WAVESTONE

WORLD'S BEST DRIVERLESS METRO LINES 2017

MARKET STUDY ON DRIVERLESS METRO LINES AND BENCHMARK OF NETWORK PERFORMANCE

WAVESTONE

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Wavestone is a consulting firm, created from the merger of Solucom and Kurt Salmon's European Business (excluding retails and consumer goods outside of France) Wavestone's mission is to enlighten and guide their clients in the most critical decisions, drawing on functional, sectoral and technological expertise.

In tomorrow's megacities, citizens' **selected route** will take on increasing importance (in France, journey length grew by **63% between 1982 and 2008** according to INSEE, France's National Institute of Statistics and Economic Studies).

At the same time, citizens' habits regarding transport change as a result of pressure, from **environmental responsibility** which is more present in their conscience and, on the other hand, from congestion in city centers. The **"transport mix"** in big cities has clearly shifted from the individual car towards **mass public transport**.

Faced with the challenge of transporting more passengers in a **continuous and fluid** way, and with the challenge of increasing **line capacity that is already saturated**, the driverless metro system brings practical solutions: **high headway** (up to 60'' for Lille's metro), **high flexibility** (adapting the service frequency to real time demand), **high service level** (24/7 service, e.g. Copenhagen's metro) and **higher commercial speed** (up to 44km/h in Vancouver).

In addition, driverless metro systems considerably reduce **operating costs** (by up to 40%) mainly bringing with them **human resources flexibility**. This means **public transport prices are significantly reduced** and **accessible** to more of the population.

By making the most of all these advantages, the driverless metro system will, **in the next five years, strategically** meet the challenges of **decongestion** in the megacities which are coming into view in emerging countries in **Asia, Africa and South America** as well as the challenges presented by the **peripheral urbanization** of highly dense big cities in developed European countries.

This panorama on **"smartization"**, which **optimizes and streamlines** urban mobility highlights **France** as the flagship of driverless metro system operations. The **momentum of its authorities and industry** in the segment has propelled the country to the top of the pack in the global driverless metro market.

A transport system's performance is based on **strategic choices** made over the long term by the organizing transport authority and **tactical and operating choices** made by the operator.

Through its vision, the organizing transport authority comes up with a **transport solution** that meets mobility demands **modelled for several years** (generally, the organizing transport authority's vision is for a 10-30-year period). In reality, this choice which seems to have little impact on metro line operations proves **decisive** for:

/ **Mobility quality** perceived by the user, closely linked to the **density of the stations** (varying between 0.54 station/km for Dubai and 2.17 stations/km for Lausanne), with the theoretical headway and **therefore the transport system's capacity** (varying between 1' for the Lille

*See glossary.

metro and 6' for the Dubai metro), at the commercial speed brought about by the **choice of rolling stock** and accessibility, often standardized by strict rules

- A recovery in the operator's operations which depend on the quality of the **return good disposed of by the organizing transport authority and the ageing** of the network and rolling stock. As a result, **investment for the operator and additional operating costs** for maintenance are to be planned for

The study shows that **the operator** has a much more important role to play than the organizing transport authority in **improving the service delivered to the customer:** the transport experience. It may **compensate for choices** made by the organizing transport authority which are judged as sub-optimal, ensuring **a high rate of punctuality and frequency** (varying between 93% for Lausanne and 99.73% for Taipei) and a group of innovative **connected services** which transform urban mobility.

Likewise, the **operator's expertise** is crucial in guaranteeing **efficient, reliable and above all profitable operations**, particularly for ageing networks and rolling stock such as that found on the following metro systems: Lille (35 years' old), Lyon (26), Taipei (21) and Vancouver (31). Network operations of this type may easily generate uncontrollable maintenance costs which have a direct impact on the organizing transport authority and the user through a **higher transport price**.

Transport **service quality perceived** by the customer is also thought to be linked to settings that are endogenous to operations, which do not depend on the organizing transport authority. This perception of quality is achieved through a passenger **satisfaction level** measured by the operator itself, with the operator's own indicators undergoing **self-monitoring** i.e. monitoring by the organizing authority which seeks to measure **the difference between the thresholds set in the operations contract and users' perceived performance**.

