# AUTOMATED AND AUTONOMOUS PUBLIC TRANSPORT

## POSSIBILITIES, CHALLENGES AND TECHNOLOGIES

SYSTRA


# Automated and Autonomous Public Transport

**POSSIBILITIES, CHALLENGES AND TECHNOLOGIES**

## Content

# Public Transport and the challenges of tomorrow's mobility: the opportunities offered by autonomous technologies

**Pierre Verzat**
Chairman of the Management Board, SYSTRA

“The challenges of urbanisation and the increase in travel needs require a profound change in mobility solutions. This transformation has already started and will accelerate the introduction of modern technologies in our traditional public transport systems. With 60 years of proven experience, SYSTRA is ready to face these challenges.”

In dense urban environments, where there are increasing needs brought about by population and economic growth, public transport solutions show unrivalled ability, performance levels, and security. In a world where environmental pressure is increasing, the energy efficiency of public transport is a major asset. Finally, public transport promotes inclusive mobility and a lower cost for the traveller.

At SYSTRA, we believe that tomorrow's mobility will be multimodal and integrated, based on structured and high-capacity public transport networks: Rail, Metro, Tramway, Bus Rapid Transit; associated with flexible, individualised and connected secondary modes. High and low-volume transport modes will coexist in a fluid and intelligent way, enabling optimised door-to-door travel possibilities. In other words, this is a sustainable mobility offer that best exploits the possibilities offered by technical and social innovations.

In recent years, several phenomena have transformed mobility and more specifically, the uses for the automobile. Making automobiles autonomous is made possible by the continued emergence of new technologies such as machine learning, image analysis, and LIDAR. Driving systems are increasingly intelligent. Furthermore, the notion of a 'sharing economy' has generated new uses for the automobile such as carpooling and car-sharing. These uses have grown thanks to their accessibility via web and mobile platforms. Finally, electric motors have improved, responding to stringent air quality and energy efficiency requirements, in turn driving significant changes to the energy supply infrastructure. At the intersection of these phenomena we see a new mobility solution emerging which is centred around autonomous vehicles and characterised as connected, electric and shared. The enthusiasm and economic opportunities of autonomous vehicles go far beyond the borders of the automobile industry. Major players in public transport are positioning themselves as drivers of change in the face of mobility solutions where the dichotomy between mass transport and the private automobile is blurred.

In the midst of this astounding evolution in mobility, we believe that the technologies that allow us to conceive complete autonomy of automobiles also create opportunities for public transport. They pave the way for more flexible, safer and more environmentally friendly driving, but also for an optimised use of networks and fleets, making it possible to increase capacity and improve the performance of transport systems. Nevertheless, public transport has its own constraints, including security and obsolescence management, which require a specific analysis of the possibilities, issues and technologies that are developing. >>

We have carried out research – truly technical – on the future public transport autonomy. As a result of these considerations, our white paper on the autonomisation of public transport aims to explore four main questions:

- How can technologies that allow full or partial autonomy of road vehicles lead to significant advances in the field of traditional public transport, particularly for guided railway transport networks?
- What benefits are expected and what interest is there for these modes of transport? What value can be created?
- >What are the common challenges and what differences exist between making railways and automobiles autonomous? What are the obstacles, the opportunities, possible joint undertakings?
- What vision can we form of tomorrow's public transport?

**Pierre Gosset**
Chief Technical Officer, SYSTRA

> **“In relation to everything that has been written on the subject, our thinking is original in that it assesses the relevance of using the technologies being developed on autonomous vehicles for traditional public transport modes, especially railways, metros and tramways.”**

Railway Station, Sweden. SYSTRA was responsible for ERTMS signalling modernisations in the country.

# Autonomy vs Automation

An automatic transport system is not to be confused with an autonomous system. An automated metro only has to make decisions in relation to what is in front of it. The segregated nature of the system is the first pillar of its safety. In contrast, the tram circulates in an open environment which is not segregated from other forms of traffic or pedestrians. Tram drivers must make decisions about all their surroundings. The nature of its environment poses numerous problems for automation.

The differences between 'autonomy' and 'automation' are now a source of much debate. For the sake of clarification, we have adopted the following definitions:

>> **AUTOMATIC SYSTEM:**
a system that performs task sequences based on pre-defined rules; the information needed to understand its environment is given to it to make its decisions. It can be with or without a driver.

>> **AUTONOMOUS SYSTEM:**
a system capable of making its own decisions to respond to all cases without human-defined instructions. It must therefore manage the functions of comprehension, environment analysis, and decision making – responsibilities which so far are largely reserved for human beings.

