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	12.04.2024	Roman Ließner, Irene Sturm, Adrian Egli	Initial Version (import from UC1.Railway short)
0.2	14.04.2024	Manuel Renold, Adrian Egli	Checked alignment use cases/framework and more update
0.3	16.04.2024	Ricardo Bessa	Revision
0.4	17.04.2024	Julia Usher	Revision
0.5	25.04.2024	Adrian Egli, Daniel Boos, Irene Sturm, Roman Ließner, Manuel Schneider	Final Revision
0.6	30.05.2024	Adrian Egli	Revision: Action space
1.0	08.07.2024	Ricardo Bessa	Final version

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 maximize utilization of the network's capacity. 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 with frequent adaptation and re-scheduling of 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 re-scheduling decisions.
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).
Deployment model	Cloud services and on-premises.

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 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 must 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, weather events that disrupt operations, or 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. 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 must integrate a lot of context information under time constraints

System description and role of the human operator: An AI-based re-scheduling system performs the re-scheduling task in a highly automated manner. 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 introducing 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 also 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.

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 operators, RUOM, and passengers.
- Legal and regulatory framework: Regulations with the 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, personnel 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. **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 of 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.
Trust towards the AI-System	*"(Dis)trust is defined here as a sentiment resulting from knowledge, beliefs, emotions, and other elements derived from lived or transmitted experience, which generates positive or negative expectations concerning the reactions of a system and the interaction with it (whether it is a question of another human being, an organization or a technology)"* (Cahour & Forzy, 2009, p. 1261). The human operators' trust in the AI tool can be measured using the Scale for XAI (Hoffman et al., 2018) or similar.	Linked to the human operator's appropriate trust in the AI system as a necessary precondition of adequate use.
Human motivation	*"Intrinsic motivation is defined as the doing of an activity for its inherent satisfaction rather than for some separable consequence. When intrinsically motivated, a person is moved to act for the fun or challenge entailed rather than because of external products, pressures, or rewards"* (Ryan & Deci, 2000, p. 54). The human operators perceived internal work motivation can be measured by using the Job Diagnostic Survey (Hackman & Oldham, 1974) or similar. The questionnaire needs to be adapted to the AI context (e.g., problem detection with AI assistance).	This is linked to the necessary motivation of the human operator to use the AI for complete a task and reach corresponding objectives.
Human control/autonomy over the process	Autonomy is the degree to which the job provides substantial freedom, independence, and discretion to the employee in scheduling the work and in determining the procedures to be used in carrying it out" (Hackman & Oldham, 1975, p. 162). It consists of three interrelated aspects centered on freedom in decision-making, work methods, and work scheduling (Morgeson & Humphrey, 2006). Parker and Grote (2022) view job autonomy interchangeably with job control. The human operator's perceived autonomy over the process can be measured by using the Work Design Questionnaire (Morgeson & Humphrey, 2006) or similar. The	Linked to the perceived control of the human operator as a necessary prerequisite for taking responsibility for the efficiency and effectiveness of one's own work.

	questionnaire needs to be adapted to the AI context (e.g., problem detection with AI-assistance).	
Human learning	Human learning is a complex process that leads to lasting changes in humans, influencing their perceptions of the world and their interactions with it across physical, psychological, and social dimensions. It is fundamentally shaped by the ongoing, interactive relationship between the learner's characteristics and the learning content, all situated within the specific environmental context of time and place, as well as the continuity over time (Alexander et al., 2009). The human operators perceived learning opportunities working with the AI-based system can be measured by using the task-based workplace learning scale (Nikolova et al., 2014) or similar. The questionnaire needs to be adapted to the AI context.	Linked to the objective of mutual co-learning to assist the human operator in improving his/her performance.
Decision support for the human operator	Decision support tools should be aligned with the cognitive decision-making process that people use when making judgments and decisions in the real world and ensure that the human operator retains agency (Miller, 2023). AI decision support tools should, therefore, help people to remain actively involved in the decision-making process (e.g., by helping them critique their own ideas) (Miller, 2023). The decision support for the human operator can be measured based on the criteria for good decision support (Miller, 2023) or similar. The instrument needs to be further developed.	Linked to the appropriateness of AI-based support of the human operator's decision-making process.
Ability to anticipate	*"The ability to anticipate. Knowing what to expect, or being able to anticipate developments further into the future, such as potential disruptions, novel demands or constraints, new opportunities, or changing operating conditions"* (Hollnagel, 2015, p. 4). The human operator's ability to anticipate further into the future can be measured by calculating the ratio of (proactively) prevented deviations to actual deviations. In addition, the extent to which the anticipatory sensemaking process of the human operator is supported by an AI-based assistant can be measured by using the Rigor-Metric for Sensemaking (Zelik et al., 2010) or similar. The instrument needs to be further developed and adapted to the AI context.	Linked to AI-based enabling of human operators to minimize delays for the customers.
Situation awareness	"Situation Awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1988, p. 12). The human operator's situation awareness can be measured by using the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1988) or similar.	Linked to the AI-based assistance of the human operator for developing an appropriate situation awareness.

