The Use of Artificial Intelligence and Machine Learning In Autonomous Trains, Trolleys

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Autonomous Train Technology Market Outlook - 2026

Autonomous Train Technology Market :

- Valued at $5.88 billion in 2018
- Projected to reach $15.57 billion by 2026
- Growing at a CAGR of 12.9% from 2019 to 2026

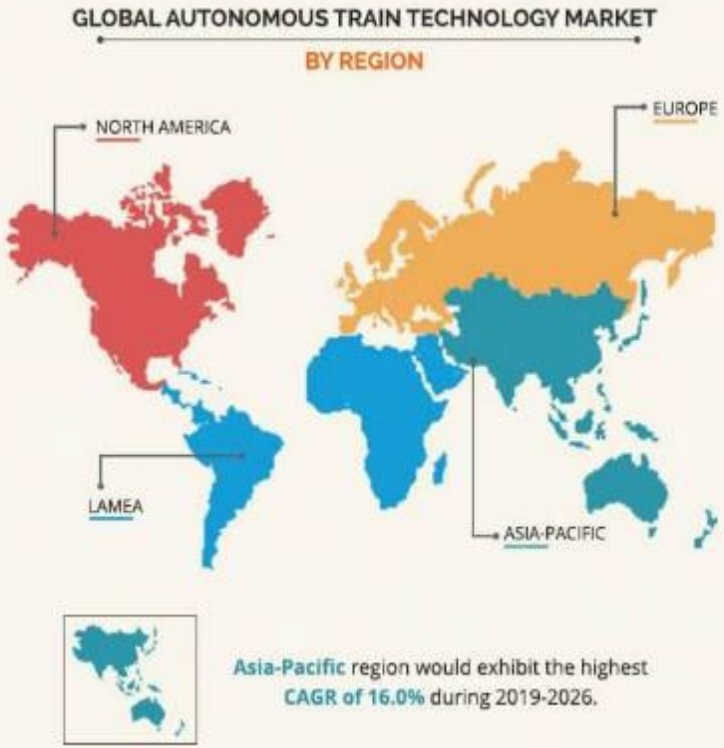
Application Market Segments:

- Passenger Train
- Freight Train

Being widely adopted in these Regions:

- North America
- Europe
- Asia-Pacific
- LAMEA

Autonomous Train Technology Market



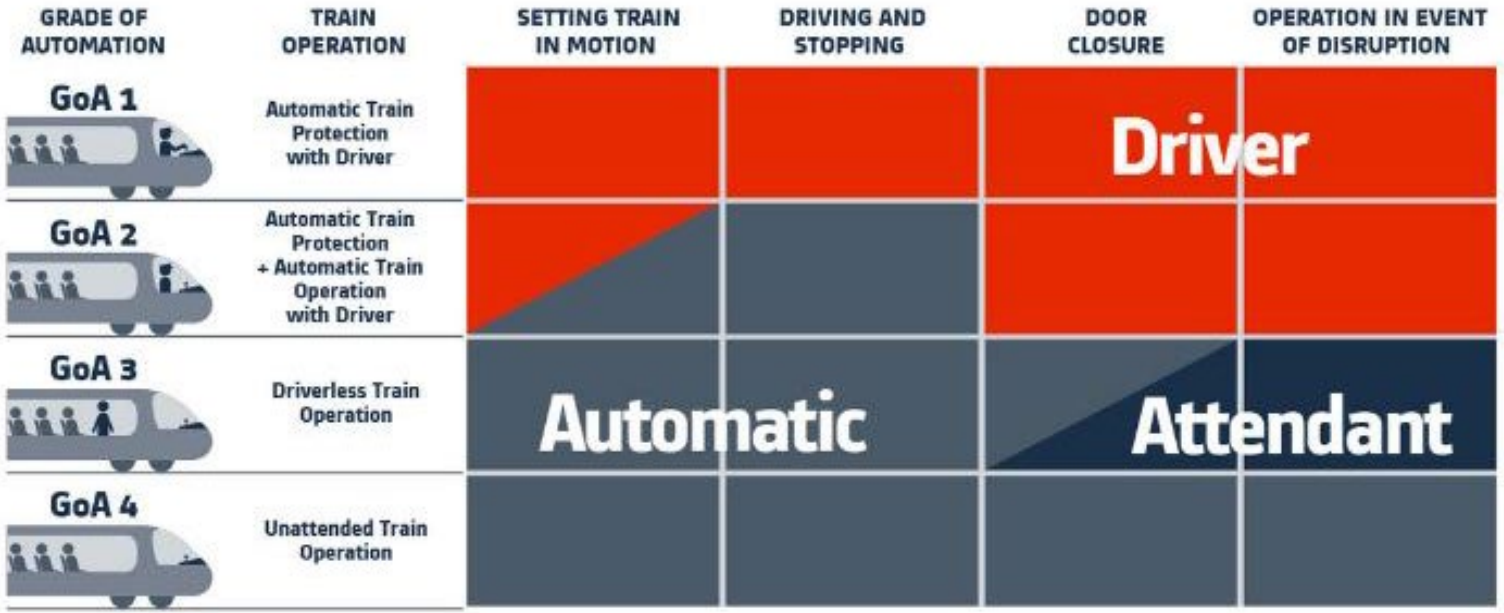
By Region

- North America
  - U.S.
  - Canada
  - Mexico
- Europe
  - UK
  - Germany
  - France
  - Russia
  - Italy
  - Rest of Europe

By Region

- Asia-Pacific
  - China
  - India
  - Japan
  - South Korea
  - Singapore
  - Rest of Asia-Pacific
- LAMEA
  - Latin America
  - Middle East
  - Africa

Grade of Automation



- Source: UITP (International Association of Public Transport)

Making the grade: the different levels of autonomy

GoA 0

- all train movements and control of wayside elements (such as track switches) are managed by manual operational procedures executed by an Operation Staff.
- There is no mandatory functions executed by an automated/autonomous system.

GoA 0 – Line of Sight Operations (LSO)		
Mandatory Functions	Operation Staff	Automated/ Autonomous System
Ensure Safe movement of trains	Yes	no
Drive Train	Yes	no
Supervise guideway	Yes	no
Supervise passenger transfer	Yes	no
Operate a train	Yes	no
Ensure detection & management of emergency situations	Yes	no

Making the grade: the different levels of autonomy

GoA 1

- A GoA 1 level system is considered a conventionally signaled system common to all subway or metro systems around the world.
- The IEC 62290-1 specification has allocated the “Ensure Safe Movement of Trains” mandatory functions to the Automated/Autonomous System.

GoA 1 – Non-Automated Train Operation (NTO)		
Mandatory Functions	**Operation Staff**	**Automated/ Autonomous System**
Ensure Safe movement of trains	no	**Yes**
Drive Train	**Yes**	no
Supervise guideway	**Yes**	no
Supervise passenger transfer	**Yes**	no
Operate a train	**Yes**	no
Ensure detection & management of emergency situations	**Yes**	no

Making the grade: the different levels of autonomy

GoA 2

- The GoA 2 level is where an automation/autonomous system becomes more effective.
- This is one of the most-common levels of automation today.
- The jump from GoA1 to GoA2 is an order of magnitude higher than the jump to any other grade (for example from GoA2 to 3 or GoA3 to 4) due to the complexity and amount of automation required.

GoA 2 – Semi Automated Train Operation (STO)		
Mandatory Functions	**Operation Staff**	**Automated/ Autonomous System**
Ensure Safe movement of trains	no	**Yes**
Drive Train	no	**Yes**
Supervise guideway	**Yes**	no
Supervise passenger transfer	**Yes**	no
Operate a train	**Yes**	no
Ensure detection & management of emergency situations	**Yes**	no

Making the grade: the different levels of autonomy

GoA 3

- In GoA 3 level, the automated/autonomous system controls the train between platforms.
- There's no driver, but there are attendants on the train.
- In this level, starting and stopping are automated and a train attendant operates the doors and drives the train in case of emergencies.