# Autonomy implies permanent interaction of the vehicle with its environment

### The Autonomous Tram example

To be autonomous, the tram must be able to capture, perceive, analyse, plan, make decisions and act without human intervention. Moreover, all of this must be carried out in real time.


Safe braking distance normal service

Safe braking distance emergency braking

Wide field of view to detect moving obstacles

# What users need from Transport Systems

SYSTRA's engagement is to analyse the expectations of transport system users by analysing the following parameters: safety and quality of service, cost, environmental impact.

The following table establishes the link between each of these parameters and the potential expectations of the different user categories: passenger, operator, driver, community or sponsor, and thirdparties.

| USER GROUP | MAIN NEEDS | Safety | Service offer | | Quality of Service | | | Environment | Costs |
|---|---|---|---|---|---|---|---|---|---|
| | | | Frequency-capacity | Flexibility | Travel time | Regularity | User Experience | | |
| **User** | Reliable Service (predictability and travel time management), system security, appropriate pricing, minimum expected performance (travel time), comfort, user experience... | x | x | x | x | x | x | x | x |
| **Operator** | A 'Simple' system to operate and maintain, control and optimise operating costs (optimisation of the economic and operational performance of the networks; optimisation of the performance of the assets; reduction of life cycle costs), flexibility in adapting capacity faced with likely change in demand over time, compliance with service level commitments for which the operator is paid by the community, management of degrade situations, safety of travellers and drivers, customer satisfaction, reducing the fraud rate and increasing revenue. | x | x | x | | x | x | | x |
| **Tram/train/ Metro drivers** | Driving ergonomics, guaranteed visibility of the environment if restricted (responsible for the operation of the vehicle) or guaranteed by the systems. | x | | | | x | | | |
| **Community** | Optimised investment and operating costs, guaranteed minimum level of service, obtaining operating safety authorisations. | x | x | x | x | x | x | x | x |
| **Third party interface with the transport system (surface): Pedestrians, cycles, cars...** | Comprehensible layouts which make it easy to understand the use and operation of the interface spaces (crossroads, pedestrian passage, level crossing...) + equipment to guarantee these safety interactions. | x | | | | | | | |

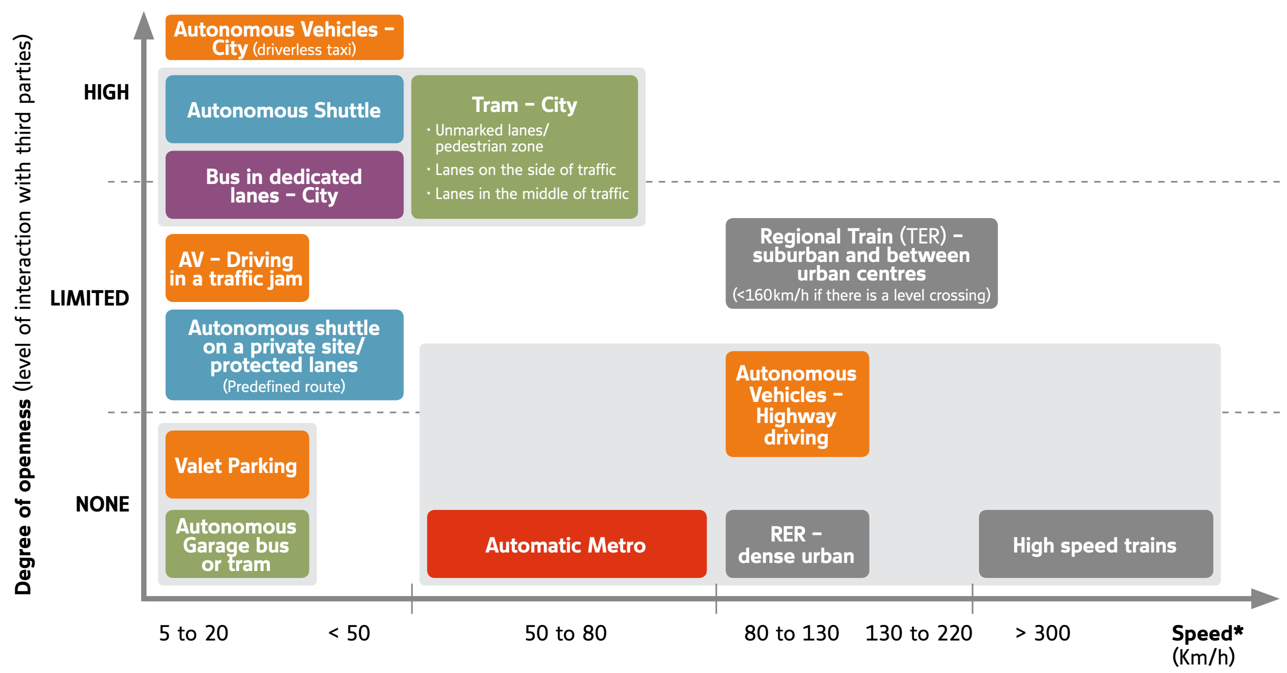
# Autonomous Public Transport Systems: what are the challenges?

