Next stop: Technology on Track

Exploring VR, AR and AI in Railway Operations

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11th Railway Talk, 09/12/2025

Railway System

Over the last 25 years, the Commission has been proactive in proposing changes to Europe's rail transport market to strengthen rail vis-à-vis other transport modes. Efforts have targeted three areas crucial for a strong and competitive rail industry:

-Opening the rail transport market to competition

-Improving interoperability and safety

-Developing rail infrastructure

[Rail - Mobility and Transport - European Commission]

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VR,AR,AI and… Human Factor

We are going to talk about….

1) Virtual Reality and applications in Railway Operations
2) Augmented Reality and applications in Railway Operations
3) Artificial Intelligence and applications in Railway Operations
4) The role of Human Factor and Just Culture




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Virtual Reality - Introduction

VR introduced in 1963 by **Ivan Sutherland**

Virtual Reality - Introduction

1965 “**The Ultimate Display**” :

a hypothetical navigable virtual world designed

and constructed entirely within a computer

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Virtual Reality - Introduction

Ivan Sutherland developed a VR and AR

head-mounted display (HMD) in 1968

Virtual Reality - Introduction

Later developed various VR devices, such as

the ‘**Data Glove**’

Virtual Reality – As Is

Four main categories of transportation and logistics are focused: air, maritime, railway, and road

six clusters of research:

1) operator training in routine procedures

2) operator training in incident handling

3) simulation of carriers

4) design of traffic infrastructure and carriers

5) psychological studies on transportation and logistics operators or associated parties

6) treatment of illness related to transportation and logistics

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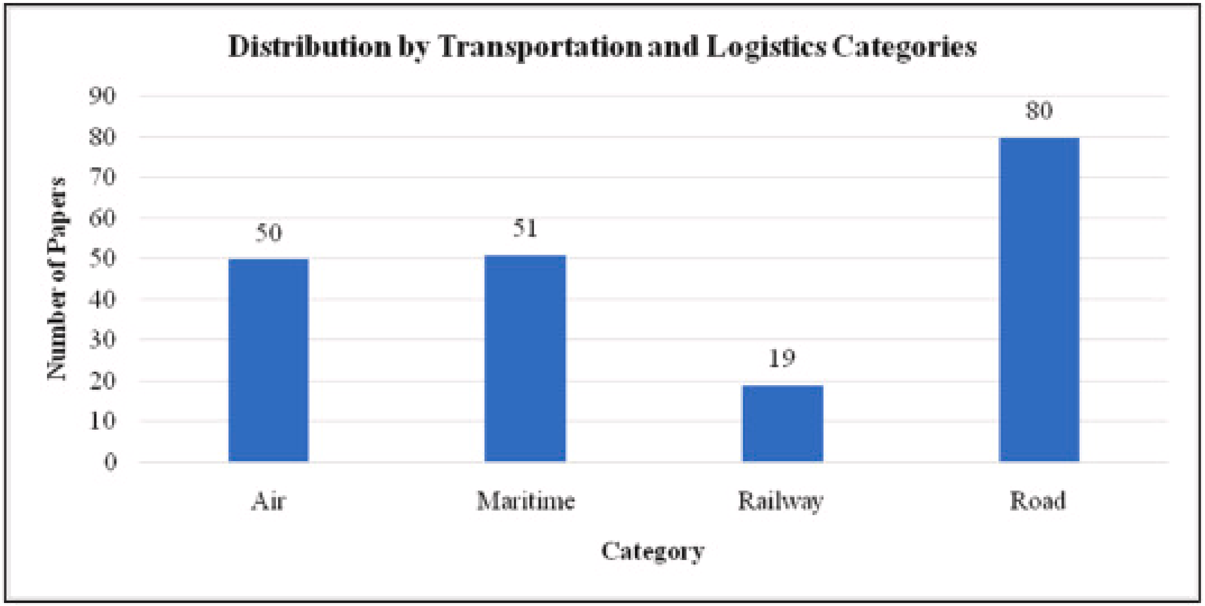
Virtual reality in transportation and logistics: A clustering analysis of studies from 2010 to 2023 and future directions – ScienceDirect

Virtual Reality



Number of VR-related transportation and logistics studies from 2010 to 2023

[Virtual reality in transportation and logistics: A clustering analysis of studies from 2010 to 2023 and future directions – ScienceDirect]

