

Digital Lifecycle Management of Railway Track Fittings Using QR Technology

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Abstract - Railway track fittings such as elastic rail clips, liners, bolts, and rail pads are used in large numbers and require proper identification and maintenance throughout their service life. Managing information related to individual fittings can become difficult when component details, installation information, and inspection records are not directly linked to the physical fitting. This work presents a digital lifecycle management system that assigns a unique QR identifier to each railway track fitting and connects it with a PostgreSQL database. The implemented system allows fitting details to be registered, installation status to be updated, and previously stored information to be retrieved by scanning the corresponding QR code. An AI-assisted image inspection module is also incorporated to support the identification of visible conditions in fitting images. The system therefore establishes a direct connection between a physical fitting and its digital record, bringing identification, installation tracking, and inspection support into a common workflow. The developed prototype demonstrates how QR-based identification and digital record management can improve component-level traceability and information retrieval for railway track fittings.

Keywords: QR Code, Railway Track Fittings, Digital Lifecycle Management, PostgreSQL, AI-Assisted Inspection, Component Traceability

INTRODUCTION

Railway transportation depends on the reliability of its track infrastructure, where a large number of individual components work together to maintain proper rail alignment and stability. Track fittings such as elastic rail clips, liners, bolts, and rail pads are small components, but their correct installation and condition are important for the overall performance of the track. Since these fittings are distributed across extensive railway networks, maintaining accurate information about individual components can become difficult when identification and inspection records are handled through conventional methods.

Railway maintenance activities increasingly use digital systems for inspection, maintenance, and asset-related information. However, there remains a practical need to establish a direct and easily accessible connection between an individual physical track fitting and its corresponding digital record. When a particular fitting is inspected in the field, identifying its associated information, installation details, and previous inspection history can require retrieval from existing records. A unique identifier attached to the physical

fitting can provide a direct link to the relevant digital information and make component-level traceability more convenient.

A standardized identification mechanism can help overcome this limitation by providing each physical fitting with a unique reference that can be connected to its stored information. QR codes provide a practical method for creating such a connection because a code can be scanned using a suitable device and linked to a corresponding digital record. When applied to railway track fittings, this approach can allow important information about an individual component to be accessed without depending entirely on manually searching through large sets of records.

The developed system establishes a unique digital identity for individual railway track fittings using QR technology and connects each identifier with a structured PostgreSQL record. The system supports registration of fitting information, installation-status updates, retrieval of stored details through QR scanning, and AI-assisted image inspection. The physical QR marking concept is intended to provide a durable association between the fitting and its digital identity.

Beyond basic identification and record management, railway maintenance also requires inspection of the physical condition of track components. Visual inspection involves examining photographs or field images to identify conditions that may require further attention. The proposed system therefore incorporates an AI-based image verification module that analyzes images of track fittings and assists in identifying visible abnormalities. This provides additional support for inspection activities while keeping the inspection information associated with the corresponding fitting record.

The overall objective of this work is to establish a digital connection between individual railway track fittings and their corresponding records. By combining QR-based identification, database-supported information management, installation tracking, and an AI-assisted visual verification approach, the system provides an organized method for managing component information. The proposed framework supports railway inspection and maintenance activities by making fitting-related information easier to identify, retrieve, and update.

LITERATURE REVIEW

The development of a reliable identification and monitoring system for railway track fittings requires consideration of both existing maintenance practices and recent digital technologies. The literature reviewed for this work was mainly examined in three areas: identification and traceability of physical components, digital approaches for storing and managing maintenance information, and image-based techniques for supporting inspection. These areas were considered to understand the limitations of conventional practices and to determine how they could be combined into a single system for railway track-fitting management.

A. QR-Based Identification

QR codes provide a convenient way of connecting physical objects with digital information. Previous work has demonstrated their use for component identification and traceability. In the context of railway track fittings, a similar approach can be used to assign a unique identity to an individual component and retrieve its associated information through scanning. This provides a simple link between the physical fitting and its digital record..