In addition to the debates that can arise (hiring new and retraining existing staff, social acceptability, responsibilities and ethical rules), making a transport system autonomous presents important challenges.

Whether it be an autonomous car, or autonomous public transport system, these vehicles have common needs: collision avoidance, high level communication integrity (between vehicles or with the infrastructure), self-monitoring of the vehicle's condition, management of degraded modes, ability to manage all situations, a minimum onboard intelligence to cover any loss of communication… The technological solutions to be deployed will each face the need for regulatory approval, certification, standardisation, regulatory developments, and will have to be justly insurable. The current legal void and lack of safety references on these types of solutions leads to many questions.

The specifics of these modes of transport bring about particular challenges which have different needs and responses. These challenges must be systematically examined against the intended uses (open or closed environment; public or private transport whether or not it is shared; circulation on highways or in an urban environment, etc.). The challenges can be of a technical, security, regulatory, social or societal nature. Nevertheless, some challenges related to the autonomy of a transport system may also be common. Even if the complexity is not identical, there is a real opportunity for the creation of intermodal technological bridges (Bus, tram, metro, train) and with the autonomous vehicle (car or shuttle).

The following diagram proposes a positioning of the different transport modes according to their level of interaction with the environment and their 'desirable' circulation speed.




* Typical traffic speed, taking into account the characteristics of the infrastructure, the permissible speed limits, and the traffic conditions.

## Challenges shared with Autonomous Cars

### NO REFERENCE/SECURITY STANDARD

Whether it be for autonomous cars, shuttles or guided systems, demonstrating safety is the primary challenge. Before allowing the circulation of such vehicles on roads or granting operating authorisation in real conditions, essential steps of validation and establishing security of the vehicle will be necessary.
Questions arise such as: Will the system that replaces the driver have to be SIL4 (Safety Integrity level), that is to say the highest level of safety? Is the GAME approach transferrable to this type of system? In the case of Deep Learning, security validation will be more complex (algorithm opacity, error rates, incomplete data, instability). There will be no reference (in the sense that 'a system is already in operation') for the 1st tram/train line which will launch this technological choice; yet the safety demonstration must be complete. In the event that the system has not been approved or certified at a safety integrity level by a manufacturer, the project itself must incorporate the implementation of the generic safety case and other cases (in France, this is done with the Independent Safety Assessment).

### EVOLUTION OF THE REGULATION

Whether it is autonomous cars or other autonomous transport modes, developments in the current regulations and legislation will be foreseen. On the one hand, this will allow for the necessary testing to develop the reliability of these technologies, and on the other, to provide authorisation for real operating service. For autonomous cars, it is the highway code (specific to each country) that applies. In France for example, an autonomous tram will be concerned both by the STPG Regulation (safety of guided public transport system) and by the road regulations.

### LIABILITY IN CASE OF ACCIDENTS

Like with autonomous cars, the question of liability in the event of an accident must be determined (the constructor? the operator? the mobility authority?). In addition, tolerance for the risk of accidents involving public transport could be lower compared to an accident involving private

▲ Autonomous Shuttle, Paris, France

automobiles. Moreover, this level of safety involves both the passengers of public transport and other roadway users. What will be the level of risk acceptance? Who will qualify it?

### THE FIGHT AGAINST CYBERCRIME

Even if the technologies are not yet defined for a tram or an autonomous train, these modes will most likely face the problem of cybercrime. As soon as there is communication between the vehicle and its environment, the vehicle must be ready to make a decision when it sees something, or by some remote control if it is operated in this manner. In a more global way, new digital threats generated by increased connectivity (intrusion into systems, data theft, cybercrime, etc.) will have an impact on operational safety.

### PERIOD OF COHABITATION BETWEEN AUTONOMOUS VEHICLES AND VEHICLES DRIVEN BY HUMANS

Seen as a period of transition, many questions arise in terms of 'driving practices' and shared responsibilities. Machine learning will have to develop strategies which adapt the driving in response to any and all situations. A period of 10 to 20 years is foreseen for this transition. This same issue is directly transferrable to railways, for which network characteristics, a multiplicity of operators and a heterogeneity of rolling stock begin to complicate the technical development of autonomous solutions. In the end, it should be stressed that the deployment of autonomous vehicles on our roads, even if progressive, can only be beneficial for the tram and for the train, considering that the accident rate of these modes is mainly linked to the wrong behaviour by third parties, in particular those which are motorised.