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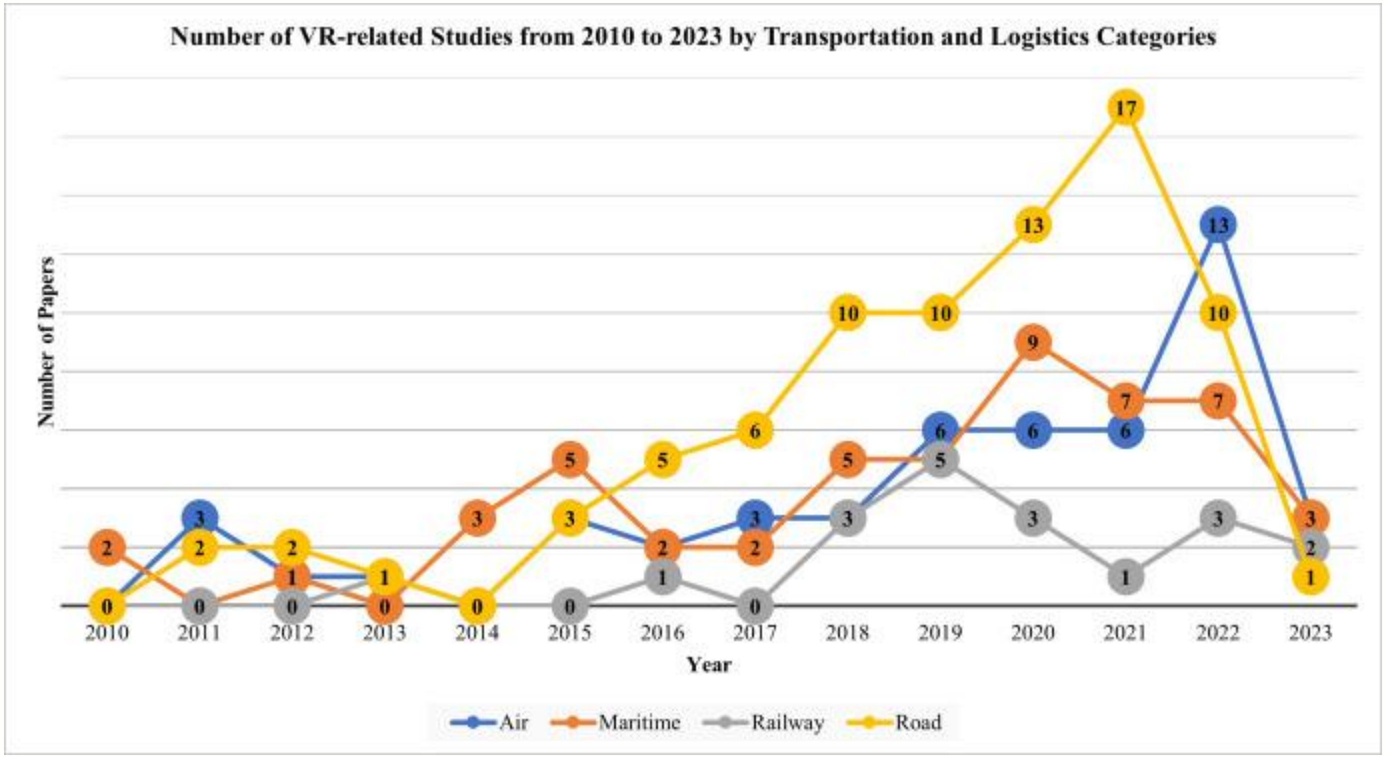
Virtual Reality



Distribution by categories of VR-related transportation and logistics studies

[Virtual reality in transportation and logistics: A clustering analysis of studies from 2010 to 2023 and future directions – ScienceDirect]

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Virtual Reality

The clustering analysis of the collected studies revealed the following six clusters in VR-related research on transportation and logistics

1) operator training in routine procedures

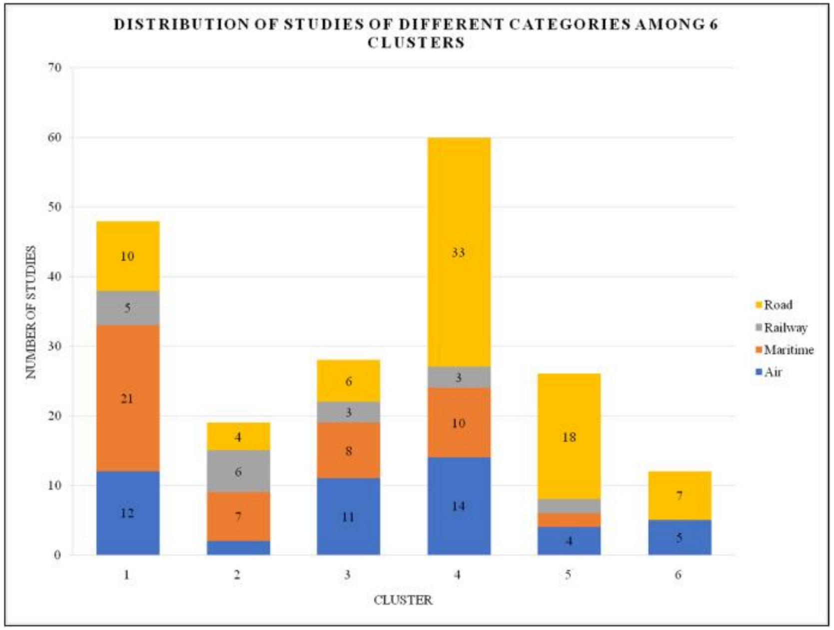
2) operator training in incident handling

3) simulation of carriers

4) design of traffic infrastructure and carriers

5) psychological studies on transportation and logistics operators or associated parties

6) treatment of illness related to transportation and logistics



Distribution of VR-related studies of different categories of transportation and logistics among the 6 clusters

[Virtual reality in transportation and logistics: A clustering analysis of studies from 2010 to 2023 and future directions – ScienceDirect]

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Virtual Reality

The innovative features that particularly characterize VR are Immersion and Interactivity.

Immersion is the ability to remove the user from the real world through the use of screens or head-mounted displays, while **Interactivity** is the ability to produce a continuous flow of images at the exact moment they are requested.

The VR application we will see is designed to simulate, train, or support checking and maintaining bolts on railroad tracks.

Virtual Reality - Infrastructure

Initial immersion and orientation. At launch, operators are placed in a virtual environment that mimics a section of track. Users can physically "rotate" and observe the surrounding area to familiarize themselves with the environment. Virtual signs and markers (such as "Defects: 5 m") indicate the distance and direction of the defects to be analyzed.

[Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI]

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Virtual Reality - Infrastructure

Navigation by teleportation. The application guides users through interactive "totems," virtual structures that provide textual and graphical instructions. The first totem explains how to move around the environment: the user points the controller at an area of the ground and presses the basic button (i.e., trigger) to "teleport" to the desired location. On the other hand, the second and third totems illustrate the steps for checking and controlling bolts, with instructions on selecting and interacting with an element.