Wavestone chose to compare users' satisfaction levels in **two domains** for which **the operator's margins** are significant: people's cleanliness and safety. For the first domain, lines including Lyon, Barcelona, Rennes and Taipei top the rankings with positive opinions from users, reaching **99.3%** for Lyon, versus less than **70%** for Vancouver and Milan. For the second domain, **the operator's efforts are crucial** even if the **socio-economic context** of the area served by the metro line has an important role. Regarding safety, Copenhagen, Dubai and Taipei come out with user satisfaction rates that exceed **90%**.

Nevertheless, the comparison of users' satisfaction between different networks remains a tricky task due:

- The difference in terms of **methods for measurement** between the different lines and the type of surveys or inquiries conducted

- The diverse nature of the **socio-economic differences** of the served areas, between cities and even countries
- Citizens' different perceptions faced with **qualitative issues** (safety, cleanliness) based on their country
- The **scope of the inquiry** which varies according to author (operator, organizing transport authority and third party). The scope for an authority or third party is often larger than that of an operator, which is sometimes impartial

Finally, in its analysis, Wavestone adopts a **weighting factor** which reflects the **old-age of the infrastructure and rolling stock**. At similar operating performance, a network with major operating constraints due to its age, reveals an operator's potentially more advanced **competency**. A change to this factor would have an impact on the global ranking: by reducing such this factor, the best metro lines in the ranking may see their rank lowered, but the score will no longer precisely reflect their operational excellence.

As part of the development of its expertise in the transport sector, **Wavestone's Transport & Travel practice** has taken a deeper look at **mass urban transport** by drawing on the existing network of our **international offices** to enhance the knowledge base of our **local** and **international** clients.

The trend of automation affecting all transport modes (including autonomous cars, autonomous buses and hyperloops) quickly shifted the focus of the study to **driverless metro lines**, a mature and rapidly expanding technology, the data for which is fully accessible, unlike those for disruptive systems, which are new and have little market presence.

To carry out the study, **Wavestone** limited the scope to a representative and coherent sample:

- Driverless metro lines* mainly transporting **passengers on back-and-forth journeys** including commutes.
- Collective driverless transport lines such as light rail transit (LRT)*, people movers* and automated guided transit (AGT)* are not included in the benchmark target as their context, service and operation are not comparable with "heavier" systems such as metros and are not used in the same way.
- The study analyses **25 of the 40 driverless metro lines** existing worldwide in February 2017, for which information is considered as **available, accessible and reliable,** notably **thanks to our international offices,** thus providing the items necessary for a comparative analysis.

This survey is notably based on:

- **The collection of documents** from different sources and supported by Wavestone's international offices.
- **A series of interviews** with major players in urban transport and experts in the field.
- **Analysis work** serving to compare driverless metro lines in three respects: the performance of infrastructure and rolling stock; the reliability and quality of the service; and the innovation demonstrated by the operators.

*See glossary.

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More specifically, he addresses problems mixing energy and transport: smart city, green mobility, etc.

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INTRODUCTION OF THE STUDY

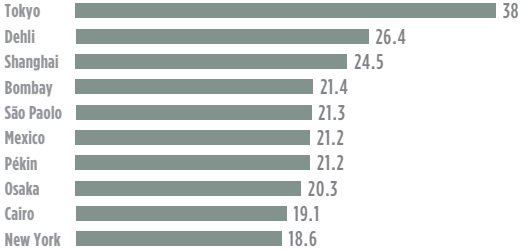
MOBILITY, A KEY ISSUE IN TOMORROW'S CITIES

URBANIZATION IS ON THE RISE IN ALL THE WORLD'S MEGACITIES, PARTICULARLY IN EMERGING COUNTRIES

The **global urban landscape is in the midst of e deep-seated change**. In 1950, only New York and Tokyo had a population of over ten million. In 2016, some 31 cities are home to over ten million people, six of them in China and five in India. The figure will rise to 41 by 2030. The world is currently home to 7.3 billion people, over 54.5% of whom live in cities. By 2050, the world population will rise to roughly 9.7 billion, with **over 65% of the total living in cities**.