B. Digital Record Management

Digital databases are increasingly used to organize information related to infrastructure components and maintenance activities. A structured database can store component details, installation status, and inspection-related information. For the proposed system, PostgreSQL is used to maintain the records associated with individual track fittings.

C. AI-Based Visual Inspection

Recent inspection approaches use computer vision and artificial intelligence to analyse railway infrastructure images and identify visible abnormalities. Several studies have investigated deep-learning-based detection of railway fastener defects and track components using object detection and image-based inspection techniques [1], [2], [3], [4], [6], [8], [10]. These studies demonstrate the growing use of AI-based methods for automated railway component inspection.

D. Review Methodology

The review was conducted by examining existing approaches related to QR-based identification, digital asset management, and AI-based visual inspection. Their applications and limitations were considered in relation to railway track-fitting management. The findings were used to define the requirements of the proposed QR-based identification and AI-assisted inspection framework.

RESEARCH GAP

Recent research has shown that AI and computer vision can effectively detect defects in railway fasteners and track components [1], [2], [3], [4], [5], [6]. Existing research has extensively explored railway component inspection, defect detection, and computer-vision-based condition assessment. Separate work has also demonstrated the use of QR codes and digital identifiers for traceability. However, these functions are often considered independently. A component-level system that connects the identity of a physical railway fitting with its registration details, installation status, and inspection information through a common digital record is less explored. This work addresses this gap by integrating QR-based identification, PostgreSQL data management, installation tracking, and AI-assisted image inspection within a single workflow.

Table 1 Research Gap Identified from Existing Work

Existing Research Focus	Research Gap	Proposed Approach
AI-based railway defect detection	Mainly focuses on detecting defects	Combines AI verification with component identification
Railway fastener inspection	Limited connection with individual component records	Uses a unique QR code for each fitting
Digital railway records	Identification and inspection data may remain separate	Links fitting information through a centralized database
Automated visual inspection	Mainly focuses on image-based condition assessment	Connects AI verification with QR-based fitting records

PROBLEM STATEMENT

Railway track fittings are installed in large numbers across extensive railway networks and require regular inspection and maintenance. Managing information about these individual components becomes difficult when identification, installation records, and inspection information are maintained through conventional methods. The major problems considered in this work are described below.

A. Difficulty in Individual Component Identification

Traditional track maintenance depends significantly on manual inspection and documentation. Details related to fittings may be recorded in inspection sheets, registers, or separate digital records. During subsequent maintenance activities, locating the information associated with a particular fitting can require additional time and effort. Manual entry can also result in incomplete or outdated records when information is not updated consistently.

B. Linking Physical Components with Digital Records

Different types of fittings, including elastic rail clips, liners, bolts, and rail pads, are installed at numerous locations along railway tracks. When individual fittings do not have a readily accessible identifier linked to their digital records, distinguishing a particular component from others and retrieving its associated information can become more difficult. This can limit component-level traceability and make systematic information retrieval more challenging.

C. Installation and Lifecycle Tracking

Installation information is an important part of track-fitting management. In conventional methods, installation details may be maintained separately from the physical fitting. As a result, checking whether a particular component has been installed or updating its status can require manual verification. A direct digital connection between the physical fitting and its stored record can make this process more organized.

D. Distributed Component Information

Information related to a track fitting may include its type, identification details, installation status, location, and inspection observations. When such information is stored across different records, retrieving the complete history of a component becomes inconvenient. A centralized database can provide a structured way to maintain these details and reduce unnecessary duplication of records.

E. Visual Inspection Support

Railway tracks contain a large number of fittings that may need to be visually examined during inspection. Manual inspection requires continuous attention from personnel and can become time-consuming when large areas have to be covered. Differences in lighting, viewing conditions, component position, and image quality can also affect visual assessment. An AI-assisted image verification approach can provide additional support by analyzing captured images and identifying components that may require closer inspection.