GoA 3 – Driverless Train Operation (DTO)		
Mandatory Functions	**Operation Staff**	**Automated/ Autonomous System**
Ensure Safe movement of trains	no	**Yes**
Drive Train	no	**Yes**
Supervise guideway	no	**Yes**
Supervise passenger transfer	no	**Yes**
Operate a train	**Yes**	no
Ensure detection & management of emergency situations	**Yes**	no

- A train equipped with a GoA 3 automated/autonomous system is aware of its surroundings along the track.
- Trackside devices installed along the track detect obstacles that may obstruct train movement such as tunnel ventilation doors or work crews performing maintenance at track level.
- These devices connect to a wayside unit that sets the movement authority for all trains.

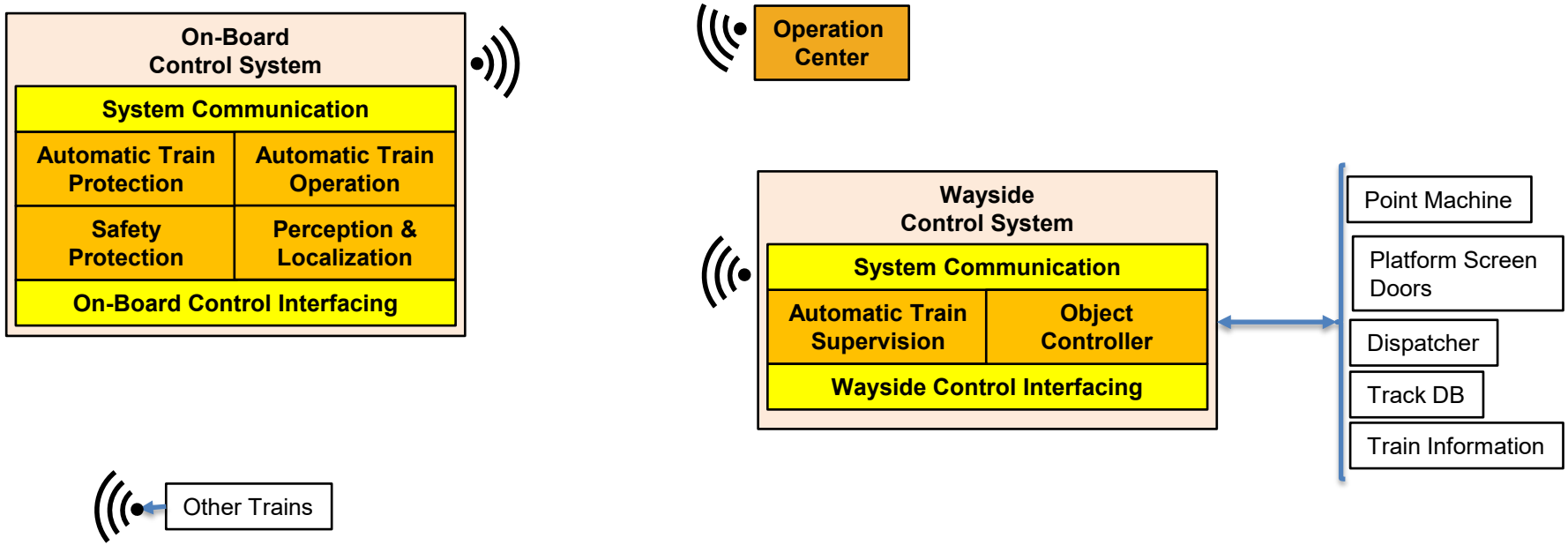
Making the grade: the different levels of autonomy