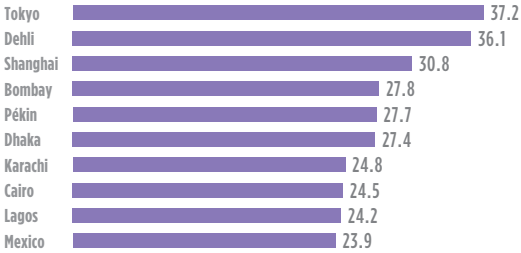
The number of megacities is on the increase, a trend accompanied by urban sprawl, which gives these cities an interface role through an effective transport system:

2016 - The World's 10 Biggest Cities (population in millions of inhabitants)



- China (19% of the world population) and India (18%) are the world's most populous countries, each with over one billion inhabitants.
- Only four megacities are not on the Asian continent: São Paulo, Mexico, Cairo and New York.
- None of the megacities are in Europe, and Cairo is the only one in Africa.

2030 - The World's 10 Biggest Cities (population in millions of inhabitants)



- Seven of the ten most populous cities are in Asia
- India will overtake China as the world's most populous country in 2022.
- Bangladesh (Dhaka) and Pakistan (Karachi) are highly populated and capital-centric.
- The population of Nigeria (Lagos) will overtake that of the USA in 2050, with the country becoming the world's third most populous.

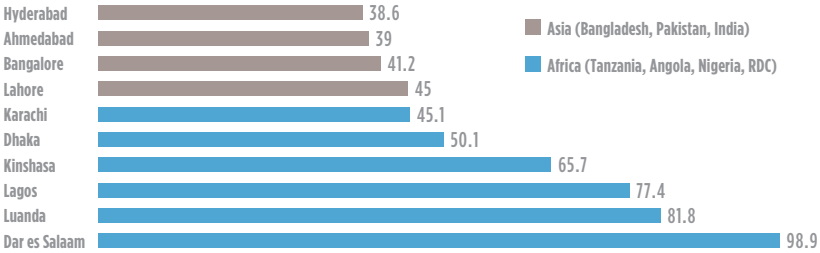
Source: United Nations, The World's Cities in 2016.
*See glossary.

AFRICA AND ASIA ARE SET FOR STRONG URBAN GROWTH, LEADING TO THE ADVENT OF NEW MEGACITIES ON THE TWO CONTINENTS

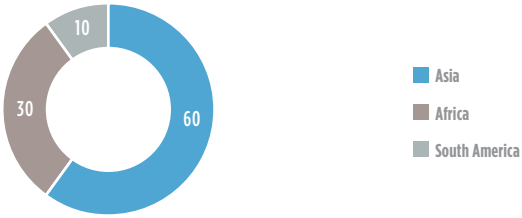
Megacities are concentrated in Asia and Africa: in 2016, 17 of the world's 31 cities with over 10 million inhabitants were in Asia (55%) and 3 in Africa (10%). In 2030, 23 of the world's 41 cities with over 10 million inhabitants will be in Asia (56%) and 6 in Africa (15%).

The 10 new megacities will be in Asia (Pakistan, India, Thailand, Vietnam), Africa (South Africa, Tanzania, Angola) and South America (Colombia).

Top 10 Cities with the Strongest Population Growth between 2016 and 2030



Geographical Breakdown of Cities Entering the Rankings of Megacities with Over 10 million Inhabitants in 2030



Source: United Nations, The World's Cities in 2016.

The rapid expansion of these cities, and the emergence of a middle class resulting from the far-reaching economic transformation in these regions, make urban mobility a key issue for these countries. The urban transport market will be increasingly concentrated in these two regions in the coming decades.

TO PREPARE FOR DOUBLE-DIGIT URBAN GROWTH, THE WORLD'S BIGGEST CITIES NEED TO START THINKING ABOUT SUSTAINABLE MOBILITY HERE AND NOW

Worldwide, the urban population overtook the rural population in 2007. In a world of cities, city dwellers, whether commuting or traveling for family or leisure purposes, are in movement: **mobility is an integral part of their everyday lives**.

