# 1 Description of the use case

## 1.1 Name of the use case

| ID | Application Domain(s) | Name of Use Case |
|---|---|---|
| UC01.Railway | Railway network | Automated re-scheduling in railway operations |

## 1.2 Version management

| Version Management | | | |
|---|---|---|---|
| **Version No.** | **Date** | **Name of Author(s)** | **Changes** |
| 0.1 | 22.11.2023 | | |
| 0.2 | 19.12.2023 | Irene Sturm | Major Updates |
| 0.3 | 21.12.2023 | Roman Ließner | Major Updates |
| 0.4 | 06.01.2024 | Ricardo Bessa | Revision |
| 0.5 | 13.2.2024 | Daniel Boos<br>Adrian Egli | Review and cleaning |

## 1.3 Scope and objectives of use case

| Scope and Objectives of Use Case | |
|---|---|
| **Scope** | Traffic density on the European rail networks is constantly increasing. This increases the complexity of rail traffic management in operations: timetables are constructed to utilize the network's capacity maximally. At the same time, new construction or maintenance of railway infrastructure must be planned and carried out efficiently.<br>In railway operations, the already densely planned schedules are disturbed by unexpected events, such as delays, infrastructure defects, or short-term maintenance. The execution of the planned timetable can only be achieved by acting on these events by frequently adapting and re-scheduling the planned train runs. Today, maintaining smoothly running operations requires that in operational centers, highly skilled personnel monitor the flow of traffic day and night and quickly make decisions about re-scheduling of trains. |
| **Objective(s)** | The system's objective is to fully automate re-scheduling in railway operations to fulfill all offered services and minimize delays for the customer (passenger). |

## 1.4 Narrative of use case

| Narrative of Use Case |
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| **Short description** |
| In railway operations, traffic on the network is planned to fulfill the intended service that was contracted with the Railway Undertaking Operating Managers (RUOM), e.g., to execute train runs on the network so that the requested commercial stops are fulfilled in a punctual manner. In operations, such a pre-planned schedule is executed. Unexpected events, such as infrastructure malfunctions or delays occur. In case of such a deviation, the automated system has to re-calculate the schedule so that the requested services can be fulfilled with as little delay as possible. Adapting the schedule includes interventions, such as changing the speed curves of trains, changing the order of trains at the infrastructure element, changing the routes of trains, or changing the platform of a commercial stop in a station. A highly automated AI-based system is designed to manage and optimize railway schedules in real-time, ensuring efficient rail network use while minimizing delays for passengers. The system is constantly monitored by a human operator who can adjust the system's configuration and identify the need for adaptation and re-training. |
| **Complete description** |
| **Description of the re-scheduling task:** Re-scheduling trains in railway operations means monitoring the movement of trains on a railway network and reacting to unexpected events, such as signal failures, track blockages, or weather events that disrupt operations, to other significant delays, and also proactively to predicted deviations that affect planned operations in the future. Re-scheduling measures include changing a train's speed, path, or platform for stopping. In a densely |

utilized railway network, local re-scheduling decisions potentially affect the entire flow of traffic, and their effect can propagate far into the future. This means that the re-scheduling task is a very complex decision-making task that needs to integrate a lot of context information. In addition, decisions must be taken quickly.

**System description and role of the human operator:** The re-scheduling task is performed in a highly automated manner by an AI-based re-scheduling system. This system observes the real-time state of all the trains and tracks in the control area of interest and automatically detects the need to intervene, decides on an intervention, and executes this intervention. Such an AI system for highly automated re-scheduling in operations is something new and unusual. The approach followed here can be understood as a first step towards the introduction of such a system. The highly automated AI system is treated as a new tool that is supervised and evaluated by an expert. The goal is to find the limits of the automated system as a starting point for improving and configuring it.