Figure 3. (**a**) Totem 1 instructions and (**b**) Totem 2 and Totem 3.

[Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI]

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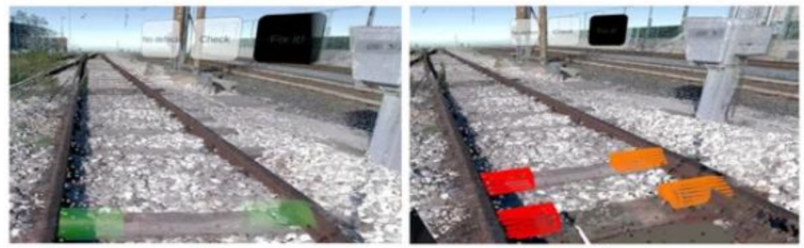
Virtual Reality - Infrastructure

Identification and selection of bolts. Once the bolts to be checked are reached, graphical highlights (colored columns or cylinders) are noted to overlay interactive information on the track. The user, via the controller, can point to each bolt and activate contextual menus.

Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI

Virtual Reality - Infrastructure

Bolt status classification. Upon clicking on a single bolt, three representative status options appear:



(a) (b)

Figure 5. (a,b) Two different views of tabs with which to select the status of bolts.

•No defect.
•Check (to be checked).
•Fix it! (needs replacement or repair).

Each time the operator selects one of these items, the cylinder associated with the bolt changes color (e.g., green, orange, or red) depending on the selected status, providing immediate visual feedback. It is worth pointing out that the classification panel can show actual pictures of the bolt or asset to be repaired, acquired by other means, such as a diagnostics train, providing a way for planners to confirm the necessity to proceed with the repair work.

[Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI]

Virtual Reality - Infrastructure

Confirmation and completion of operations. When finished, when all bolts have been evaluated and have taken on the correct coloring corresponding to their status, the user heads to the last totem. Here, he finds the final instructions to confirm the inspection's outcome. Once the confirmation button is pressed, the application registers that the operation is complete.

[Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI]

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Virtual Reality - Wagons

• **inspector's visibility** (area 1) - the instructor observes the inspector's actions as if he were the inspector himself;

• **car fault assignments** (area 2) - the instructor selects the necessary checkboxes in the list of faults, hence in the 3D model of the car, the corresponding parts of the car are replaced with faulty ones;

[VR Training for Railway Wagons Maintenance: architecture and implementation - ScienceDirect]

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Virtual Reality - Wagons

• **mini-map** (area 3) - displays the current location of the instructor's and inspector's avatars relative to the car model;

• **instructor's visibility** (area 4) - the instructor observes the 3D scene and uses the mouse to change the viewing angle of his avatar.

[VR Training for Railway Wagons Maintenance: architecture and implementation - ScienceDirect]

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Virtual Reality-Wagons

The inspector's helmet displays the interface corresponding to area 1

[VR Training for Railway Wagons Maintenance: architecture and implementation - ScienceDirect]

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Virtual Reality - Conclusions

With VR integration, it is possible to achieve increased accuracy in defect detection, faster maintenance processes, and better overall quality of work performed. In summary, the VR application allows:

•**To train personnel** in the bolt assessment and maintenance procedure in a safe and infinitely replicable context without the need to be physically present along the tracks.

•**To assist operators** in real time by indicating components to be inspected and actions to be taken, also in a future advanced version integrated with real systems.

•**To reduce errors** through a graphical UI and step-by-step instructions that minimize the risks of incorrect assessment or incomplete actions.

•**To document and analyze data on bolt status** (i.e., correct, to be checked, to be replaced) so that it can be tracked automatically, simplifying maintenance reports and statistics.

Augmented and Virtual Reality for Improving Safety in Railway Infrastructure Monitoring and Maintenance | MDPI

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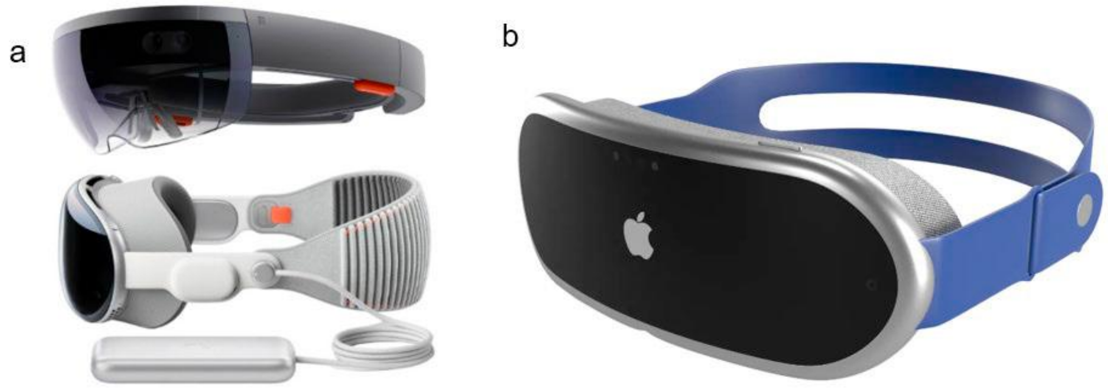
Augmented Reality - Introduction

Augmented Reality (AR) is a technological evolution of virtual reality. While VR completely reconstructs real parts of a given context in a digital environment, AR consists of techniques capable of providing the user with a reality “enhanced” by digital images.

AR, in fact, starts from a real context that is captured—such as a video feed from a camera—and adds synthetic content to it interactively, providing useful information to the operator who uses such technological devices.