Today's cities are congested, traffic-jammed and polluted. **Tomorrow's cities need to address the mobility issues of their inhabitants – and the management of transport flows has become a crucial issue**. Tomorrow's hyper-connected and smart cities (which are just around the corner) also need to take a new approach to mobility:

Mobility **adapted to the characteristics of tomorrow's cities**: the modern metropolis – the **"Smart City"** – is larger and more densely populated, a place of 24-7 mobility with peaks in transport use that require transport authorities to be adaptable.

Mobility that **respects the environment**: mobility today is overly polluting; it needs to be approached as part of the efforts to shrink the environmental footprint of the Smart City.

Mobility that **goes above and beyond the traditional, technical and functional definition of transport to adopt a service-based and more modern approach:** mobility conditions (comfort and well-being, waiting times, information access) are becoming crucial, with users more concerned about the time than the distance of their daily journeys.

Mobility that **takes account of the back-and-forth travel** characteristic of large cities, in which inhabitants take the same routes back and forth in the same day, mainly as part of their commutes.

CLICKABLE, EFFICIENT AND PERSONALIZED TRANSPORT FOR AUGMENTED MOBILITY IN THE SMART CITY

For economic and ecological reasons, large cities around the world are seeking to shift to a **Smart City model**. They are exploring a broad range of fields – including energy, waste management, water supply and enhanced transport – and digital technology is playing a vital role in optimizing the way these services work.

And so **the transport sector is in the midst of a major transformation**, with far-reaching changes in the offer and in

user behavior since the arrival of digital technology. A day-to-day issue for all the population, transport is naturally a key focus in efforts to develop Smart Cities.

Data is used to **assist passengers**, who now have access to an unprecedented urban transport offer with increasingly varied transport modes (collaborative modes, bike fleets, self-service cars, etc.) accessible in just a few clicks thanks to digital advances in the sector. Transport data, widely shared on an open-data basis, are behind new comparative services, such as CityMapper.

The availability of transport data is also enabling transport organization authorities to **better plan the development of their networks** by adapting transport offers to passenger flows, with electronic tickets improving the analysis of journeys, connections and so on.

The use of real-time sharing is improving the responsiveness of the transport offer and serving to enhance mobility. Transport users are increasingly called on to provide information on the functioning of the network in real time (with Waze and Moovit, for example), and the information collected in real time is supplied to transport authorities through partnerships (as with the Waze Connected Citizens Program).

SHORTER JOURNEYS AND LIGHTER TRANSPORT MODES AROUND DENSE AND INCREASINGLY DECENTRALIZED AGGLOMERATIONS

Commutes are growing increasingly longer. **The average commute distance in France has risen 63% in the last 30 years.** This is mainly a result of the **widespread migration of inhabitants to peri-urban areas**, which in turn results from the substantial growth in the population of cities and increasing pressure on urban areas.

The **socio-economic** and **ecological** impact of the daily commutes stemming from this shift is considerable. The economically active population is more stressed and **productivity is on a non-stop decline**, negatively impacting the urban economic fabric.

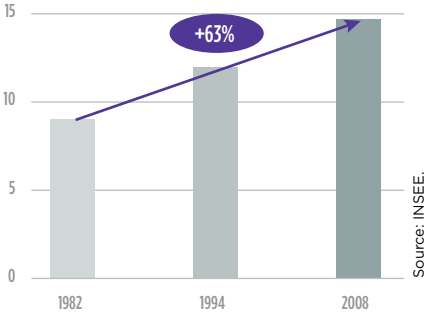
To address this problem, countries, and often developed countries, are seeking to bring homes closer to workplaces and even **concentrate them in peri-urban micro-centers** (such as those in Seine Saint-Denis and Paris-Saclay outside Paris).

The adoption of this approach in the national strategies of various countries,

along with **the rise of these "micro-cities"**, whose populations are considerably lower than those of cities, presages a **switch from a mass transit network, such as the metro, to much lighter micro-networks such as people movers and trams**.