F. Need for Component-Level Traceability

The above limitations show the need for a system that connects the physical track fitting with its digital information. A unique QR identifier can provide this connection, while a database can maintain the associated records and installation status. The addition of AI-based image verification can further support condition assessment. Therefore, an integrated approach combining QR-based identification, database management, and AI-assisted visual verification can provide a more organized method for railway track-fitting management.

PROPOSED SYSTEM

The proposed system connects each railway track fitting with a digital record using a unique QR code. The system is designed to simplify component identification, information management, installation tracking, and inspection support. PostgreSQL is used to store the information associated with each fitting, while an AI-based image verification module supports the analysis of fitting images and identification of visible abnormalities.

A. QR-Based Fitting Identification

Each track fitting is assigned a unique QR code that acts as its digital identity. The QR code is associated with the corresponding fitting record in the database. When the code is scanned, the system identifies the fitting and provides access to its stored information. Laser-based marking is proposed for placing the QR code on the physical fitting so that the identifier remains associated with the component.

B. Information Storage and Retrieval

After scanning the QR code, relevant details of the fitting can be entered and stored in the system. The same QR code can later be scanned to retrieve the stored information.

This creates a direct connection between the physical fitting and its digital record, reducing the need to search through separate manual records.

C. Installation Status Tracking

The system allows the installation status of a fitting to be updated after it is placed on the railway track. The status is maintained within the fitting's digital record, allowing users to identify whether the registered component has been installed. This provides a simple method for maintaining installation-related information.

D. PostgreSQL Database

PostgreSQL is used as the central database for storing fitting information. The unique QR identifier is linked to the corresponding database record, allowing information to be organized and retrieved systematically. The database stores fitting details, installation information, and inspection-related records associated with the corresponding QR identifier.

E. AI-Based Image Verification

The proposed system incorporates an AI-based image verification module to support the inspection of railway track fittings. Images of track fittings can be provided to the AI module for analysis. The module examines visual characteristics of the component and assists in identifying possible abnormalities or conditions that may require attention. The verification result is associated with the corresponding fitting record through its QR identifier, allowing identification and inspection information to be maintained together.

F. QR-Based Data Management and AI Verification Approach

The QR identifier provides the connection between the physical fitting and its digital record. After scanning, the stored information associated with the fitting can be retrieved and updated. During inspection, an image of the same fitting can be analysed using the AI-assisted inspection module. This separates the two functions clearly: QR technology provides component identity and lifecycle information, while AI provides image-based condition support.

For visual inspection, an image of the identified fitting is provided to the AI-based verification module. The module analyzes the image and provides an indication of possible visible abnormalities. The verification output is associated with the corresponding QR-based record, creating a connection between the physical fitting, its stored information, and its inspection result.

The overall approach creates a continuous flow from identifying the fitting to storing its information and supporting its inspection. By combining QR identification, database management, and AI-assisted image analysis, the proposed system provides a structured method for maintaining information about individual railway track fittings.

SYSTEM ARCHITECTURE

The overall architecture of the proposed system is shown in the block diagram below.