GoA 4

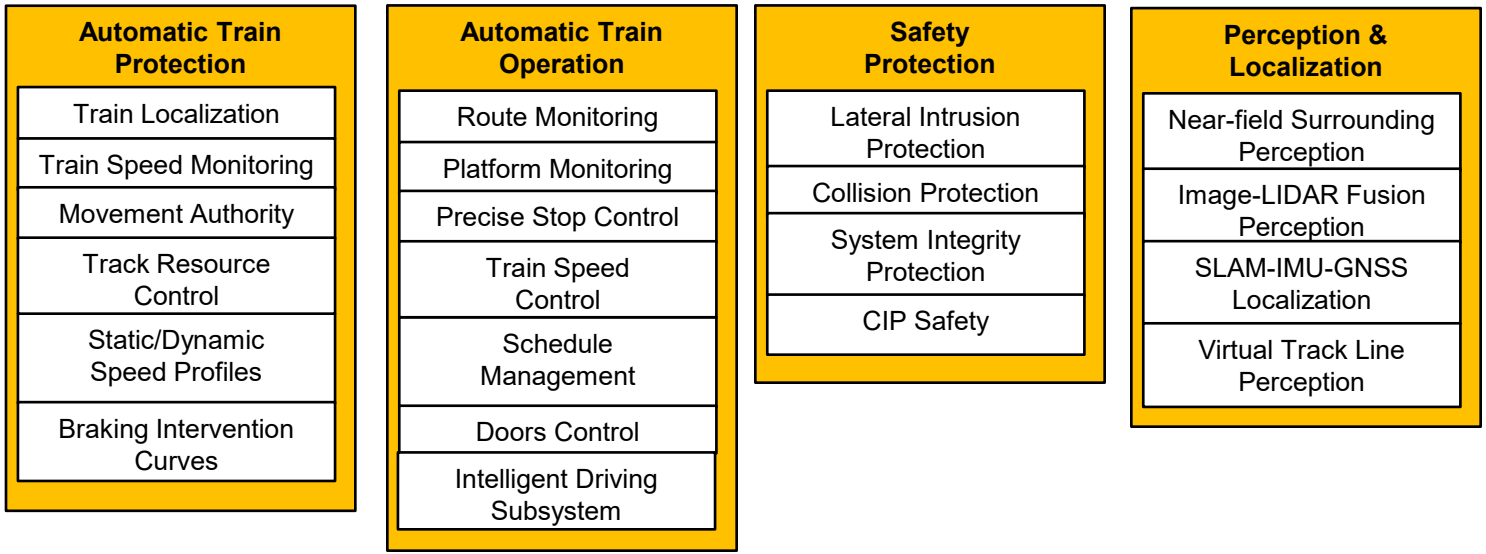
- The GoA 4 level is where starting and stopping, operation of doors and handling of emergencies are fully automated without any on-train staff.
- The train's health will be monitored remotely.
- At this level, the system is in complete control over the train, wayside and the platforms.
- Involvement from the operator has been reduced if not eliminated.
- The operator's role is to only monitor the system and get involved if there is a failure the automated system cannot handle.

GoA 4 – Unattended Train Operation (UTO)		
Mandatory Functions	**Operation Staff**	**Automated/ Autonomous System**
Ensure Safe movement of trains	no	**Yes**
Drive Train	no	**Yes**
Supervise guideway	no	**Yes**
Supervise passenger transfer	no	**Yes**
Operate a train	no	**Yes**
Ensure detection & management of emergency situations	**Yes**	**Yes**