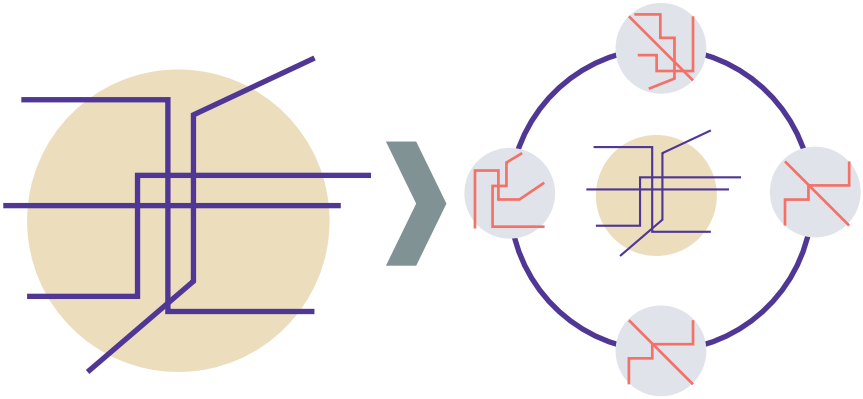
A product of this model, the **Grand Paris Express** rapid transit system serves to **decentralize the City of Paris and paves the way for the arrival of tomorrow's peri-urban micro-cities**.

Average Commute Distance in France (in km)



Current Urban Transport Model

Future Peri-Urban Transport Model



Metro-style mass transit line

Light tram or people-mover line with very low capacity

TOMORROW'S SMART CITY WILL BE SERVED BY A HIGHER-PERFORMANCE MASS TRANSIT SOLUTION: THE DRIVERLESS METRO

"New mobilities" are a new way for getting from A to B made possible by emerging models and technologies and rolled out through high user adoption rates, **including electric cars, autonomous shuttles and carpooling**. But these systems are not adapted to mass transit, involving faster passenger throughput rates on high-pressure routes and in a sustainable manner.

Driverless metros stand as an **intelligent and innovative mass-transit solution**. Driverless technology meets a certain number of the objectives involved, including high capacity, speed and regularity, reduced operating costs, adaptability, and flexibility in terms of human resources. It fulfills the criteria of a new approach to mobility:

It is adapted to the requirements of future cities

> it is **integrated in the urban environment** and responds to the demand for diversified mobility from Copenhagen and Toulouse to Dubai and Vancouver;
> it is **more flexible** to operate, both in technical and HR terms: automatic solutions can be quickly adapted to available capacity by minimizing or even eliminating constraints linked to drivers.

It creates a better service for passengers
> it helps to **reduce waiting times on platforms** by providing a more frequent service and faster commercial speed than conventional metros while maintaining top-level punctuality;
> it offers a better passenger experience through more recent trains and renovated stations.

It is a reliable means of transport requiring leading-edge expertise

By eliminating the risk factors stemming from human driving, the driverless metro achieves **higher safety and reliability rates** than conventional metro systems*; the introduction of platform doors also limits the risk of accidents and human presence on the track.

*See glossary.

FOR EXAMPLE, THE DRIVERLESS METRO IS CENTRAL TO THE GREATER PARIS TRANSPORT STRATEGY AND THE DECENTRALIZATION OF THE CITY