The purpose of AR, unlike VR, is therefore not to achieve photorealism in order to transport the user into a different context from the one they are actually in, but rather to integrate the real world the user currently occupies with informations, images, manuals, and to connect the operator directly to control centers, so as to carry out certain tasks—especially in the field of maintenance—more quickly and with greater safety.

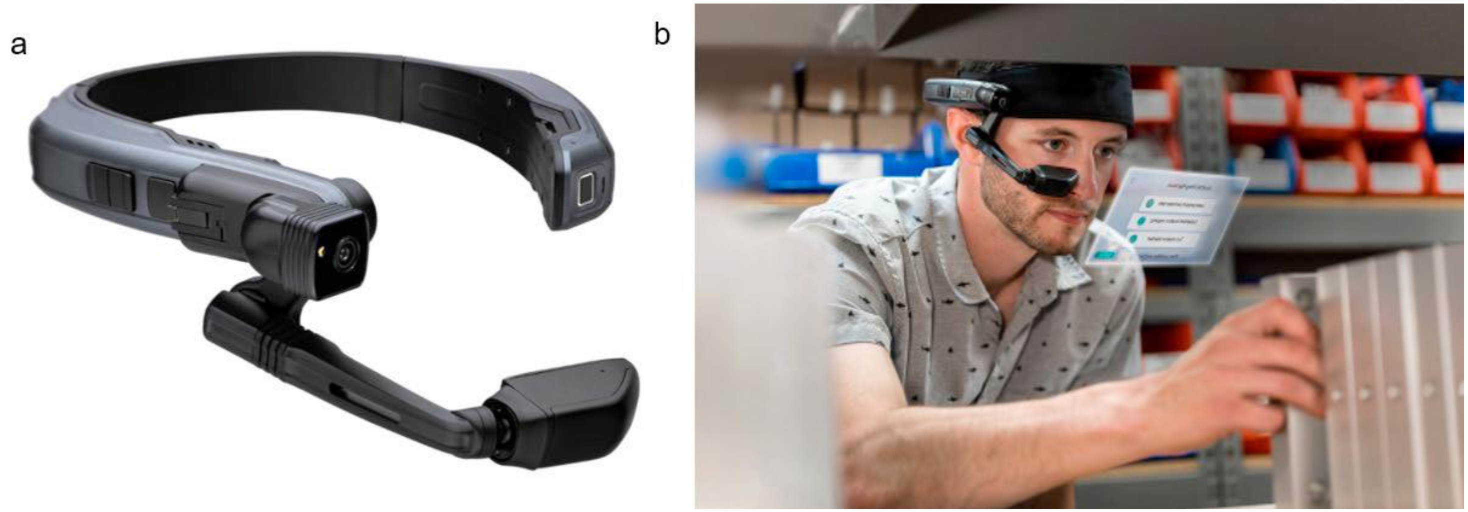
Augmented Reality – Devices



(a) Example of hardware devices used for augmented reality ("Geekwire," n.d.);
(b) Example of hardware devices used for augmented reality ("Spieltimes," n.d.).

[Use of Augmented Reality in Railway Transport - ScienceDirect]

Augmented Reality – Devices



(a) Exampled the possible use of augmented reality without disrupting the user's field of view (Ayes.cz);

(b) Exampled the possible use of augmented reality without disrupting the user's field of view (Ayes.cz.).

[Use of Augmented Reality in Railway Transport - ScienceDirect]

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Augmented Reality in Railway Operations

a

b

(a) *Examples of possible use of augmented reality without disturbing the user's field of vision (Spasova, 2022);*

(b) Examples of possible use of augmented reality without disturbing the user's field of vision ("Railbusinessdaily," n.d.).

Use of Augmented Reality in Railway Transport - ScienceDirect

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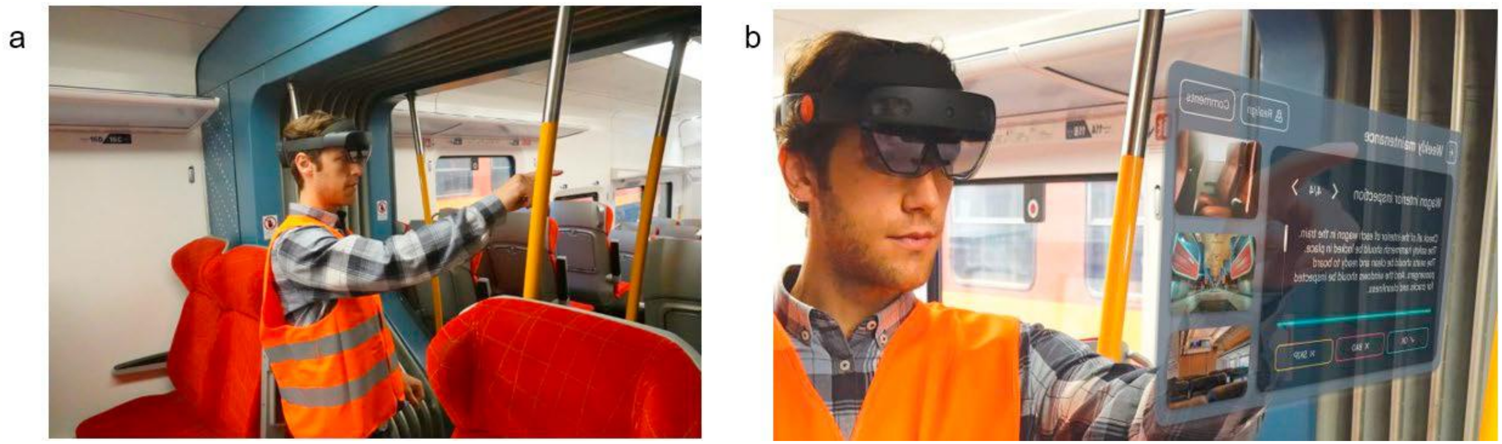
Augmented Reality in Railway Operations



(a) Examples of possible use of augmented reality with the use of the entire field of vision of the user ("I1," n.d.);
(b) Examples of possible use of augmented reality with the use of the entire field of vision of the user ("I1," n.d.).

