1 Description of the use case

1.1 Name of the use case

ID	***Application Domain(s)***	***Name of Use Case***
UC2.Railway	Railway network	AI-assisted human re-scheduling in railway operations

1.2 Version management

Version Management			
Version No.	***Date***	***Name of Author(s)***	***Changes***
0.1	22.11.2023	Irene Sturm Adrian Egli	Initial Version
0.2	12.12.2023	Daniel Boos Adrian Egli	Major Updates
0.3	06.01.2024	Ricardo Bessa	Review
0.4	13.2.2024	Daniel Boos 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. 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. Already 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)	Aims to use AI-based methods to assist the human dispatcher in railway operations in re-scheduling train runs to fulfill all offered services and minimize delays for the customer (passenger).

1.4 Narrative of use case

Narrative of Use Case
Short description
In railway operations, traffic on the network is planned to fulfill the intended service contracted with the Railway Undertaking Operating Managers (RUOM). In railway traffic operations, a pre-planned schedule is executed. Unexpected events, such as infrastructure malfunctions or delays, occur. In this use case, a disruption or deviation occurs, and a dispatcher needs to become aware of the situation, analyze it, and decide to fulfill the requested services as close as possible to the pre-planned schedule. In our case, the dispatcher should be supported by an AI-assisted system to choose some actions, e.g., changing the speed, order, or routes of trains. The support system takes the state of all trains in the dispatcher's control area as input and suggests options, i.e., sets of actions, to the dispatcher.
Complete description
Train dispatching is responsible for managing the movement of trains across a complex rail network. The human dispatchers rely on a computerized dispatching system to help them plan and monitor train movements. However, unexpected disruptions, such as signal failures, track blockages, or weather events, can cause significant delays and disruptions to the train schedule. In the event of a disruption, dispatchers need to quickly make decisions to reschedule trains and minimize the impact on passengers and freight. This can be complex and time-consuming, especially considering the intricate network of tracks, train priorities, and passenger demand.

In this use case, an AI-assistant system supports the human dispatcher. This system gets the real-time state of all the trains and tracks in the dispatcher's control area and derives possible dispatching options, in case of deviations from the pre-planned schedule due to disruptions or delays. The options are presented in near real-time to the dispatcher and consist of a set of actions the dispatcher can perform to bring the trains back or close to their pre-planned schedules.

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, 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. **Set up/configuration of human-AI teaming:** The human defines the boundary requirements, including the flexible allocation of decision-making authority between human and machine.
3. **Schedule execution:** The initial operational plan is put into action. 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 and traffic density management.
4. **Monitoring:** At any time in operations the human dispatcher can monitor the flow of traffic in the area of control. There exist visual displays of the traffic running through the network and in addition metrics are available. Information about the current intended plan is available.
5. **Detection of deviation:** At any time in operations an emerging deviation of the actual state of the system from the planned state is detected by the human-AI team. 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.
6. **Action (re-scheduling):** Different potential action paths according to the set up/configuration human-ai teaming from step 2:
    a. 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 and provides suggestions. The human agent can choose to select one of the suggestions by the AI systems, initiate a new solution search, or choose their own course of action.
    b. 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. Humans propose a solution, and the AI system provides quantified feedback. Human adapts the proposed solution and initiates action.
    c. 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 and proposes a solution. The human provides feedback (e.g., context that is not known to the system). AI adapts the solution based on the feedback and they jointly initiate action (human-AI negotiant).
7. **Execute solution:** 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.
8. **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.
9. **Co-learning:** AI agent learning loop using observations of human decision-making process. Human learning process (e.g., to detect emerging deviations or to develop solutions) is explicitly supported by human-ai interaction.

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.

Human dispatcher:

- Damage to the reputation, safety issues as well as a potential general perception of an opaque AI-system being in control of running trains can cause a decrease in the trustworthiness of the railway operator from a customer perspective, both for individual travelers and cargo transport.
- The usefulness and understandability of the AI-system output to the dispatcher may influence the trustworthiness of the AI-system from the perspective of the dispatcher. Low trustworthiness might render the use of the AI system irrelevant as the dispatcher will not trust the options generated by the system, and the assumed benefit will not materialize.

System's threats and vulnerabilities

Accountability: who is responsible for delays and in general bad performance of the AI-system, and accidents and other harm caused by the AI-system.