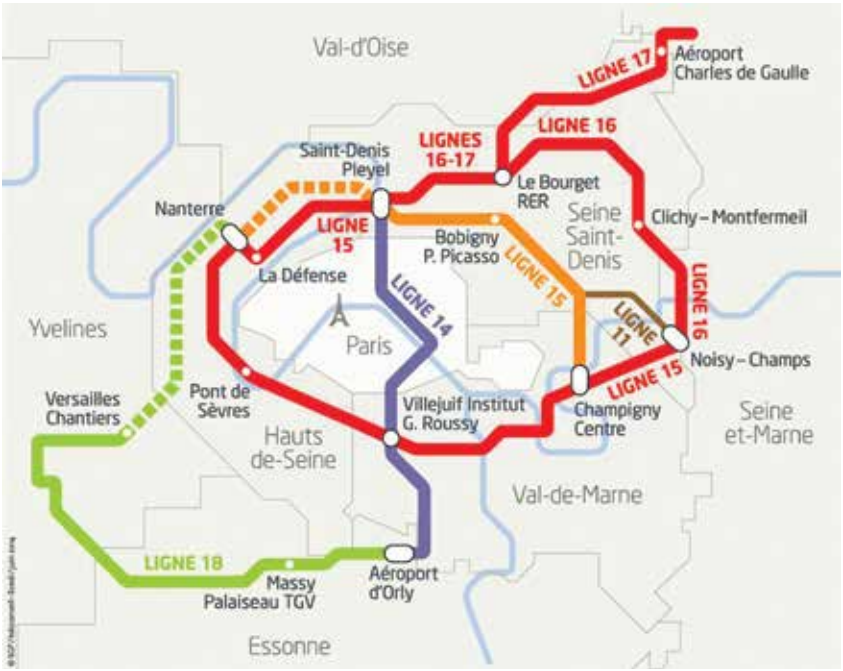
The **initial part** of the Greater Paris transport plan concerns the **modernization and extension of the existing network**. This includes extending the RER E line and the metro line, creating high-level-service buses and trams, modernizing RER trains and improving Transilien regional train lines.

The **second part** of the transport plan is focused on the creation of new driverless metro lines, the "Grand Paris Express". The aim is to build 205km of metro lines and 72 new stations, to enter into service between 2018 and 2030.

As with similar projects in other large cities, the **Grand Paris Express** project was selected with a view to decentralizing the city, reducing commute times and, above all, creating peri-urban socio-economic centers of interest able to relieve congestion in the capital.

The law relative to Greater Paris provides for a **specific organizational model** for the Grand Paris Express, whereby **technical infrastructure management is handled by RATP** and the **operation** of the lines is **handled by operators** selected through tenders.

While the reform of collective transport in Île-de-France **brings all operators access to the network in free and non-discriminatory conditions** (and formally provides for a seamless connection between the activities handled by RATP and those handled by the network manager), **operators have expressed reserves as to the organization model selected and the fairness of the call for competition**.


Val-d'Oise
LIGNE 17
Aéroport Charles de Gaulle
LIGNE 16
LIGNES 16-17
Saint-Denis Pleyel
Le Bourget RER
Nanterre
LIGNE 15
Seine Saint-Denis
Clichy – Montfermeil
Bobigny P. Picasso
LIGNE 15
La Défense
LIGNE 14
LIGNE 11
LIGNE 16
Yvelines
Paris
Noisy – Champs
Versailles Chantiers
Pont de Sèvres
Villejuif Institut G. Roussy
LIGNE 15
Champigny Centre
Seine et-Marne
Hauts de-Seine
Val-de-Marne
LIGNE 18
Massy Palaiseau TGV
Aéroport d'Orly
Essonne

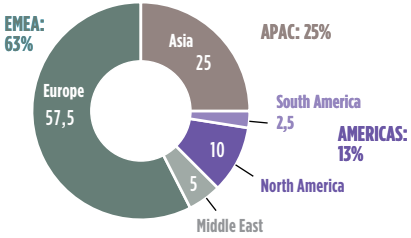
KEY FIGURES ON DRIVERLESS METRO LINES WORLDWIDE AND THE FINANCIAL PERFORMANCE OF AUTOMATION

THE WORLD'S 40 DRIVERLESS METRO* LINES ARE CONCENTRATED IN THE EMEA REGION AND SOUTH-EAST ASIA

Nearly **3/4** of driverless metro lines are located in cities with **dense urban populations** (over 4,000 inhabitants/km²).