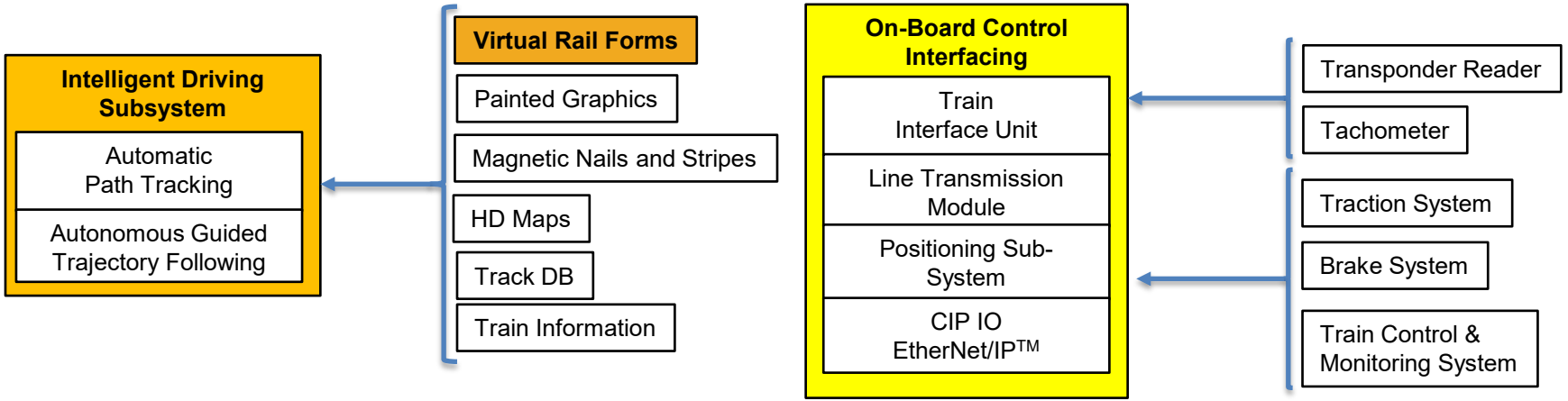
Autonomous Train Control System



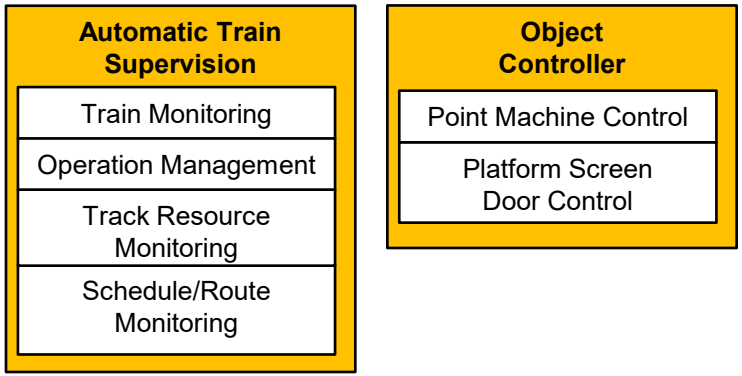
On-Board Control System



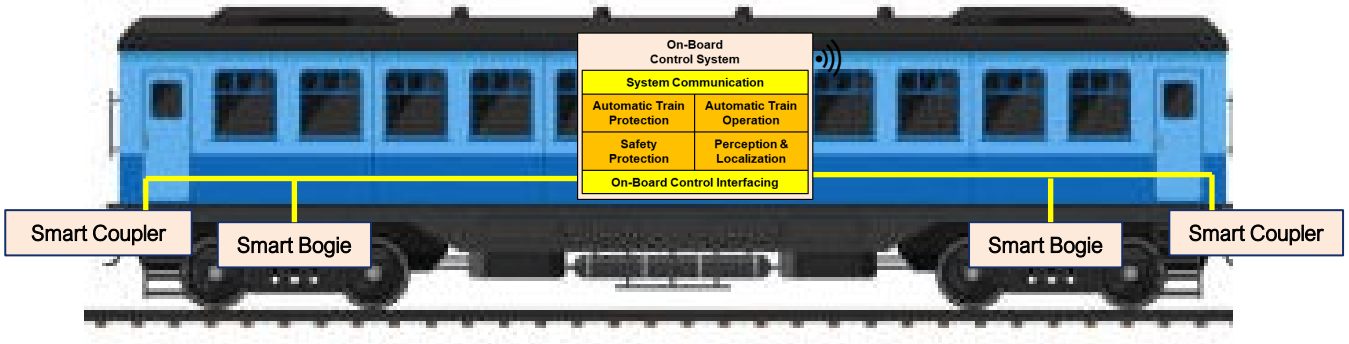
On-Board Control System



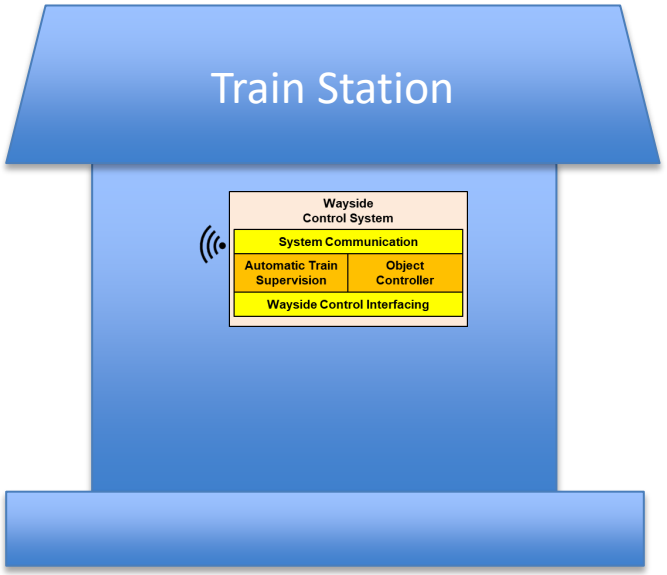
Wayside Control System

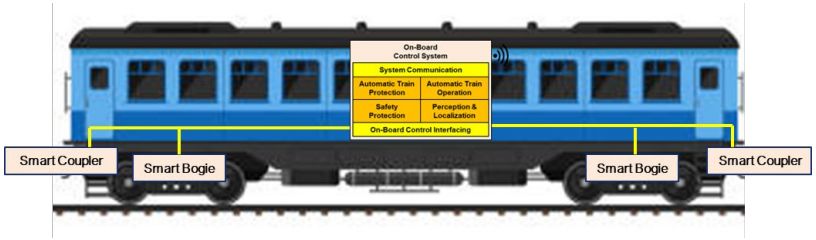


Autonomous Train Car



Autonomous Train System



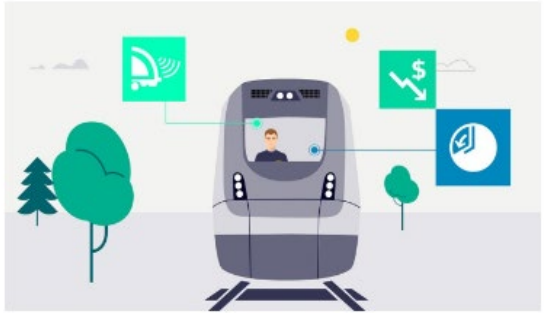


Smart Track Sensors

Smart Track Switches

Autonomous Train Use Cases

Assisted train operation | Driverless depot operation | Driverless vehicle stabling and provision | Driverless train operation on specific sections | Fully automatic operation on entire lines



Assisted Train Operation:

- Drivers are helped to avoid collision with obstacles on the line
- Assist in monotonous or difficult traffic situations to minimize consequences and costs of accidents
- Increased driver and passenger safety.
- Higher availability of trains and tracks

Benefits:

- Avoid or reduce damage from accidents:
  - Lower Repair costs
  - Higher train availability
- Improved punctuality and flexibility
- Smooth acceleration and braking provide improved passage comfort.
- Improved safety.

Autonomous Train Use Cases

Assisted train operation	Driverless depot operation	Driverless vehicle stabling and provision	Driverless train operation on specific sections	Fully automatic operation on entire lines

Driverless Depot Operation:

- Autonomous driving in the depot on semi-protected track areas at low speed.