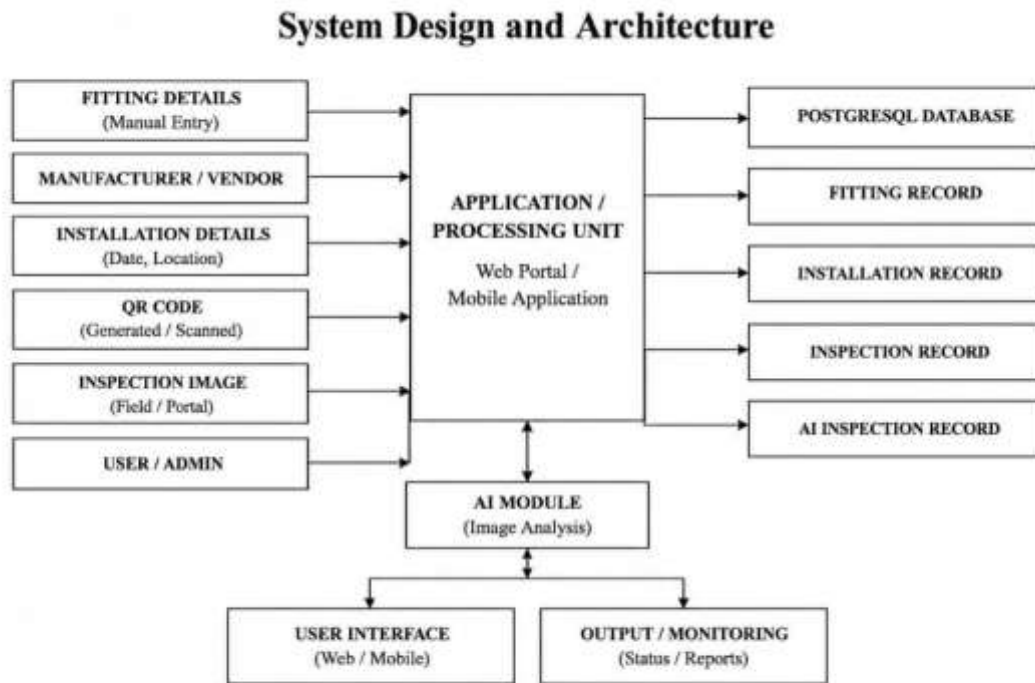


Figure: Block Diagram of Proposed System

Table 2 Representative Database Structure

Entity	Representative Fields	Purpose
Track_Fitting	Fitting_ID, QR_ID, Fitting_Type, Location, Status	Stores fitting identity and basic details
Installation_Record	Installation_ID, QR_ID, Installation_Date, Status	Maintains installation information
Inspection_Record	Inspection_ID, QR_ID, Inspection_Date, Observation, Image	Stores inspection information
AI_Inspection_Record	Verification_ID, QR_ID, Image, Condition, Result	Stores AI-assisted verification results

This architecture provides a digital link between individual railway track fittings and their associated information, supporting organized tracking and AI-assisted inspection within the same workflow.

METHODOLOGY/WORKFLOW

The proposed system connects each railway track fitting with its corresponding digital record through a unique QR code. Initially, the fitting details such as component type, manufacturer, vendor, supply information, and warranty details are entered into the

system. A unique QR code is then generated and linked to the fitting record stored in the PostgreSQL database.

After the fitting is installed, the installation date, location, and installation status are updated in the same record. During subsequent inspection, the QR code can be scanned to quickly retrieve the fitting's associated information and previous records. An image of the fitting can then be captured or uploaded for AI-assisted condition assessment. The inspection result is stored with the corresponding fitting record, allowing the identification, installation, and inspection information to be maintained together throughout the fitting's lifecycle.

This workflow provides a direct link between the physical track fitting and its digital information, supporting easier information retrieval, traceability, and inspection record management.

The proposed system follows the sequence:

