enabled by this workflow can significantly reduce costs by addressing issues before they escalate into expensive repairs.
- Efficient resource allocation based on data-driven insights helps minimize wasted effort and optimize manpower and material use.

5.4. Enhanced Reporting and Insights

- With AWS analytics tools, stakeholders get detailed reports and insights, providing a deeper understanding of track conditions and the effectiveness of maintenance activities.
- Enhanced reporting capabilities ensure better accountability and transparency in maintenance operations, fostering trust and reliability among stakeholders.

5.5. Strategic Business Inputs

- The use of scalable cloud technologies like AWS Data Lake ensures that the infrastructure can adapt to growing data needs and evolving business requirements.
- Leveraging advanced data analytics and integration capabilities provides a competitive advantage by ensuring high operational efficiency and reliability.

5.6. Seamless Workflow Integration

- The seamless integration of various technologies and platforms (like AWS IBM Maximo) facilitates a smoother workflow, reducing bottlenecks and enhancing collaboration across departments.
- This integrated approach also fosters collaboration between IT and operational teams, bridging the gap between data technology and maintenance execution.

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