### THE COST OF TECHNOLOGY AND ITS RETURN ON INVESTMENT

With equivalent capacity (ensured by the system as one way to 'sell' the idea), the cost criteria for a transport system is a compelling argument for communities. Cost must integrate investment, operation, maintenance and upgrades over a complete life cycle. As a result, the addition of new technologies must be able to justify the investment. A value analysis must therefore be carried out on a case by case basis, and according to the context (existing line or retrofit, accident rate, labour cost, etc.) and the operator needs.
Moreover, the volume of investments needed to develop autonomous technologies should be compared with the volume of the market in question.

### SAFETY VERSUS SERVICE AVAILABILITY

This problem also exists for autonomous cars and shuttles. However, for public transport, the objective of performance is paramount to guarantee the attractiveness and of the system and its ability to stand the test of time, especially ifone speaks of a mode with high level of service.

### CONSIDERING DEGRADED MODES

During operation, trams and trains must manage particular situations referred to as degraded modes. A degraded mode may be caused by the failure of any element which otherwise contributes to the service provision (the element may be internal or external to the tramway/train system). Such failures may require on-site human intervention (dispatched via the centralised traffic control centre) or even permanent removal of the element which is the source of the degraded mode (avoidance strategy). These situations, currently managed by the driver, must be listed and identified.

## Unique challenges of Guided Transport Systems

### ANTICIPATING POTENTIAL DANGERS IN ORDER TO AVOID EMERGENCY BRAKING

Any scenario that involves emergency braking directly affects the safety of passengers who may be victims of a fall (they are not belted as they are in a car), as well as the availability of the transport system (commercial speed, damage to rolling stock). Emergency manoeuvres must therefore remain exceptional.
The capacity to anticipate potential dangers, equivalent at least to that of a driver, will be required from onboard intelligence systems. This means to avoid emergency braking which could cause other, severe accidents. The kinematic characteristics of a tramway, braking and trajectory for example, are unique and must be considered for evaluation of the braking distance. Consequently, the question arises about the field of view that the onboard system must consider and safeguard: how far? What perimeter (length, width)?

### PASSENGER EXCHANGE IN THE STATION

In addition to closing the doors and stopping time at the station, departure from the station in the presence of numerous pedestrians must also be managed.
Also, it is important to think about the evolution of the layout of stations to limit deviant behaviour in the absence of a driver and discourage passengers from crossing in front of the vehicle. This could also result in a warning system for pedestrians (audible and or visual) to catch their attention.

### NEED TO MANAGE REGULATION ACROSS THE ENTIRE LINE

For tram lines circulating in urban areas, the general challenges for the operator are to allocate the trams along the line (operation based on headway rather than timetable), to balance the passenger density in the tram, and to guarantee limited station stopping time. These points translate into a need for regulation, where the role is to best ensure the distribution of trains along the line based on a global vision. Instructions are thus passed on to the drivers so that they adapt their movements with respect to other trains on the line, trains which could be in advance or delayed. When speaking of automation, this level of line management must be integral to the 'automation' system as it will have to manage the best running speed while dealing with obstacle detection in front of the train in real time. Trade-offs of traction power versus energy consumption and challenges of risk management therefore arise.

# What does Autonomy mean for Rail Transport?

- TRAM
- METRO
- RAILWAY

▲ Bordeaux Tram, France

TRAM

# Towards reinforcement of embedded onboard driving systems and making the Tram autonomous within depots

## Definitions, characteristics of tramway transport mode

- Capacity (PPHPD): Up to 10,000
- Cost (€M/km): 15 to 30
- Integrated into an open urban environment, strong interaction with all road users and public space (pedestrians, cycles, cars…)
- Different types of insertion vis-a-vis road traffic: fully segregated lanes, partially segregated protected lanes, shared lanes
- Stations opened and integrated in an urban space, with possibility to easily cross the tracks from one platform to another
- Urban:
  - commercial speed of 18-20 km/h, with stations every 400 m, dedicated site, priority at traffic lights
  - not subject to highway code, with high speeds up to 60-70 km/h when infrastructure and environment permit
- Principle of driving by sight: The driver is responsible for the spacing between preceding trams and the control of his vehicle at any time
- The driver is the safety authority; In case of danger, braking is the only solution
- Driving style to be adopted: anticipatory (general monitoring of the surroundings), relational (exchanges with pedestrians), defensive (but not to take on delay)
- Generally consistent rolling stock on the same line
- Electric Traction
- No need for interoperability, unlike for trains