Benefits:

- Operational even with reduction of personnel
  - Example: Reduced staff due to COVID.
- Reduction of accidents involving people in hazardous zones
- Optimized vehicle transfer
  - Shorter wait times

Autonomous Train Use Cases

Assisted train operation | Driverless depot operation | **Driverless vehicle stabling and provision** | Driverless train operation on specific sections | Fully automatic operation on entire lines

Driverless Vehicle Stabling and Provision:

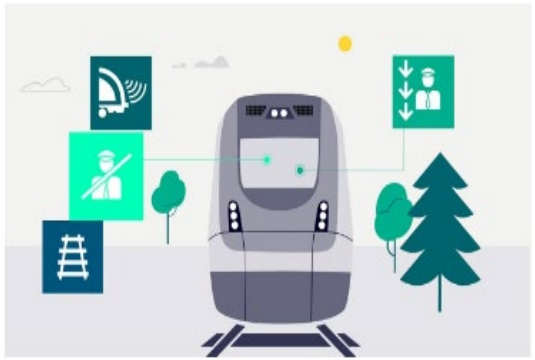
- Automated transfer of trains to the stabling yard at end of operations
- Automated provision of trains at start of operations

Benefits:

- Reduce non-productive, time-consuming vehicle transfers
- Faster provision of additional rail vehicles at time of peak demand
- Trains can operate in parallel instead of wait for worker to hop between trains.

Autonomous Train Use Cases

Assisted train operation | Driverless depot operation | Driverless vehicle stabling and provision | **Driverless train operation on specific sections** | Fully automatic operation on entire lines



Driverless train operation on Specific Sections:

- System takes over complete driving responsibility in suitable areas
  - Fully segregated line sections

Benefits:

- Fewer non-productive, time-consuming vehicle transfers
- Drivers can be deployed elsewhere in passenger rail operations
- Improved safety for all users

Autonomous Train Use Cases

Assisted train operation	Driverless depot operation	Driverless vehicle stabling and provision	Driverless train operation on specific sections	Fully automatic operation on entire lines

Fully Automated Operation on Entire Lines:

- Driverless and unattended train operation on entire lines.

Benefits:

- No need for drivers or conductors
- More space for passengers
  - Elimination of driver's cab
- New operating models possible
  - Shorter Headways
  - Demand-driven train operation
  - Elimination of fixed timetables

Additional Autonomous Train Benefits

Increased capacity

Automation expand passenger capacity by increasing the number of trains a line can handle.

Many networks are already operating at full Capacity and simply cannot handle Additional trains, but automation creates Space by eliminating the variables caused By human behavior.

Greater flexibility

Automating train fleets creates predictability and that predictability enables greater flexibility.

When supported with Automatic Train Operation, operators have more choices. They can automate service on seldom used or remote lines, automatically park a train and keep it idle indefinitely or quickly respond to changes without needing a human driver to always be present

Lower costs

Services like maintenance account for a large part of the costs of operating a fleet.

Autonomous train technology ensures that trains are operated as efficiently as possible; reducing wear and tear while minimizing the incremental inefficiencies that are natural to human influence.

Additional Autonomous Train Benefits

Enhanced passenger experience

Automatic train operation is not just for engineers and operators, it greatly improves the travel experience for passengers.