[Use of Augmented Reality in Railway Transport - ScienceDirect]

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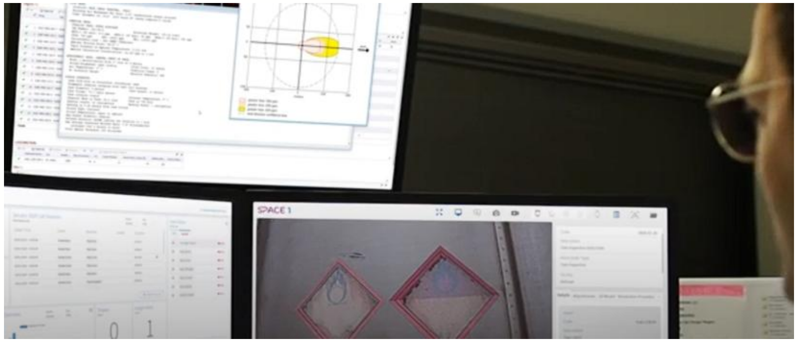
Augmented Reality in Railway Operations



[Rail Cargo hands-free inspections on Cargo trains with OverIT]

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Augmented Reality - Conclusions

The use and application of augmented reality in rail transport can generally be divided into the following areas:

- education and training
- operation
- supporting activities
- service
- safety
- digitalisation of processes

Use of Augmented Reality in Railway Transport - ScienceDirect

Artificial Intelligence

"AI refers to systems that display intelligent behavior by analyzing their environment and taking action – with some degree of autonomy – to achieve specific goals"

Controlling the environment with Artificial ... | Open Research Europe

Artificial Intelligence

Unsupervised Learning

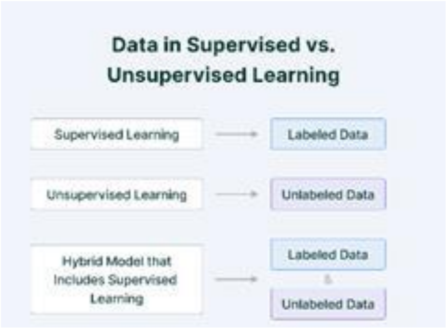
Unsupervised learning systems are capable of learning without the need for pre-classified data.

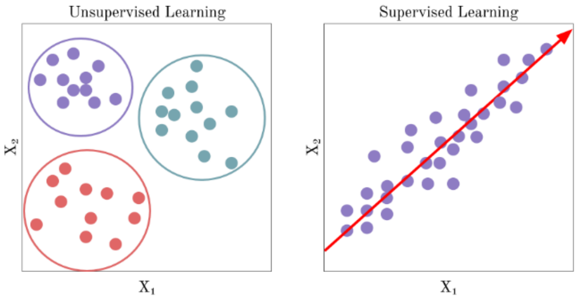
Supervised Learning

This is a learning technique in which the model is fed training examples composed of an input vector *x* and the expected outcome *y*. In this case, the example is said to be *labeled*, meaning pre-classified.

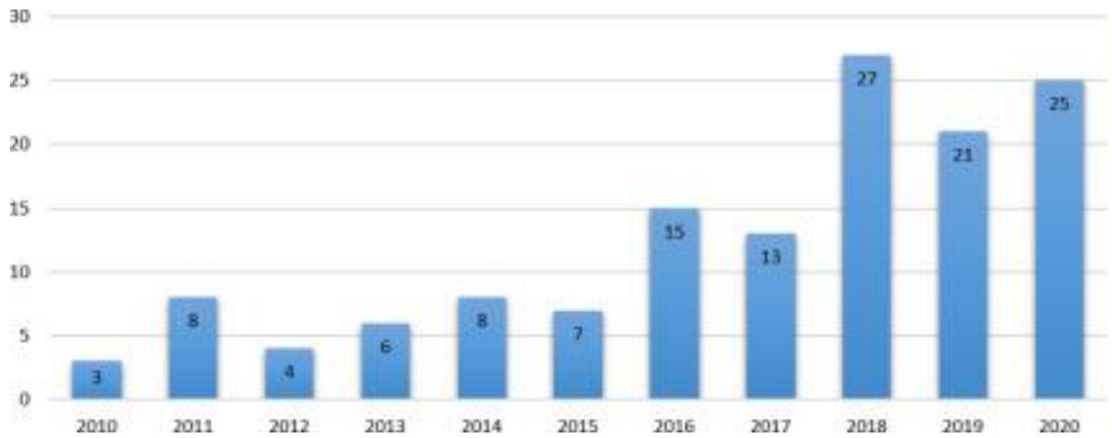
Semi-Supervised Learning

In this case, learning takes place by using input data that is only partially pre-classified (*semi-labeled*).