1.6 Features of use case

Task(s)	Planning, prediction, optimization, interactivity, and recommendation.
Method(s)	Reinforcement learning has been applied to this use case, but other AI approaches are possible.
Platform	Flatland digital environment.

1.7 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 UC2.Railway.

1.9 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 and security of passenger and employee 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
SDG9. Decent work and economic growth / SDG9. Industry, innovation and infrastructure / SDG11. Sustainable cities and communities / SDG13. Climate action

2 Environment characteristics

Characteristics	
Observation space	Fully observable with limitations due to the unpredictable duration of delays and malfunctions. Data update is near real-time (rather seconds than hours). Domain: defined on a continuous space. Size: Depending on the type of observation considered local or global, the total size can depend, but it will generally be very large. Noise: The observation can be noisy due to the communication system and the various signaling devices (*signal box*). (In addition to more than 10,000 trains (per day), there are over 32,000 signals and over 14,000 switches in the Swiss rail network. All of this information must be considered and observed; thus, the global observation is very large.)
Action space	Mixed action space: actions like which route to take on a switch are discrete, as well as decisions like whether a train should accelerate or decelerate. However, dependent on the algorithmic approach, the rate of acceleration, deceleration, velocity to move forward, and similar can be modeled both discrete and continuous. Size: Depends on the algorithmic approach. While the action space grows linearly with the number of trains for the algorithmic part, it grows exponentially if there is a central actor controlling all the trains. The action space of the human dispatcher is, in any case, exponentially growing with the number of trains. Furthermore, the dimensionality of the action space depends on infrastructure and timetable elements like switches, signals, and scheduled stops. Hereby, the impact on the dimensionality of the action space depends not only on the actor's nature in the algorithmic part but also on the type of task, i.e., if the task is tackled episodically or sequentially on the algorithmic side. For the human dispatcher, the task is generally considered to be sequential since an action is usually dependent on previous actions taken. Time horizon: An action typically takes from a few minutes to a couple of hours. The action space of the flatland environment is 5 (go left, go forward, go right, stop, none). However, each train run (agent) must perform one of these basic actions at each decision point (time step). This means that the total number of actions to be selected is very large and stays in linear relation to the number of agents - i.e., in a problem-solving scenario with n agents and m time steps, the actions should be chosen in such a way that the combination of selected actions leads to the desired outcome or optimal solution. Each agent has a set of actions to choose from, from which they must select one at each time step. Therefore, the solution involves n x m x a possible action. (Up to 800 trains run simultaneously on the Swiss rail network. In many cases, they interact directly or indirectly with each other.).
Type of task	The nature of the task depends on the algorithmic approach. While AI models can determine which action to take fully based on the current state without including information about past actions and would therefore be considered episodic, other approaches can, to a large degree, approach problem-solving as a sequential task, for example, if planning is involved. The human dispatcher usually approaches the task sequentially.
Sources of uncertainty	Stochastic, with the following sources of uncertainty: 1) Weather conditions can impact, e.g., the friction of wheels on rails, which leads to different acceleration and deceleration behavior. 2) The travel demand influences both the total load of a train and the delay to board other passengers. 3) Disruptions: Train level – locomotives or another rolling stock issue that may arise

	and result in a delay; Infrastructure level – signal malfunctions or construction sites. 4) Sensors and communication level – a failure may introduce noise and uncertainty in observing the environment.
Environment model availability	A specific model of the environment is not available. Although a good approximation of it can be achieved as the basic laws of physics are defined and clear. However, a model of the environment will be simplified in general and subject to uncertainty (see above).
Human-AI interaction	Co-learning between the human and AI: The interaction between humans and AI is done just after fully automated rescheduling when the super users analyze the outcome of the operations. (Learning from post-perspective analytics).