81% of driverless metro lines are located in cities with **over 500,000 inhabitants.**

Worldwide
40 Lines in 26 Networks

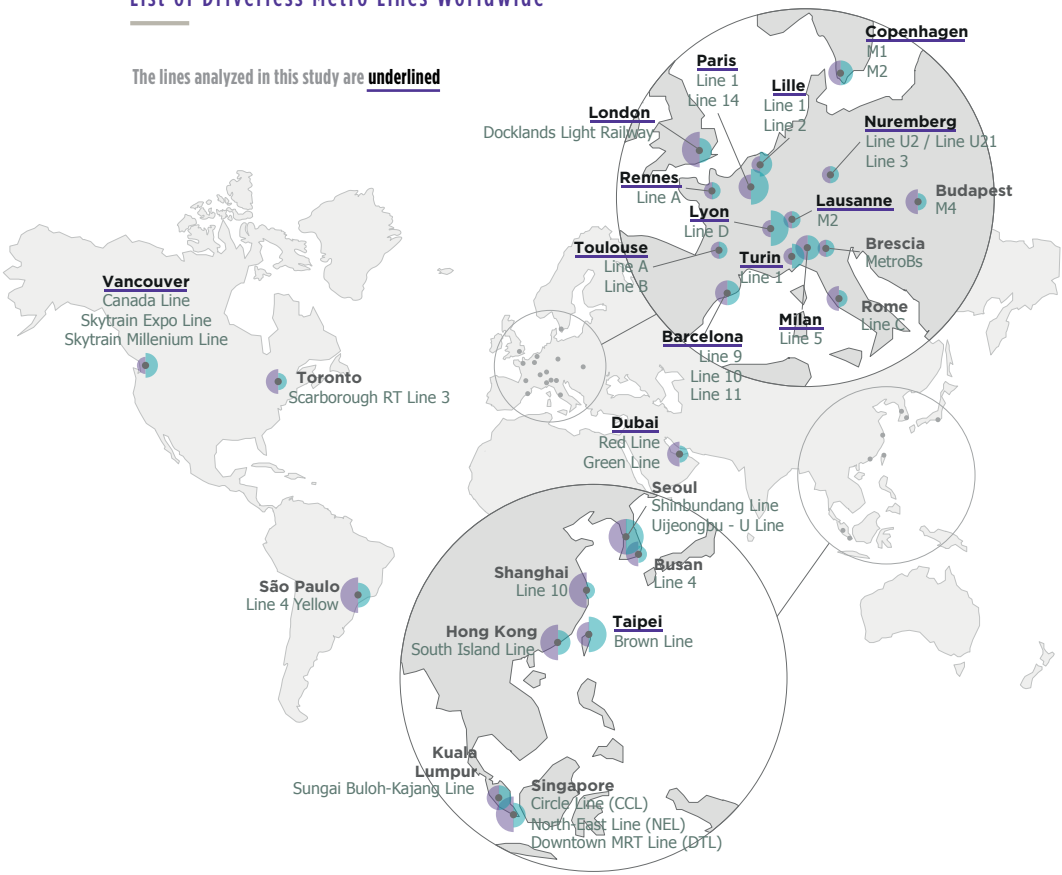


NB: The UITP Observatory of automated metros has counted 55 lines due to including in its scope certain people mover lines, LRT systems, AGT systems, trains with a >100 passagers/train capacity (vs a capacity of >400 PAX/train for the Wavestone study), monorail trains (vs only due or 3-rails for the Wavestone study) as well as Maglev technology (vs only pneumatic or steel for the Wavestone study): scope differences with this benchmark Observatory attributable to the fact that the Wavestone study aims to compare performance on equivalent urban mass-transit technologies and use.

*In the scope of this study, the definition of "driverless metro" is slightly different from the one adopted by the UITP, that considers 55 lines. The UITP includes in its definition people movers, LRT and AGT, which is not the case of the current benchmark.