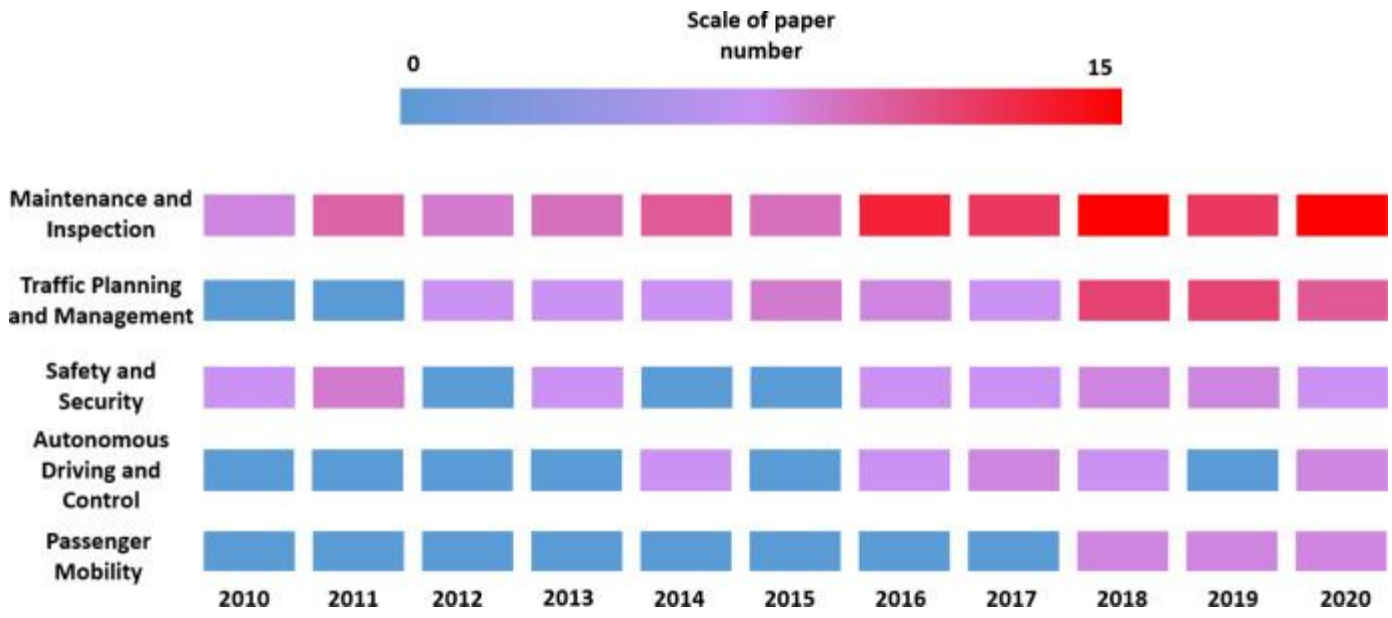
Artificial Intelligence



Distribution of papers for the period 2010–2020

A literature review of Artificial Intelligence applications in railway systems - ScienceDirect

Artificial Intelligence



Distribution of papers in each rail sub-domain over years

[A literature review of Artificial Intelligence applications in railway systems - ScienceDirect]

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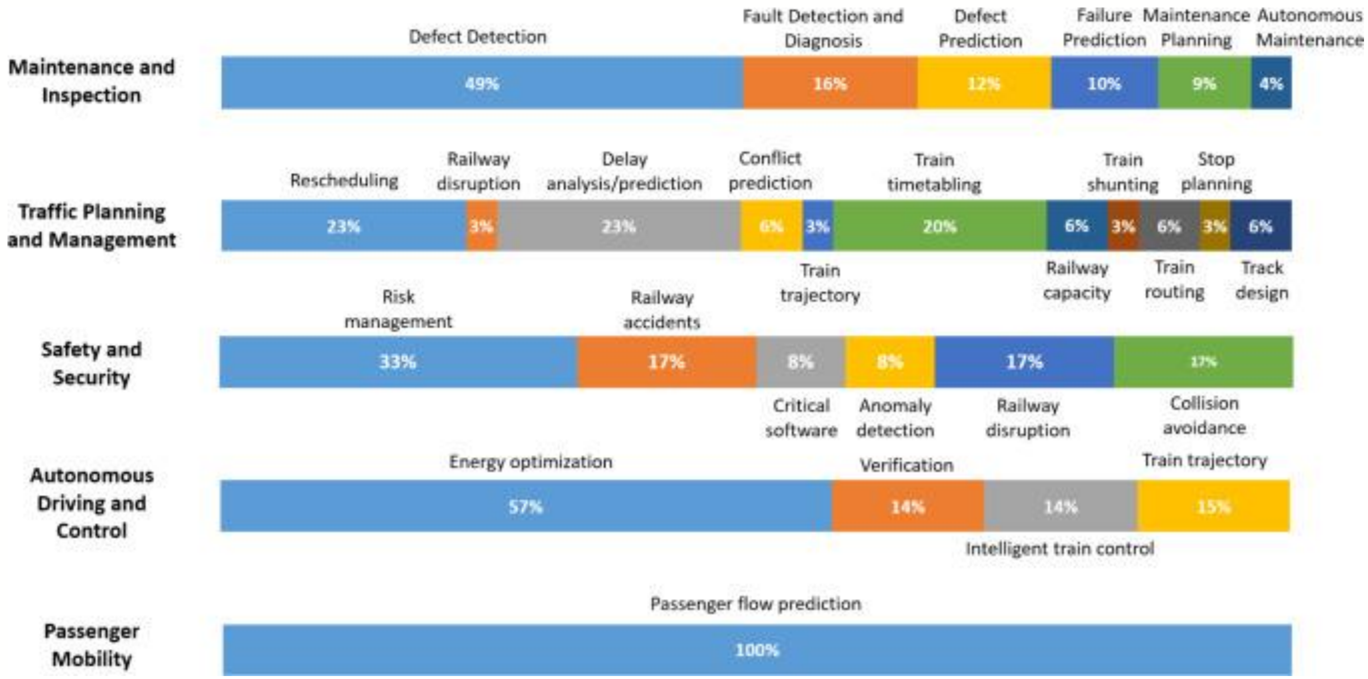
Artificial Intelligence