Tours Tram, France

## Specific interests and advantages of autonomous trams

- Safety improvement? Depends on the accident rate and the level of professionalism of drivers. In France, there is a low accident rate: ~ 1 victim (injured or killed) per million journeys – mainly related to collisions with third parties not complying with road signs (60% of events, but 80% of serious victims)
- Frequency and capacity improvements? The interval of the tram is limited by a crossing intersection (the duration of the green light for other roadway users)
- Improvement in journey time? The challenge is to avoid reducing commercial speed. A very proven technology is needed to avoid unexpected stops. Stations should be designed in a way to dictate passenger flows and manage safe exchanges (closing doors, crossing passengers in front of the vehicle)
- Improvement in regularity? Risk management specific to the open road will remain a reality. According to the context: less accidents mean fewer delays
- Improvement in flexibility? If there is no driver: supply can evolve in real-time according to changes in demand or specific events. Scope is not limited and service level can increase with only a marginal cost
- Improving the user experience? For (panoramic cab) and against (potential insecurity if the tram is without onboard personnel)
- Energy savings? A possible gain of 5 to 15% per user with respect to private transport. There is a compromise to be achieved between travel time and energy consumption (eco-driving) which will be more difficult than for the metro because of the risks and unpredictability of the open road. There are limited gains from braking energy recovery (hazard factor)
- A strong stake in terms of operating savings if the autonomous tram can actually operate without a driver (drivers account for up to 50% of operating costs)

## Challenges of an autonomous tram

- Additional complexity in security validation if Deep Learning is used (opacity of the algorithms, error rate, incompleteness of data, instability)
- Limited market size vs. R&D costs for the adaptation of autonomous vehicle technology
- Safety vs. availability of the service/overall performance of the system: an imperative for a tram which cannot leave its guideway and change itinerary to compensate for the loss of speed or regularity as an autonomous shuttle can do
- Stopping distance far superior than road vehicles (wheel rail contact and no belted passengers):
  - 50 km/h, stopping distance: 100 m
  - 3 times more than for a car
- departure of the train in the station with the presence of many pedestrians in front of the train

## Identified Initiatives

- **Coming from the Metro world:**
  Al Safuh Tramway in Dubai, the first tram equipped with a system derived from CBCT technologies, with human driving permanently controlled by an ATP. A reliable and safe system, but has not improved commercial speed
- **Coming from the automotive world:**
  - Simple driving aid systems which currently have significant and blocking limitations for autonomy
  - Autonomous garage experimentation is in progress with Alstom-RATP

▲ Dubai Tram, UAE

## Our Vision

### Two preferred areas of development in the short-medium term:

- Total autonomy within the depot (from simple automatic storage to a perimeter which encompasses other functions: sandblasting, washer, preparation and taking vehicles out of service); Autonomy in terminal areas in addition to an autonomous depot
- Driving assistance given to the tram driver for a more economical and safer trip. Just as with the autonomous car, gradual rise in driving aid technologies which address the concerns of the operators (avoidance of collisions, overspeed protection, driving with low visibility, problem of training or turnover of operating staff...)

### What we also believe:

- More connectivity between the train and its infrastructure, for increased perception
- Materialisation of the tram safety bubble (danger zone in which the tram is no longer able to stop)

**A NEW FRAMEWORK TO QUALIFY AUTOMATION LEVELS?**

To start considering a possible framework, we have defined 6 levels of automation for the tram

**LoA0:** No automation

**LoA0 +:** The system controls the speed (with a gentle and progressive sanction mode)

**LoA1:** The system helps the driver to drive better (speed setpoint, passive driving aids)

**LoA2:** The driver assists the system to be driven (control and speed control by the system, acti

initiated either by the driver or by the system...)