In operations, the AI system re-schedules in a fully automated manner while the human supervisor monitors:

- The system's state in operations (e.g., number of trains, potential bottleneck in current and planned network usage)
- KPIs for the actual situations (e.g., current delay)
- Confidence/certainty of the AI system
- Intensity of intervention (how much changes to the current operational plan did the AI perform?, e.g., change platform)

The supervisor uses this information to:

- Decide at which point it would be advisable to switch off the AI system and take over control.
- Decide to re-configure/adjust the system in operations.

The overarching goal in this setup is to learn the existing solution's limits: in which situations does the AI system reach appropriate decisions? These insights should not only be generated from metrics extracted in tests and analyzed post-hoc, but in a realistic operational context that the human operator is familiar with.

**Operational scenario:** For an operational scenario, there exists a definition of the intended service that was contracted with the network operator's customers (Railway Undertaking Operating Managers (RUOMs)), e.g., a set of train runs with a sequence of commercial stops. For all commercial stops, there exists a time constraint, defining:

- Latest arrival
- Minimal dwell time
- Earliest departure

An initial schedule exists that is executable and fulfills the intended services, such as the arrival and departure times of trains at commercial stops, while taking into account operational requirements (safety systems, additional constraints). A schedule contains all the information that is needed to execute train runs.

A schedule is **acceptable** if all hard constraints are fulfilled:

- Commercial stops were performed in the right order before the end of the scenario.
- Minimal dwell time for each stop has been respected.
- Earliest departures for each stop have been respected.

A schedule is punctual, i.e., fully fulfills the intended service; if the schedule is acceptable for all commercial stops, the constraint of “latest arrival” has been respected.

The following steps are performed in the use case:

1. **Definition of System Parameters:** Detailed parameters are set for the pre-planned schedule, including the prioritization of trains in case of disruptions, acceptable delay margins, and specific criteria for train prioritization (e.g., passenger load and destination importance). This step also includes the configuration of safety systems, network capacity limits, and any special operational requirements unique to certain routes or times.
2. **Schedule Execution:** The initial operational plan is executed in operations. This includes the deployment of trains according to the pre-planned schedule, monitoring of train movements, adherence to the sequence of commercial stops, and ensuring compliance with operational requirements like safety systems. The state of the system is also displayed to the human supervisor in an appropriate manner.
3. **Triggering Re-scheduling**: The re-scheduling process can be initiated by a variety of

triggers, such as infrastructure changes (e.g., blocked tracks, malfunctioning switches), train delays, or equipment malfunctions. The system is designed to detect these deviations in real-time and assess their impact on the overall schedule. The exact nature of this trigger or several different triggers needs to be defined and should also be configurable for usage.

4. **Display of Deviation and Triggering Re-calculation**: Upon detecting a deviation, the system provides a detailed display of the issue, including its nature, location, and expected impact on the schedule. It then notifies the human supervisor and initiates the re-calculation process.
5. **Automated Schedule Re-calculation**: The Traffic Management System (TMS) automatically recalculates the schedule from the point of deviation to the end of the operational scenario. The goal is to create an adapted schedule that is acceptable (meeting all hard constraints) and minimizes total delays, particularly focusing on the 'latest arrival' times at commercial stops.
6. **Execution of Adapted Schedule**: The newly adapted schedule is then put into operation. The system continuously monitors for any further deviations and adjusts the schedule as needed to maintain operational efficiency and adherence to time constraints.
7. **Human Review and System Adjustment**: A human supervisor reviews the performance of the system, analyzing how effectively it responded to deviations and the impact on service delivery. Based on this review, adjustments are made to the system's parameters, such as altering the prioritization criteria, adjusting acceptable delay thresholds, or refining the algorithm for schedule recalculations. This step ensures continuous learning and improvement of the system based on operational experiences and organizational goals.

***Stakeholders***

**Railway network operator:** Operator of the railway network in charge of maintaining the flow of traffic on the railway network to provide high quality-of-service to their direct customers (RUOMs) and the passengers.

**Network supervisor:** Human supervisor of the automated railway system (something like the former dispatcher who is not dispatching himself anymore but monitoring the system state),

**RUOM:** Railway Undertaking Operation Manager offering passenger and freight traffic services.

**Neighboring areas of control/operational centers.**

**Passenger:** The primary end-user of the railway services whose travel experience and satisfaction are directly impacted by the efficiency and punctuality of train operations.