3 Technical details

3.1 Actors

Actor Name	*Actor Description*
Dispatcher	The dispatcher is a human responsible for monitoring and analyzing railway traffic. The main role is to ensure the safe and efficient movement of trains by controlling the flow of traffic and making decisions based on real-time information. The dispatcher determines the order of trains and may deviate from planned routes when necessary to accommodate unexpected situations or optimize the overall operation. The decisions play a crucial role in maintaining the smooth functioning of the railway system.
Traffic control system	The traffic control system collects information such as traffic signals, train positions, and current train speeds and also provides a human-machine interface for controlling ongoing traffic. The system's goal is to manage the flow of traffic efficiently, centrally, and safely. This necessitates the comprehensive collection of available information to effectively support the decision-making process, which is primarily performed by human dispatchers. Consequently, the traffic control system is vital and should be implemented with a human-centered approach unless a fully automated solution is available.
Train run (Driver)	A train run refers to the operation of a train on a specific route or journey from one station to another. It encompasses the entire process of a train traveling along its designated path, including departure from the originating station, intermediate stops (if any), and arrival at the destination station. The current position and speed of the train are communicated to the traffic control system.

4 Step-by-step analysis of use case

4.1 Overview of scenarios

Scenario conditions					
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 locations, 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 fulfills the intended services, such as the arrival and departure times of trains at commercial stops.	The 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 the 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 adapts 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

4.2 Steps of the training scenario

Step no.	Event	Name of process/ activity	Description of process/ activity Service	Information producer (actor)	Information receiver (actor)	Information Exchanged
1	Start	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.	Administrator	Network Operator	SYSPAR
2	System params defined	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.	Dispatcher	TMS	EXECPLAN
3		Triggering Re-scheduling	The re-scheduling process can be initiated by a variety of triggers defined by the scenarios listed in 4.1. Examples of such triggers are infrastructure changes (scenario 1), heavy weather events (scenario 2) or station closures (scenario 3). 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.	TMS	Dispatcher	STATE

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.	TMS	Dispatcher, Simulation	EXECPLAN
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.	TMS	Dispatcher	STATE

5 Information exchanged

Information exchanged		
Information exchanged (ID)	***Name of information***	***Description of information exchanged***
SYSPAR	System Parameters	A series of parameters is necessary to initialize the environment and provide all operative information to the agent(s).
EXECPLAN	Operational plan	The planned schedule is to be executed, including information such as commercial stop sequence and operational requirements.
STATE	State of the system	Detailed information on the current state of the system. Particular focus is given to any information about deviations from the expected system state.

6 Requirements

Requirements		
Categories ID	**Category name for requirements**	**Category description**
Ro	Robustness	It encompasses both its technical robustness (the 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	The 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., the 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.
Fa	Fairness	Ensure the recommendations and predictions of the AI system are in line with the principles of fairness (i.e., fair distribution of the benefits and strain/harm)
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	The system performs well in situations with many fast-changing elements
Ro-3	Retrospective quality control	The quality of provided options can be assessed in retrospect
E-1	Capacity to handle operating scenarios with high complexity	The 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.
E-3	Generalization to different scenarios	The system's ability to handle previously unseen scenarios and generalize to areas of observation and action space not visited during training (e.g., different speed profiles, rails configuration etc.)
Re-1	Compliance with legal standards and regulations	Adherence to data protection laws, safety regulations, cybersecurity, and ethical guidelines governing AI systems in public transportation and the EU AI Act.
I-1	Interpretability of suggestions	The process through which the AI system learns and operates, including how it generates suggestions, is transparent and understandable to the human dispatcher. Further, the decision-making that leads to the suggestion, as well as its limitations, are explained to the human dispatcher.
Fa-1	Distribution of Delays	The system should not unfairly favor specific regions, connections, or groups of individuals. This means that when system disruptions cannot be avoided, they should be distributed fairly. Measures should be put in place to ensure that these constraints are observed.
Re-2	RUOM Favouritism	The system should not unfairly favor specific RUOMs. Re-scheduling in railway operations must impact the RUOMs fairly. Measures should be put in place to ensure that these constraints are observed.
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.

7 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)	It provides permanent control across the network, automatically sets routes for trains logs train movements, and detects and solves potential conflicts.
Co-learning	Co-learning indicates that human or AI in a team has the ability to interact, learn from/with, and grow with their collaborator. Co-learning aims 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.