Papers in 5 railway sub-domains with respect to their focus

[A literature review of Artificial Intelligence applications in railway systems - ScienceDirect]

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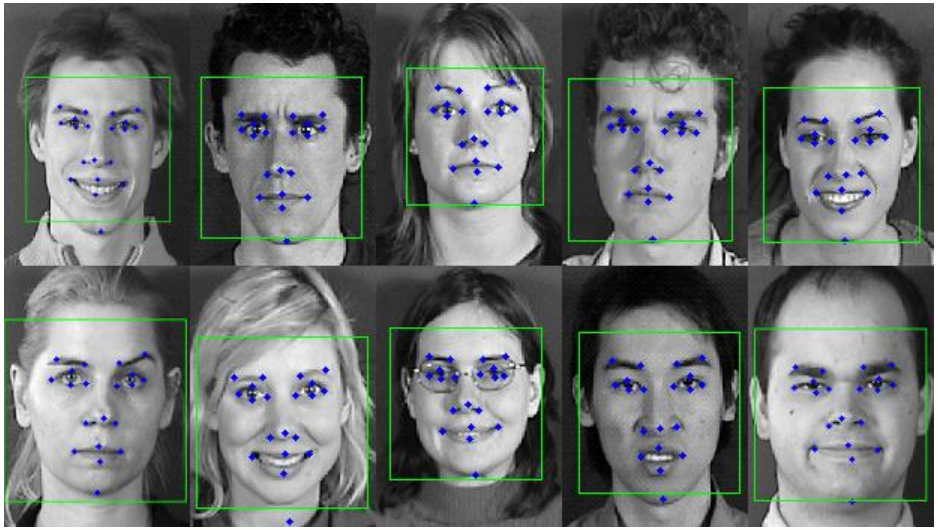
Computer Vision

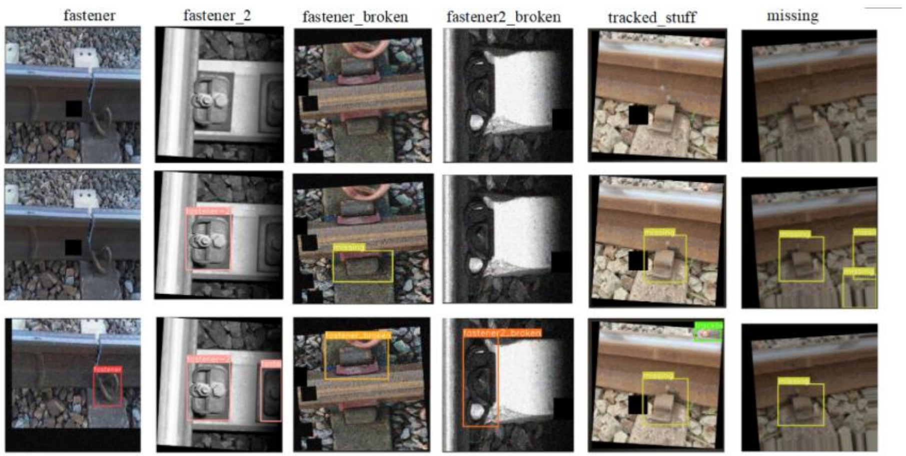
Computer vision is a subfield of artificial intelligence (AI) that equips machines with the ability to process, analyze and interpret visual inputs such as images and videos.

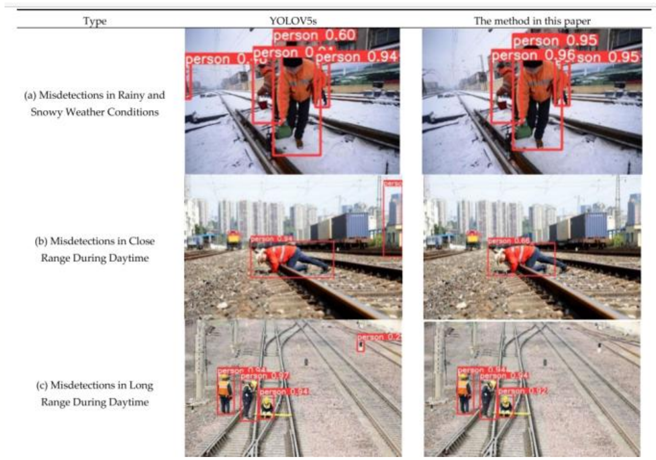
Computer vision algorithms can be trained on a wide range of tasks, some of which include:

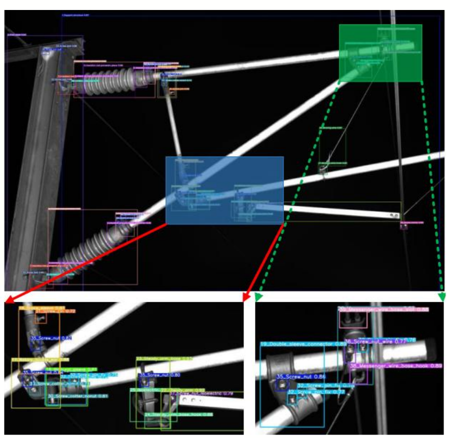
- Image recognition
- Image classification
- Object detection
- Scene understanding
- Facial recognition
- Pose estimation
- Visual inspection