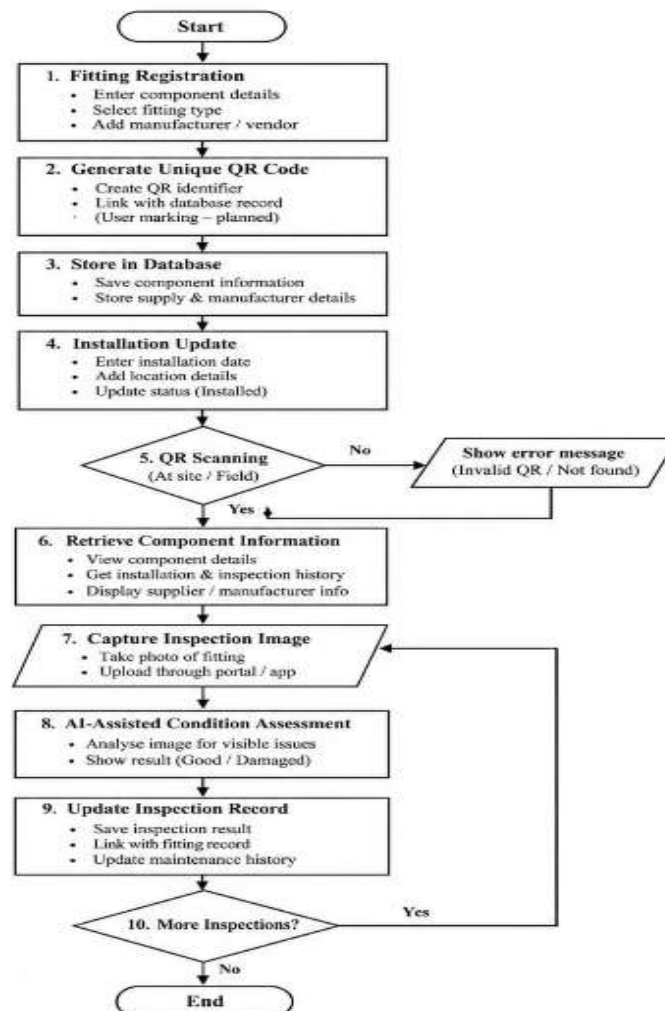


Figure 1 Flow chart of the proposed solution.

The workflow shown in Fig. 1 is carried out in the following stages.

- 1) Fitting registration: the details of the track fitting, such as component type, manufacturer or vendor, supply information, and warranty details, are entered into the system.
- 2) QR code generation: a unique QR code is generated for the registered fitting so that it can act as the digital identity of that component.
- 3) Database storage: the fitting details are stored in the PostgreSQL database and linked to the generated QR identifier.
- 4) Installation update: after the fitting is placed on the track, its installation date, location, and installation status are updated in the same record.
- 5) QR scanning and record retrieval: during inspection, the QR code on the fitting is scanned. If the code is valid, the stored details, installation information, and previous records of that fitting are displayed; otherwise an error message is shown and the code is scanned again.
- 6) Inspection image capture: an image of the fitting is captured in the field or uploaded through the portal.
- 7) AI-assisted condition assessment: the image is analysed by the AI module to identify visible abnormalities or conditions that may require closer attention.
- 8) Inspection record update: the result is saved in the record of the same fitting. If more fittings remain to be inspected, the process returns to QR scanning; otherwise it ends.

IMPLEMENTATION AND EVALUATION

A. Implementation

The developed system establishes a digital connection between individual railway track fittings and their associated information. The implementation combines QR generation and scanning, digital data storage, installation tracking, and AI-assisted image inspection within a common workflow.

The QR code serves as the primary identification mechanism of the system. A unique QR code is assigned to each track fitting and linked to its digital record. Physical laser marking is considered as a future implementation for durable marking on the fitting. The identified fitting can include components such as elastic rail clips, liners, bolts, and rail pads. When the QR code is scanned, the system uses the unique identifier to access the corresponding record and display the information associated with that particular fitting.

The system allows relevant information about a fitting to be entered and stored after identification. Details associated with the component are maintained in a PostgreSQL database, where each record is connected to its respective QR identifier. The stored information can be retrieved through subsequent scans and updated whenever changes occur. This provides a structured method for maintaining component information and reduces the dependency on searching through separate records.

Installation tracking is incorporated into the same digital record. After a fitting is associated with its corresponding record, its installation status can be recorded and updated through the system. This creates a direct relationship between the physical component, its identification code, and its installation information. The same approach can also support the storage of inspection observations and other relevant information associated with the fitting.

The developed system connects each railway track fitting with a unique QR identifier and its corresponding digital record. The workflow covers fitting registration, QR generation, component information management, installation tracking, QR-based information retrieval, and AI-assisted inspection.