**Government and society:** The quality of railway services is a concern of the government and society.

***Stakeholders' assets, values***

**Railway network operator:**

- Available capacity on the network: a low-quality re-scheduling functionality will consume more capacity on the network.
- Reputation: low performance of the AI system can lead to a bad reputation in terms of operational stability, punctuality, etc., which might cause customers to not rely on and to use less the services offered. This also concerns network operator, RUOM and passenger.
- Legal and regulatory framework: Regulations with discrimination-free treatment of RUOMs.
- Unintended behavior of the AI-system and actions by malicious actors can potentially compromise the safety of the train passengers, personal on the train and on and in proximity to the tracks, as well as infrastructure like tracks, power lines, tunnels, stations, etc.

**Network supervisor:**

- Trust in the automated TMS
- Transparency of system's decisions
- Stability and reliability, in particular in abnormal situations

***System's threats and vulnerabilities***

**Accountability:** who is responsible for delays and, in general, bad performance of the AI system.

**Security:** A highly automated AI system introduces the risk of severe abnormal situations on the railway network. Although in railway systems, the immediate danger of train collision is addressed by separate systems that the AI system will not control, there is a risk of severe traffic congestion with significant economic effects on the network in case of a malfunctioning AI.

## 1.5 Key performance indicators (KPI)

| Name | Description | Reference to the mentioned use case objectives |
|---|---|---|
| Acceptance score | Tracks the frequency of human operator interventions in AI decisions. Target: Reduce to less than x% of cases. Calculation: (Number of human interventions / Total AI decision instances) x 100. | Reflects the reliability and trust on the AI system. |
| Punctuality | Measures the percentage of trains arriving at their destinations on time. Target: Achieve a punctuality rate of x% or higher. Calculation: (Number of on-time arrivals / Total number of arrivals) x 100. | Linked to the objective of minimizing delays. |
| Response time | Assesses the speed at which the AI system responds to disruptions or changes. Target: Response within x minutes of disruption detection. Calculation: Average time taken from disruption detection to system response. | Related to the objective of rapid re-scheduling. |
| Delay Reduction Efficiency | Quantifies the effectiveness of the system in reducing delays. Target: Reduce overall delays by 30%. Calculation: (Total delay duration before AI implementation - Total delay duration after AI implementation) / Total delay duration before AI implementation. | Linked to the objective of minimizing delays. |
| Proactiveness | Ratio of (proactively) prevented deviations to actual deviations | |
| Trust | Measure of confidence of the human supervisor in the AI-based system | Reflects the reliability and trust in the AI system. |

## 1.6 Standardization opportunities and requirements

| Classification Information |
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| **Relation to existing standards** |
| *ISO/IEC 23894:2023, Information technology — Artificial intelligence — Guidance on risk management*. Autonomous management and optimization of railway scheduling in real-time are high-stakes tasks, and therefore, risk management specifically related to AI is fundamental.<br>*ISO/IEC 38507:2022, Information technology — Governance of IT — Governance implications of the use of artificial intelligence by organizations*. Autonomous AI requires an analysis of governance implications and also a redefinition of the organization structure.<br>*ISO/IEC 24029-2:2023, Artificial intelligence (AI) — Assessment of the robustness of neural networks — Part 2: Methodology for using formal methods*. Since artificial neural networks can be a component of the autonomous AI system, formal methods to assess the robustness properties of neural networks are fundamental to certify and monitor autonomous systems.<br>In railway transport, there are different levels of automation (Grade of Automation, GoA) defined in the IEC 62267 Standard ("Railway applications - Automated urban guided transport (AUGT) - Safety requirements”). This standard covers high-level safety requirements applicable to automated urban guided transport systems, with driverless or unattended self-propelled trains, operating on an exclusive guideway.<br>*DIN EN 50126, Railway Applications – The Specification and Demonstration of Reliability, Availability, Maintainability and Safety (RAMS)*. It considers the generic aspects of the RAMS life cycle and provides a description of a Safety Management Process. It provides guidelines for defining requirements, conducting analyses, and demonstrating the reliability, availability, maintainability, and safety aspects throughout the lifecycle of railway applications.<br>*DIN EN 50128, Railway applications – Communication, signaling and processing systems*. Outlines the procedural and technical criteria for crafting software intended for programmable electronic systems in railway control and protection applications. |
| **Standardization requirements** |
| Develop a unified set of standards for safety systems and operational requirements that are |