Security: AI-system introduces the risk of malicious actors disrupting operations either through the disabling or disruption of the AI system or by influencing system to produce output that causes delays, accidents, etc.

1.5 Key performance indicators (KPI)

Name	*Description*	*Reference to the mentioned use case objectives*
Assistant relevance	Situation awareness of the human operator using the system It is based on an evaluation by the human operator of the relevance of action recommendations provided by the AI assistant and measured by the number of recommendations from AI assistant effectively used by the human operator.	Linked to the capacity of the AI system to support the dispatcher in choosing some actions
Human Information Processing	Volume of information that the human takes into account when taking decisions with AI support (as compared by taking decisions with no AI-support).	Linked to the cognitive load of human dispatchers
Punctuality	Aggregated measure of delay in a scenario (defaults to be defined).	Linked to the objective of minimizing delays.
Response time	Time needed to produce a new schedule in case of a disturbance event.	Related to the objective of rapid re-scheduling.

Proactiveness	Ratio of (proactively) prevented deviations to actual deviations.	Linked to the need to conduct predictive analysis
Comprehensibility	Defined as the ability to understand a decision logic within a model and therefore the ability to use this knowledge in practice (Futia and Vetrò, 2020). Futia, G. and Vetrò, A. (2020). On the Integration of Knowledge Graphs into Deep Learning Models for a More Comprehensible AI. Information, 11 (2), 122-132. Herm, L. V., Wanner, J., Seubert, F., & Janiesch, C. (2021). I Don't Get IT, but IT seems Valid! The Connection between Explainability and Comprehensibility in (X) AI Research. In ECIS.	Linked to interpretation of what has been learned and decision logic
Acceptance	Acceptance of the system by a human user (e.g., Using TAM model (technology acceptance model).	Reflects the reliability and trust on the AI system.
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
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. *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. *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. 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. *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. *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
Opportunities for standardization and deriving recommendations for critical operations management and support, especially regarding co-decision making and human computer interaction, as well as safety requirements. See also UC1.Railway.

1.7 Societal concerns

Societal concerns
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.

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.

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.

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.

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.

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 (SGD) to be achieved

SGD9. Decent work and economic growth / SGD9. Industry, innovation, and infrastructure / SGD11. Sustainable cities and communities / SGD13. Climate action

2 Overview of scenarios

Scenario conditions					
No.	**Scenario name**	**Scenario description**	**Triggering event**	**Pre-condition**	**Post-condition**
1	Reactive Re-Scheduling	The reactive re-scheduling by the human-AI team once a deviation or disturbance has already occurred.	An emerging disruption or deviation occurring (e.g. blocked track, malfunction train)	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). 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	Co-learning for reactive re-scheduling	The co-learning process initialized by the reactive re-scheduling by the human-AI team once a deviation or disturbance has already occurred.	Human and AI action and interaction during the re-scheduling process occurring after a disruption or deviation.		
3	Proactive re-scheduling	Proactive re-scheduling by the human-AI team upon detection of weak signals.	Detection of precursors or weak signals indicating a probability of larger disruptions and deviation in the future	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). 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 without the presence of any additional weak signals.
4	Co-learning for proactive re-scheduling	Co-learning process initialized by the proactive re-scheduling By the human-AI team	Human and AI agent action and interaction during the detection and rescheduling phases.		

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	Reasonable recommendations in new situations (not seen during model training)	Systems provides reasonable solutions for situations not seen during training
Ro-2	Good performance in operating scenarios with high variability	System performs well in situations with many fast-changing elements
Ro-3	Retrospective quality control	Quality of provided options can be assessed in retrospect
E-1	Capacity to handle operating scenarios with high complexity	System derives options fast and with high quality in complex situations with many trains, switches and other elements involved.
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	Understandability of options	Dispatcher can understand general aim of options provided by the system
I-2	Process transparency	Dispatcher understands the process of generating the options and the objectives of the AI agent
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 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	
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.
Co-learning	Co-learning indicate that human or AI in a team has the ability that can interact and learn from/with, and grow with their collaborator. The goal of co-learning is to support two dynamic growing entities to build mutual understanding, facilitate mutual benefit, and enable mutual growth over time. *Source: Huang, Y. C., Cheng, Y. T., Chen, L. L., Hsu, J. Y. J. (2019). Human-AI Co-learning for data-driven AI. arXiv preprint arXiv:1910.12544.*
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.