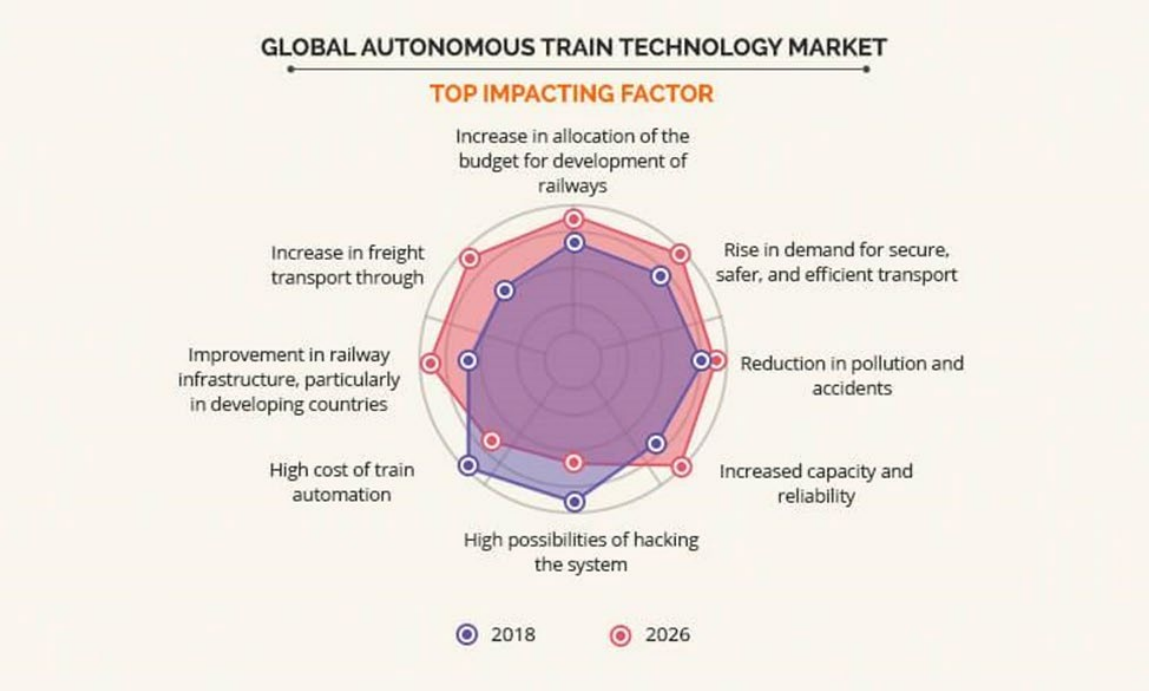
Supported by technology, drivers can focus on passenger attendance and strategic decision, meaning passengers will notice smoother acceleration and stopping, more comfortable curves and seamless transport options that have fewer delays.

More sustainable

Eco-driving rail automation systems reduce energy consumption and are key to making the rail industry more sustainable.

Automatic train operation orchestrates rail fleets, empowering operators to run their trains more efficiently. Performing as a single connected system, this improved synchronization translates into maximum performance that helps reduce emissions and limit energy use.

Autonomous Technology Market Segments



Additional Autonomous Train Benefits

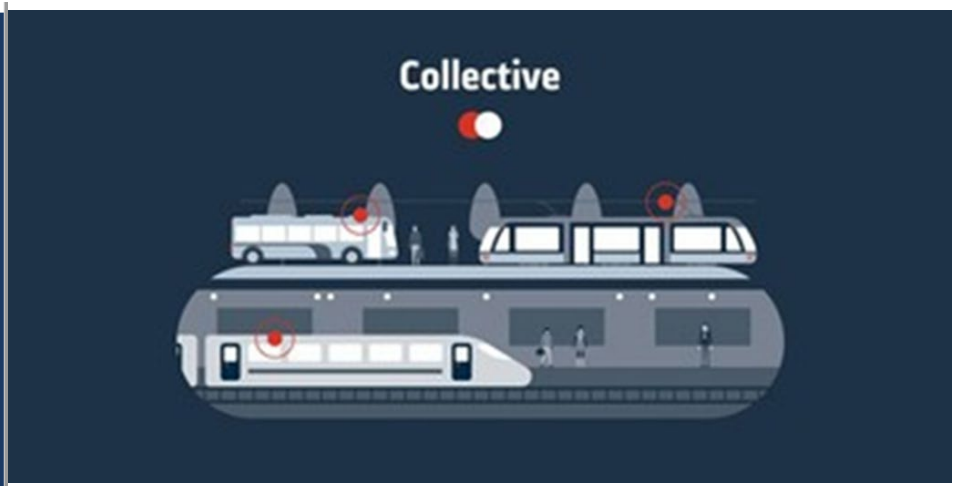
AI applications in public transport

Results from a survey conducted by the UITP (International Association of Public Transport) indicate the direction of travel when it comes to AI usage. Respondents were drawn from a range of public transport-related organizations, including authorities, operators, industry providers and research institutes.

Percentage of organizations surveyed using, testing and/or offering AI

- Real-time operations management **25%**
- Customer analytics **25%**
- Intelligent ticketing system **21%**
- Predictive maintenance **17%**
- Scheduling and timetabling **17%**
- Multimodal journey planner **17%**
- Disruption management **15%**

Source: UITP (International Association of Public Transport)



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