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| applicable across various railway networks. Note that railway-specific safety standards lack comprehensive specifications for handling AI applications. For instance, they lack references to critical aspects such as system definitions (e.g., operating boundaries), conditions of use, hazard identification, definition of risk acceptance criteria, and fundamental safety requirements.<br>Establish a standard set of KPIs for measuring the performance of AI-based scheduling systems. Moreover, it is also necessary to conduct conformity assessments according to the AI-Act, meaning that the risk-based approach from the AI-Act should be standardized where safety proofs could be derived analytically (i.e., formal verification methods) or based on the results of extensive test series (like it is done nowadays for software). |

## 1.7 Societal concerns

| ***Societal concerns*** |
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| ***Description*** |
| **Privacy and data protection:** The use of AI in railway scheduling involves the collection and analysis of large volumes of data, including potentially sensitive information. There is a concern about how this data is stored, processed, and protected, especially in compliance with data protection regulations like GDPR. Ensuring the privacy of passengers and the security of their data is paramount.<br>**Transparency and accountability**: There is a societal demand for transparency in how AI systems make decisions, especially in critical infrastructure like railway systems. The public might be concerned about the lack of understanding of AI decision-making processes and the accountability mechanisms in place in case of failures or errors.<br>**Employment and skill shift:** The automation of train scheduling might lead to concerns about job displacement and the need for reskilling of railway staff. While AI can optimize operations, it also changes the nature of work, requiring a shift in skills for human operators who now need to oversee and interact with advanced AI systems.<br>**Public trust and acceptance:** For the successful implementation of AI in public transportation, gaining and maintaining public trust is crucial. There may be apprehensions and resistance from the public regarding the shift to AI-driven systems, especially among those accustomed to traditional methods.<br>**Safety and security:** The use of AI-systems for critical operational scenarios raises concerns regarding the continued safety and security of these systems. Understanding failure modes, developing robust models, and ensuring resilience to adversarial attacks are among the many topics to be tackled.<br>**Inequality:** Such systems might introduce inequality in service quality for different geographic regions or categories of passengers due to the opacity of the system, bias and self-learning aspects. |
| ***Sustainable Development Goals (SDG) to be achieved*** |
| SGD9. Industry, innovation and infrastructure / SGD11. Sustainable cities and communities / SGD13. Climate action |

## 2 Overview of scenarios

| Scenario conditions | | | | | |
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| No. | Scenario name | Scenario description | Triggering event | Pre-condition | Post-condition |
| 1 | Re-Scheduling at the occurrence of infrastructure malfunction | The automated railway management system faces a challenge when a sudden infrastructure malfunction occurs (trigger event). This requires an immediate and strategic response to ensure continued service delivery and minimize disruptions. | A change in the infrastructure, e.g., a track becomes unexpectedly blocked | Intended service: a set of train runs with Start- and end location, a sequence of commercial stops, both with time information (Latest arrival, minimal dwell time, earliest departure).<br>An initial (microscopic) operational plan that is executable and fulfils the intended services such as the arrival and departure times of trains at commercial stops. | System has produced a new operation plan that is executable in the simulation and leads to an "acceptable" state at the end of the scenario |
| 2 | Emergency response to weather challenges | This scenario deals with sudden weather challenges, such as extreme weather conditions, impacting railway operations. | A weather challenge arises, such as a severe storm, heavy snowfall, or flooding, affecting parts of the railway network. | A standard operational plan is in place, but it does not account for a general degradation of state of operations, such as a general reduction of speed in a larger part of the network or the entire network. | The system quickly evaluates the impact of the environmental challenge on the network. It re-calculates a plan that adapt to the new situation. |
| 3 | Closure of a large station | This scenario addresses the challenge of adjusting the schedule in case of a closure of a whole station. | Closure of a station. | A standard operational plan is in place that foresees a number of trains performing commercial stops in the affected station. | Re-calculated plan |