**LoA3:** The driver becomes an attendant and intervenes when necessary

**LoA4:** The tram drives itself, without the presence of any onboard agent

METRO

# Automatic metro is the reference solution for all new lines

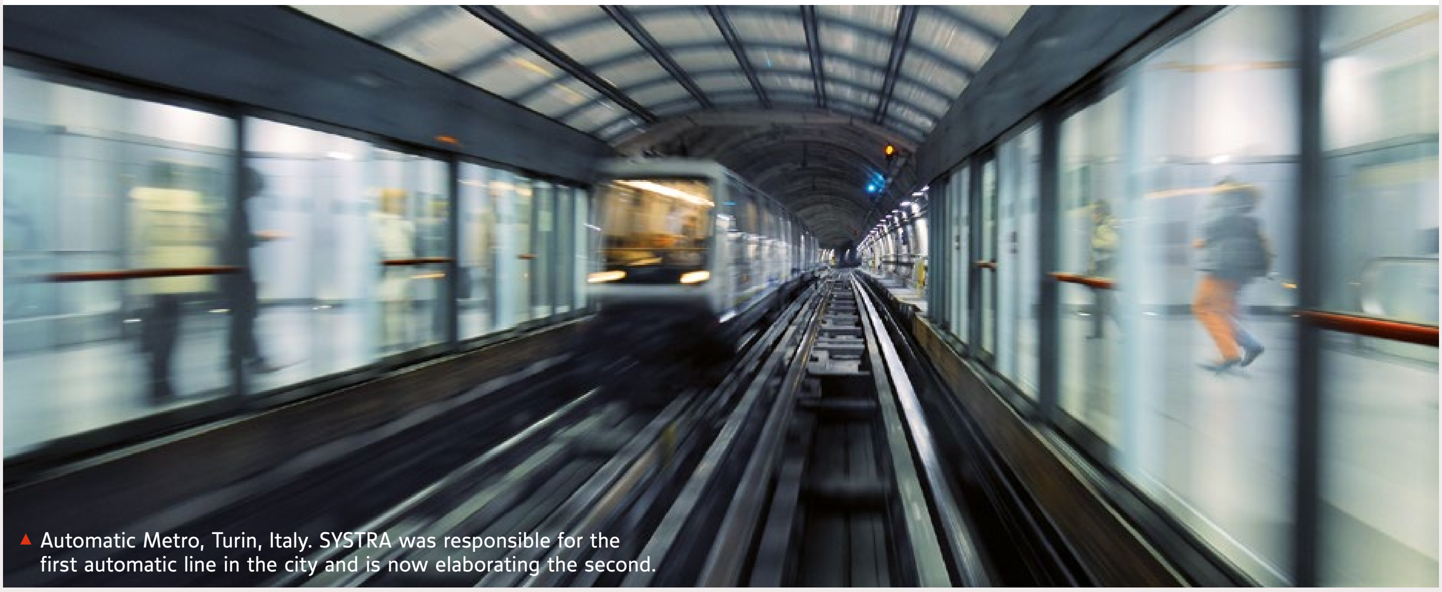
## Definitions and characteristics of the metro transport mode

- Various terminologies: Heavy, light, monorail derivatives
- Capacity (PPHPD): Up to 70,000
- Average commercial speed: 30 to 60 km/h
- cost: 30 to 130€M/km
- Dedicated infrastructure, usually underground or viaduct, sometimes at grade level
- Fully segregated infrastructure with no interaction with the external environment (road traffic, pedestrians, cycles...)
- Crossing the tracks is prohibited
- With or without driver
- With or without operating staff on board
- With or without platform screen doors
- Manual or automatic driving. For manual, the driver must respect the lateral signalling provided to protectthe blocks (fixed) and the spacing between the subsequent trains
- Automation: CBTC technology, enabling moving blocks with variable length
- Electric Traction
- General case: homogeneous service, homogeneous rolling stock, 1 operator

**Existing framework (EN 62290) defining 5 levels of automation**

| Automation levels | Non-Automated<br>Conductor + ATP (Automatic Train Protection) | Semi automatic<br>ATO (Automatic Train Operation) + human supervision and actions | Automatic<br>Full automation, no human action required on board | |
|---|---|---|---|---|
| Driver onboard | GoA1 | GoA2 | | Conventional lines |
| Train staff but no driver | | GoA3 | GoA4 with agent on board | Automated lines |
| No staff on board | | | UTO or GoA4 | |

- No need for interoperability unlike the train
- A ‘blind’ system, unable to interpret its environment (but also no need)
- At the highest levels of automation (GOA3 and 4), the ‘track supervision’ (Preventing collision of the train with possible obstacles/people on the track) is no longer the responsibility of the driver. The detection of obstacles located on the track is not managed from the vehicle but by external equipment and through the application of rules for the safety of the train



▲ Automatic Metro, Turin, Italy. SYSTRA was responsible for the first automatic line in the city and is now elaborating the second.

## Interest and improvements of automatic Metro

Automatic metro, a mature technology in service for over 50 years, which has enabled:

- Increasing the overall system capacity via:
  - decrease in spacing between the trains (min. interval with current Technologies: 85s)
  - Removal of driving cabin (+ 6% capacity/car)
- High level of security
- High level regularity and reliability
  - 33% decrease in delays of 5 mn between GoA1 and GoA4
  - GoA4 availability: 99.99%
- Optimisation of operating speed and rolling stock
- Reducing energy consumption by 15% thanks to ATO (best speed curve) and ATS (synchronisation of accelerating and decelerating trains)
- Gain in operational flexibility with personnel management simplification (extend service hours with marginal cost; quick adaptation of service level in case of events...)
- Downsizing of personnel and operating costs, according to the strategies deployed by the operators:
  - Survey carried out on 23 UTO lines: reduction of 30 to 70% of staff; Reduction in salary costs according to the salary level of staff working on the UTO line
  - RATP, Paris Metro: Operating costs reduction of 30% between UTO and classic line
  - 2017 Wavestone Report: operational costs reduction of 40% between automatic and classic Metro including energy/personnel/ maintenance stations
- Productivity Gains
- UTO: higher investment cost but profitable over ten years
- Opportunity to train staff for new functions
- Decrease staff absenteeism, attributed to a greater diversity of tasks compared to driving

