# Artificial intelligence for railroads: Potential and challenges for application

Artificial intelligence methods have great potential, but there are also many challenges. The following article analyzes the current situation.

## 1. Introduction

Artificial intelligence (AI) and machine learning (ML) methods should be implemented more efficiently and attractively. Application is multifaceted and has great potential, but is repeatedly a topic of discussion. Not long ago, there was a call for tech experts to pause development (see [1]). But that call was contradicted by a number of people, including computing science professor Johanna Börklund at Umeå University in Sweden, who said, "There is no reason to hit the brakes." Instead, transparency requirements for developers should become more stringent. Safety standards are necessary to create rules for the use of the technology [1]. The article below will consider potential AI fields of application in railroads and the areas in which AI is already being used. It will then analyze the open fields of action and the obstacles to developing this potential to its fullest.

## 2. State of the art, potential, and challenges

An extensive overview of the use of AI methods in the transport sector can be found in "A literature review of Artificial Intelligence applications in railway systems" (Tang et. al.) [2], which analyzes about 140 scientific articles on AI published between 2010 and 2020 and evaluates their application.

This evaluation clearly shows that the primary application in rail transport is currently maintenance and inspection. Other sub-domains are safety and security, autonomous driving and control, planning and management, and passenger flow prediction.

Railway application areas fall roughly into the infrastructure, operation, and vehicle categories. Existing AI algorithms can be used in these three areas and subdivided into categories according to their application as shown in Figure 1.

## 3. Using AI for infrastructure

Rail transport is an overall system encompassing vehicles, processes, and infrastructure. The great spatial extent of rail networks and the large number of infrastructure elements (tracks, switches, signals, etc.) entail correspondingly large maintenance cost and effort.

AI methodologies have the potential to pave the way to condition-based or predictive infrastructure maintenance, reducing maintenance costs [3]. The key is to detect infrastructure element condition using field data and estimate its development, especially wear, as precisely as possible. Maintenance measures with fixed and carefully chosen intervals (such as replacement after a given date) can thus be made more flexible and linked to condition (such as replacement when failure is imminent).

AI requires data to work. Infrastructure component data sets and associated wear forecasts must be generated continuously from sensors installed either in the infrastructure or the vehicle. sensors on in-service vehicles is a promising approach to continuous monitoring of the entire track network [4]. Repeated transit under similar conditions is especially valuable for comparability and development of infrastructure conditions. The large quantities of data thus accumulated require automated assessment. This can be done by supervised and unsupervised AI (with or without the help of reference data). Unsupervised learning are aimed at detecting anomalies and thus faults in the infrastructure. Supervised methods can use reference data to deliver qualitative and quantitative information about such items as track condition

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or track fault classification. Vibration data provide especially relevant information. Examples are axle bearing acceleration to determine track geometry or defects [5] and camera images for automated detection of visible faults in the track infrastructure [6]. Position information (from satellite navigation and inertial sensors) are important for establishing the link to the infrastructure transited [7].

Track-side sensor data can provide continuous monitoring of especially critical infrastructure elements such as switches. For instance, AI can analyze switching curve waveforms to detect defects [8].

## 4. AI used in rail vehicles

Across a rail vehicle's life cycle, AI will be used in various phases with current activity focused on maintenance and operation. Some of these activities will be considered below.

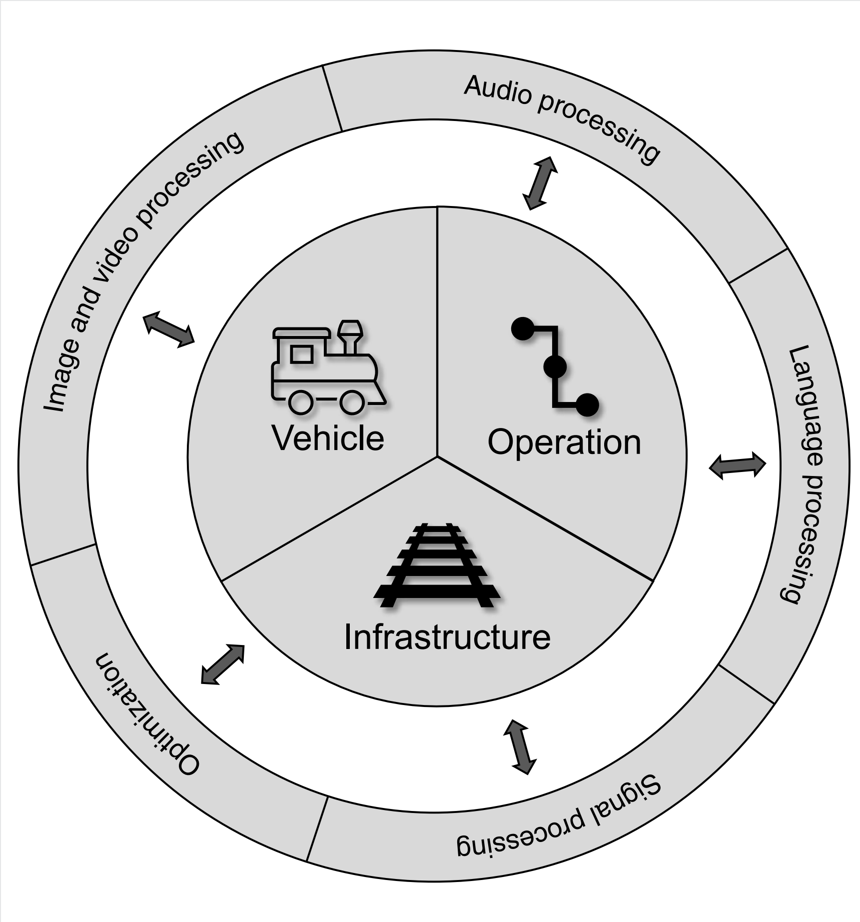
In the area of vehicle use, AI constitutes a key technology for automating driving functions.