The proposed system also incorporates AI-based image verification to support visual inspection. Images of railway track fittings can be submitted to the system for analysis, where AI-based image processing can be used to examine visible characteristics and identify possible abnormal conditions. The inspection information can be associated with the corresponding QR-based record, allowing component identification and visual assessment to be managed together.

The complete system therefore establishes a digital workflow in which a physical track fitting is assigned a unique QR identity, its information is stored in a centralized database, installation details are recorded, and inspection images can be analyzed using AI-based techniques. This integrated approach provides a structured framework for identifying, tracking, and monitoring railway track fittings throughout their usage.

B. Evaluation and Discussion

The proposed system provides a structured method for identifying and managing railway track fittings through unique QR-based identification. By associating each fitting with a separate digital record, the system makes component information easier to access and organize. Scanning the QR code provides a direct way to retrieve the information related to the corresponding fitting.

The database-based approach also improves the organization of fitting records. Information such as component details and installation status can be maintained under the same identifier, reducing the need to manage these details separately. This creates a clearer relationship between the physical fitting and its associated digital information.

The QR-based approach can also support inspection activities by providing quick access to the history and details associated with a particular component. When inspection information or images are associated with the same record, the system can provide a more complete view of the fitting during maintenance activities.

The integration of AI-based image verification further extends the system by providing image-based support for identifying visible abnormalities. Instead of relying only

on manually reviewing every captured image, the AI component can assist in highlighting images or components that may require further attention.

Overall, the proposed framework provides a common platform for component identification, information retrieval, installation tracking, and inspection support. The combination of QR technology, database management, and AI-based image analysis provides support for identification, retrieval and inspection. The implemented prototype demonstrates that QR-based identification can provide a direct access point to the digital record of an individual fitting. The PostgreSQL database organizes component and installation information under the corresponding identifier, while the AI-assisted module provides additional support for image-based inspection.

C. Scalability and Applicability

The proposed architecture is designed to support different types of railway track fittings while maintaining a common identification and data-management process. The use of a unique QR identifier provides a consistent connection between each physical fitting and its digital record, allowing the same framework to be applied across different railway locations.

The database structure can accommodate additional information associated with each fitting, including installation details, inspection observations, maintenance records, and location information. Organizing these records under a common QR identifier provides a structured method for maintaining component-level information and retrieving it when required.

The implemented architecture uses a common QR-based identification mechanism that can be applied to different types of railway track fittings. Each fitting can maintain an individual digital record while following the same registration, installation, and inspection workflow. The database structure can also accommodate additional information such as location, inspection observations, maintenance history, and component status. This structure allows the system to be extended to a larger number of fittings without changing the basic identification mechanism.

CONCLUSION

The developed system provides a digital approach for identifying and managing individual railway track fittings through unique QR-based identification. Each fitting can be associated with a structured digital record containing component and installation information, allowing the record to be retrieved through QR scanning. PostgreSQL provides centralized storage for the associated data, while the AI-assisted image inspection module provides additional support for identifying visible conditions in fitting images.

The main contribution of the system is the connection established between the physical fitting and its digital lifecycle information. Instead of treating identification, installation tracking, and inspection information as separate activities, the developed

workflow associates them with a common fitting identity. The prototype demonstrates the feasibility of this approach and provides a foundation for future field validation, durable physical marking, larger-scale deployment, and integration with existing railway information systems.

Future work will focus on extending the prototype for practical railway deployment. The planned improvements include implementing durable laser marking of QR codes directly on track fittings, integrating the system with authorized railway platforms such as UDM/TMS, and testing the solution under real field conditions. The AI-based inspection module can also be improved using a larger and more diverse dataset to support reliable detection of visible fitting conditions. Further work can include automated inspection record updates, lifecycle analytics, batch and vendor-level quality analysis, and scalable deployment for different types of railway track fittings.

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