## Identified Initiatives

- **Automatic metro (CBTC technology):** In 2013, ~ 50 lines in the world (700 km), 1,800 km are expected in 2025
- **'Autonomous' metro:** Consideration is underway by industrial suppliers

## Our Vision

Three axes of development to explore in the medium term:

- **Train-centric system**
  - Removal of trackside equipment
  - Transfer of responsibility to onboard equipment
- **A train that sees what's going on in front of and around it**
  - Adding autonomous vehicle features to a train (sensors and information processing chains), a possible solution to avoid platform screen doors? (measured in relation to improvement of regularity which is brought about by the fact that they physically prevent intrusions along the track)
- **Fully 'Robotise' the operational control centre, providing a 100% autonomous system, particularly for degraded modes management**

## Challenges of automating/ autonomising the Metro

- Automation: Challenges mastered, mature technology and ROI of 10 to 15% for a UTO line
- Autonomy: Lower costs (capex and OPEX) related to CBTC automation with less trackside equipment, while guaranteeing the same level of security/reliability/ availability/performance. Yet it is a solution to certify/approve

RAILWAYS

# Towards a more autonomous train on high-capacity networks

## Definitions and characteristics of suburban and High Speed train transport modes

- Capacity (PPHPD):
  **Train:** Up to 25,000
  **Regional Line:** Up to 70,000 (90 sec. interval with up to 1,700 passengers for 2 carriage trains)
  **High Speed:** 20,000 (16 trains/h with base 1,200 passengers per train)
- Speed (km/h):
  **Train:** 80 to 220
  **High Speed:** France: 320, China: up to 350
- French regulation:
  Speed < 160 km/h if crossings
- Cost (€M/km):
  high speed from 10 to €25M
- Many variables:
  - Technological
  - Service (intra-urban, regional, national, cross-border)
  - Environments travelled across
- Interoperable system:
  - **Suburban:** Several trains and/or operators on the same network
  - **High speed:** ERTMS and/or several signalling systems
- High speed rolling stock that can circulate outside ofhigh speed lines but without reaching high speed
- Mixed traffic with freight services on high speed lines (Nîmes-Montpellier Bypass)
- Integral system segregation (outside of stations) for high speed and urban train

## Particular interest and improvements of autonomous trains

### Suburban Trains

- Safety: the general gain is not very significant. However, the problem of crossings remains, mostly impacted by the infrastructure and the V2i relationship (connectivity) than by the autonomy of the train. The prevention of intrusion risks onto the rights-of-way and respect for level crossings remains the number 1 issue in reducing accidents.
- Frequency: Frequency improvements will mainly be linked to improvements in system robustness, especially thanks to the homogenisation of driving practices (traction curves, braking, etc.)
- Travel time: non-significant gain
- Flexibility and rapid evolution of service offer in the case of changing demand (if there are no staff on board)
- Energy savings: Yes, with optimised driving profiles and energy recovery for electrical equipment
- Cost: OPEX, limited gain, the cost of the 'driving' role being insignificant, capex: existing gain, less trackside vs. more onboard/Revenues: +++, directly related to the capacity gain

### High Speed Train

- Safety: Gain is not significant, especially with the absence of level crossings. Preventing the risk of trespassing along the train's right-of-way is still the number 1 issue in reducing accidents
- Frequency: frequency depends on the infrastructure and whether or not there is mixed traffic. The signalling and blocks systems play a major role in determining the minimum headway between trains. Automation moves in the direction of reducing expensive trackside equipment which can also hinder headway improvements
- Travel time: non-significant gain
- Flexibility: Major gain if and only if a fully autonomous mode, without on-board personnel
- Regularity: More robust, less delays (significant impact)
- Energy savings: optimised economic driving modes, real gains but not the most significant (5-10%)
- Cost: OPEX, limited gain, the cost of the 'driving' role in being even less significant, capex: real gains favouring on-board systems to trackside/Revenues: not significant, as capacity gains are not achieved only through 'autonomous' technology

## Challenges of autonomising trains

### Suburban Train

Safe management of train door closures in the station without negatively impacting operations: the high capacity of this type of transport generates a specific risk in the station linked to the passenger exchange, which can impact both the safety and efficiency of the whole line