## 3 Requirements

| Requirements | | |
|---|---|---|
| **Categories ID** | **Category name for requirements** | **Category description** |
| Ro | Robustness | Encompasses both its technical robustness (ability of a system to maintain its level of performance under a variety of circumstances) as well as its robustness from a social perspective (ensuring that the AI system duly takes into account the context and environment in which the system operates). This is crucial to ensure that, even with good intentions, no unintentional harm can occur. *Source: EU-U.S. Terminology and Taxonomy for Artificial Intelligence. First Edition* |
| E | Efficiency | Ability of an AI system to achieve its goals or perform its tasks with optimal use of resources, including time, computational power, and data. |
| I | Interpretability | Make the behavior and predictions of AI systems understandable to humans, i.e., degree to which a human can understand the cause of a decision. *Source: Molnar, Christoph. Interpretable machine learning. Lulu. com, 2020.* |
| Re | Regulatory and legal | The AI system's capacity to meet its objectives while complying with relevant laws, regulations, and ethical standards. |
| O | Other | Other non-function requirements related to environmental concerns and maintenance |
| **Requirement R-ID** | **Requirement name** | **Requirement description** |
| Ro-1 | System resilience to unexpected events | The AI system should work correctly under a variety of conditions and withstand operational disruptions. This includes resilience to unexpected events like equipment failures, adverse weather, and sudden changes in the railway network. |
| Ro-2 | Cyber and data security | Focuses on protecting the system against unauthorized access, cyber threats, and data breaches. This ensures the integrity and confidentiality of sensitive operational data and safeguards the system from malicious attacks. |
| Ro-3 | System’s reliable operation and decisions | Shall show the capacity to perform its required functions under stated conditions for a specified period. This includes maintaining consistent performance and minimizing system failures or errors. |
| E-1 | Capability to optimize resources and operations | System shall maximize network utilization, reduce delays and improving overall operational effectiveness with minimal resource expenditure. |
| E-2 | Scalability | Concerns the system's ability to handle growth, such as increased train traffic or network expansion, without performance degradation. This ensures the system remains effective as the scale of railway operations increases. |
| I-1 | Provide clear, understandable explanations for its decisions | It is crucial for human operators to validate and trust the AI's decisions, especially in complex scheduling scenarios. |
| I-2 | Usability of the system from the human and other stakeholders perspective | Should include intuitive interfaces, ease of use, and effective communication of information. |
| Re-1 | Compliance with legal standards and regulations | Adherence to data protection laws, safety regulations, and ethical guidelines governing AI systems in public transportation and the EU AI Act. |
| O-1 | Maintainability | Involves the ease with which the system can be maintained and updated. This includes the ability to diagnose and fix issues, update software, and adapt to |

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| | | changing operational requirements. |
| O-2 | Environmental Sustainability | Addresses the system's impact on the environment. This includes considerations such as energy efficiency of the AI algorithms, and the broader ecological footprint of the system's implementation and operation. |

## 4 Common Terms and Definitions

| Common Terms and Definitions | |
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| **Term** | **Definition** |
| Railway Undertaking Operating Managers (RUOMs) | Company or organization that operates trains or provides rail transport services. |
| Traffic Management System (TMS) | Provides permanent control across the network, automatically sets routes for trains and logs train movements as well as detects and solves potential conflicts. |
| Trains re-scheduling | Monitoring the movement of trains on a railway network and reacting to unexpected events, such as signal failures, track blockages, or weather events that disrupt operations, to other significant delays, and proactively to predicted deviations that affect planned operations. Re-scheduling measures include changing a train’s speed, path, or platform for stopping. |