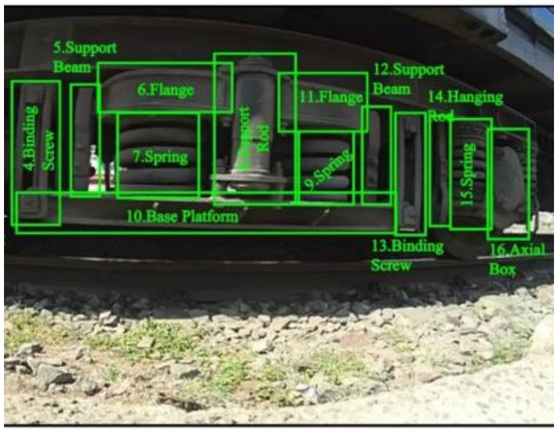


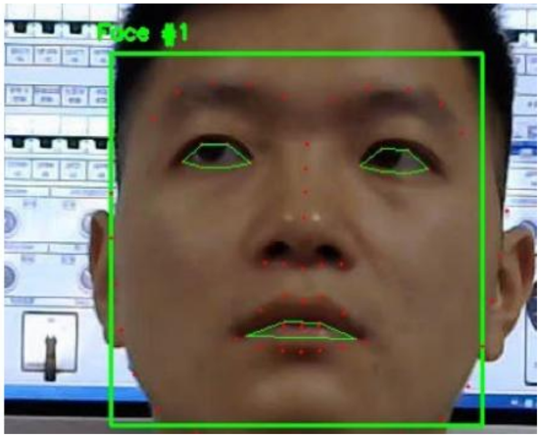
Artificial Intelligence in Railway Operations











DP-YOLO: A Lightweight Real-Time Detection Algorithm for Rail Fastener Defects | MDPI
IEEE Xplore Full-Text PDF:
CCL-YOLO: Catenary Components Location Based on YOLO and Gather-Distribute Mechanism
Train rolling stock video segmentation and classification for bogie part inspection automation: a deep learning approach
IEEE Xplore Full-Text PDF:

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Artificial Intelligence - Conclusions

Overall, these observations suggest that AI, although being at an early development stage in most railway subdomains, is attracting an increasing interest, and therefore it can be easily expected that more focus on AI-based research will characterize the future of railway engineering, planning and management. Thus, many open research topics are envisioned, some of which could contribute to general usage of AI. Future research can be expected towards developing advanced combined AI applications, using AI in decision making and assisting optimization approaches, dealing with uncertainty and tackling newly rising cyber–physical threats.

A literature review of Artificial Intelligence applications in railway systems - ScienceDirect

What come next ?

Technology must support workers

Key Words: Balance – Human Factor

EU Railway Safety Directive (2016/798)

- Recital 10: Member States should promote a culture of mutual trust, confidence and learning in which the staff of railway undertakings and infrastructure managers are encouraged to contribute to the development of safety while confidentiality is ensured.

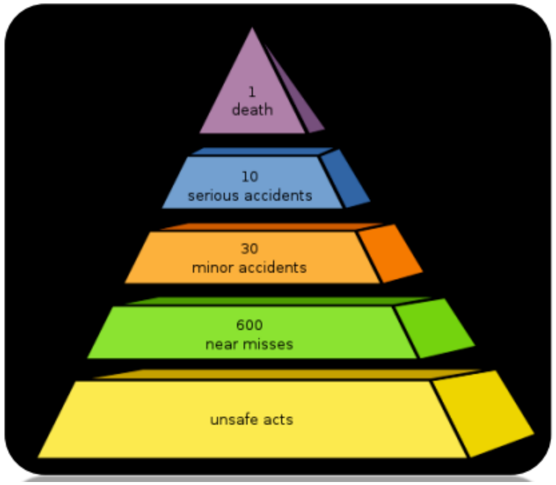
- Article 9(2): Through the safety management system, infrastructure managers and railway undertakings shall promote a culture of mutual trust, confidence and learning, in which staff is encouraged to contribute to the development of safety while ensuring confidentiality.

- Article 29(2): The Agency shall evaluate the development of a safety culture including occurrence reporting. It shall submit to the Commission, by 16 June 2024, a report containing, where appropriate, improvements to be made to the system

Introduction to the European Railway Safety Culture Model (1).pdf

Improving the system – Just Culture

To achieve this goal, it is necessary to abandon the culture of blame, encourage **free and honest reporting**, and equip ourselves to manage it (including the feedback and lessons learned).



Heinrich/Bird Pyramid

Improving the system – Just Culture

'Just Culture' means a culture in which front-line operators or other persons are not punished for actions, omissions or decisions taken by them that are commensurate with their experience and training, but in which gross negligence, wilful violations and destructive acts are not tolerated

Regulation - 376/2014 - EN - EUR-Lex

Improving the system – Just Culture

Voluntary violation, suicide, sabotage: Germanwings pilot Andreas Lubitz decided to commit suicide while flying the plane

Failure to follow procedures: the operator does not follow procedures because they want to finish quickly and go home

Rules not properly executed: continuous training and skills maintenance are necessary

Organization did not adequately select and prepare the operator

Procedure designed without considering actual application (work-as-done): all operators in the same situation make the same mistakes

Distraction during task execution: the Santiago de Compostela train driver did not realize his location because he was distracted by work-related phone calls

Blame Culture VS Just Culture - Conclusions

What went wrong?

rather than

Who caused the problem?

A just culture is the opposite of a blame culture.

A just culture is not the same as a no-blame culture as individuals may still be held accountable for their misconduct or negligence.

A just culture helps create an environment where individuals feel free to report errors and help the organization to learn from mistakes.

Just culture - Wikipedia

Thank you for your attention !

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