### Inter-urban/High Speed Trains

- Variety of rolling stock that can limit performance gains, analysis of efficiency is performed on the transport system as a whole
- The stopping distance far superior to road vehicles (rail-wheel interface and unbelted passengers):
  - TGV 300 km/h, stopping distance: 3,000 m in emergency brake and 9,000 m in service brake
  - RER 80 km/h – 300 m in emergency brake and 500 m in service brake

## Initiatives Identified

- 'Autonomous Train' Project, SNCF (2017): Considering 3 user cases (high speed, inter urban, freight), with a gradual approach on the level of autonomy of the train, complete autonomy of GoA4 being targeted by 2025. It aims to develop an ATO at GoA4 with an intermediate stage at GoA2, working with ERTMS or static signalling, and based on European standards
- TAS, April 2017 (SNCF/ALSTOM/Systems/systems), Autonomous Land-based Transport with safety in its environment. This project has two main objectives:
  - Automating the driver's monitoring of its environment
  - Virtualising the validation of the correct functioning of the automation/demonstrating security
- ProRail project in the Netherlands, April 2017
- Automatic train driving on a 20 km stretch in the Toggenburg of St. Gallen, June 2017 (Eastern Swiss company Sudostbahn - SOB), start Pilot Project 2020
- Mining freight Train in Australia over of 100 km without driver accomplished in October 2017 Wombat/Paraburdoo

## Our Vision

In 5 years, start commissioning specific use cases, at GOA2, to obtain capacity gains and optimised regulation, without completely eliminating the driver:

- Operating suburban stretches, similar in style to metro operation
- High speed lines (protected station platform, only one type of traffic)

Experiments without passengers on board allowing different user cases to be tested and to develop the technological building blocks necessary for the development of fully autonomous passenger and freight trains on the majority of the tracks (excluding high speed):

- Remote control that can later contribute to the management of degraded modes
- Autonomy on the line (freight and passenger trains) and autonomy to and from maintenance centres

### NEW FRAMEWORKS TO QUALIFY AUTOMATION LEVELS?

To start considering a possible framework, we have defined 6 levels of automation for the tram (LoA: level of Automation):

**LoA0:** No automation.

**LoA0 +:** The system controls the speed.

**LoA1:** The system allows for a movement authority and a requested speed profile. External systems are capable of detecting non-railway related risks (lateral winds) and the modification of speed is communicated to the driver by these systems.

**LOA2:** Operation system is interfaced with the onboard and ATP/supervisor equipment. The speed modification is communicated by the non-railways risk detection systems to the ATO.

**LoA3:** The driver becomes an on-board attendant and intervenes only when necessary.

**LOA4:** The train drives itself without the presence of an onboard agent.


HSR Rhine-Rhone, France

# Conclusion

SYSTRA is a consulting and engineering group and a world leader in public transport infrastructure. Our mobility solutions respond to the challenges of transforming cities and regions. High speed lines, conventional Rail, Metro, Tram... our transport infrastructures create, day after day, the mobility of tomorrow; we are always more fluid, safer, more accessible and more durable. Our engineers are proud to collaborate with our clients and to allow people around the world to move more freely. We are convinced that confidence moves the world.

In January 2018, SYSTRA's Consulting and Engineering Division published a 160-page research paper exploring the idea of autonomy for guided modes of public transport. This document is a summary of that paper. The research carried out by systems engineers on autonomy and automation provides an early response to the issues and questions of our clients in this regard, whether the latter are public stakeholders, network managers, major manufacturers or industrial manufacturers.

With our knowledge and expertise, SYSTRA is ready to face the particular challenges of each of our clients and to respond with them to tomorrow's autonomous transport challenges. Created by the evaluation of current mature technologies, SYSTRA's vision is to identify what is achievable today, exploring and obtaining quick gains. The potential future progress in the automotive and artificial intelligence sectors could change in the next few years and open new horizons for guided railway systems. What is achievable today is different from what will be achievable tomorrow. At SYSTRA, we remain attentive to technological developments and are well positioned to support innovation on projects.

# For more information

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The full report of the study: 'white paper on making Guided Rail Transport autonomous' by SYSTRA is available on request.

## Glossary

**ATO:** Automatic Train Operation

**ATP:** Automatic Train Protection

**ATS:** Automatic Train Supervision

**CBTC:** Communication Based Train Control

**Deep Learning:** software based machine learning technique

**FU:** Freinage d'urgence (emergency braking)

**FS:** Freinage de service (Service braking)

**GAME:** Globalement Au Moins Équivalent

**PCC:** OCC Operational control centre/Poste de Commande Centralisé

**PPHPD:** Passengers Per Hour Per Direction

**SIL:** Safety Integrity Level

**UTO:** Unattended Train operation

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