For automation, including partial automation, of vehicle functions, AI methods for monitoring vehicle environment predominate. They use machine vision methods to identify relevant objects with camera, lidar, radar, and ultrasonic sensors in the monitored environment. Depending on the type of detected object, this information is made available to the vehicle operator in lightly automated processes (see [9]) or used for decision-making during autonomous driving (see [10, 11]).

Much like predictive maintenance for infrastructure components, vehicle and vehicle component condition monitoring has tremendous potential for increasing availability, cost efficiency, and safety for rail service provision. Vehicles can be equipped with sensors to produce large quantities of data for analysis with AI methods to determine a vehicle condition forecast. Depending on application, cloud or edge applications are used [12].

The core of data analysis is systems for monitoring rotating components such as wheelsets and wheelset bearing components based on acceleration and vibration data (see [13]). Newer approaches that use knowledge of vehicle component conditions to achieve resilient operation are categorized as prescriptive maintenance.

For performing the maintenance itself, AI offers the potential of using language recognition and generation methods to simplify the associated processes and make them more reliable. If the dimensions of components at hard-to-reach places on the vehicle required, they can be detected at a spoken command and transferred to the maintenance documentation. Machine vision also provides the option of using augmented reality, such as the use of a smart device to deliver information that will support inspection or repair processes [14].




**1:** Potential fields of application in the railway area and application categories for AI algorithms

## 5. AI applications in railway operations

Artificial intelligence is also used for railway operations. At the moment, scheduling and disposition is the focus of research and development. Sub-categories here are strategic and tactical planning, analysis of completed transport, and dispositive rescheduling following delays or schedule changes to enhance operational efficiency (see [2]).

A major advantage of AI-supported methods in railway operations is that they can identify sufficient time gaps when there are delays and thus facilitate predictive operation. So AI should be used in scheduling and disposition to identify potential or actual conflicts and prevent or correct them and minimize delays that arise as quickly as possible and avoid new delays or delay transfer.

AI-supported processes for predictive travel can also prevent unnecessary acceleration and braking. The speed harmonization thus achieved has a positive effect on delays by reducing waiting times and enhancing the infrastructure's capacitive loads (such as [15]).

Machine learning processes are also used for passenger information such as forecast processes based on past real-time data for more reliable arrival and departure times and train and station capacity usage.

Most AI methodologies used in railway operations are formulated as optimization problems based on the fact that they are applied to problems that are currently very difficult or impossible to solve or greatly increase the size of the described problem. But they are primarily used for data-based forecast approaches (passenger forecasts or conflict avoid-

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ance) that use historical data to generate better forecasts for the future.

**6. Assessment**

For detecting the condition of vehicle components and infrastructure, it is clear that one challenge of moving applications from research to practice is the low availability of data, especially for existing vehicles. One problem is the high cost of data generation solutions. Another is the lack of IT capacity on existing vehicles. This results in a challenge for broader application, especially for adapting AI approaches that can manage with little data (few-shot learning, for example), and for implementing edge concepts for partially decentralized and, as necessary, energy-optimized data analysis in existing vehicles.

This is also true of AI-supported railway infrastructure maintenance. AI results must be robust, and the approach must be compared with existing ones. This cannot be managed in some places, especially in new applications that have been made possible by AI in the first place. It is important to give AI and other data-driven approaches a chance to make a contribution. Preparation should also be made to make data availability (with sustainable data management, for instance).

For environment motoring in automated driving, computer vision algorithms should be considered. A significant obstacle to high degrees of automation is currently less the availability of sensors and assessment than the monitoring of the unmanned driver's cab and the approval of the relevant systems for safety-relevant applications because of such concerns as various operating scenarios (harbors, industrial parks, shunting yards, etc.).

But the behavior of various actors ([16], for example) indicates efforts toward progress.

The AI methodologies used in the context of railway operations are largely in the testing and trial phase. They are being used primarily for non-safety-critical forecasts and passenger information, such as arrival and departure times, and for train and station capacity usage [14]). Another focus of AI trials is the solution of optimization problems having largely to do with analyzing historical traffic data. It is relatively early going in the implementation and testing of applications in operational conflict avoidance as part of rescheduling after operational disruptions and in strategic and tactical network planning aimed at improving performance. After the assessment of [2], AI methodologies have so far been used only for decision-making and support for dispatchers and planners.

**7. Summary**

It is clear that AI methods have a great deal to contribute to the solution of relevant problems. Realistic expectation management for AI solutions is important for a productive compromise between the extreme "AI can solve everything" and "AI is unusable" positions. AI tools should therefore not be considered in isolation, but approached as an effective tool that can harmonize with other methodologies. This secures a connection to established procedures and enhances acceptance by stakeholders. It is also clear that there is a need of guidelines and procedures for approving AI algorithms, especially in safety-critical applications. Since the capabilities and reliability of AI methods will continue to grow in the future, it is important to start preparing for their use by initiating suitable approval procedures.

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