List of Driverless Metro Lines Worldwide

The lines analyzed in this study are **underlined**



Over 5m inhabitants (city population)

Between 1m and 4.9m inhabitants (city populat

Under 1m inhabitants (city population)

Over 10,000 inhab./km^2 (population density)

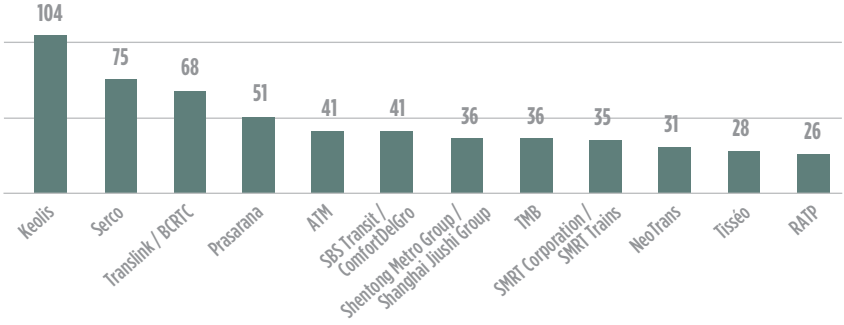
Between 5,000 and 9,999 inhab./km^2 (populati

Under 5,000 inhab./km^2 (population density)

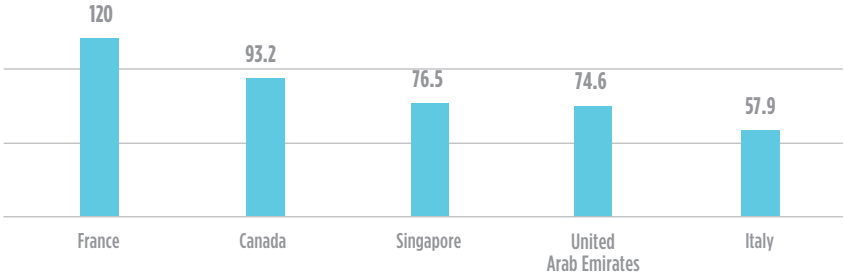
Sources: Wavestone research and analysis, UN data, UITP.

Overview and Key Figures of the World Driverless Metro Market

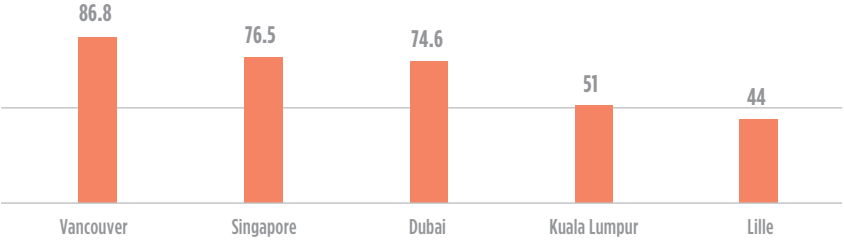
OPERATORS OPERATING THE GREATEST LINE MILEAGE



TOP 5 COUNTRIES IN TERMS OF DRIVERLESS LINE MILEAGE



TOP 5 CITIES IN TERMS OF DRIVERLESS LINE MILEAGE

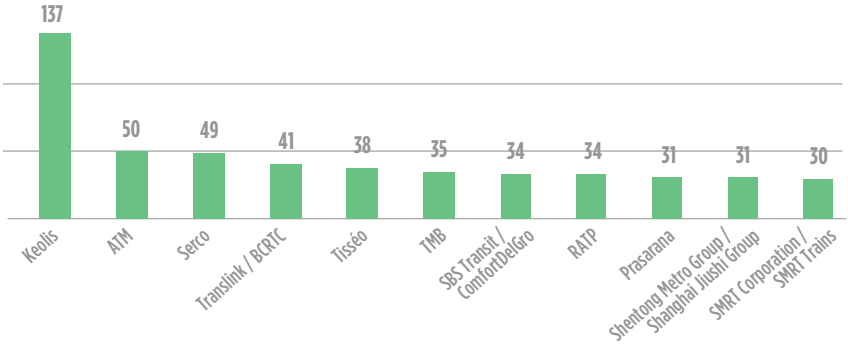


FRENCH ENTITIES OPERATE NEARLY 1/4 OF THE WORLD'S NETWORKS (23.1%), FOLLOWED CLOSELY BY THE ITALIANS (19.2%)

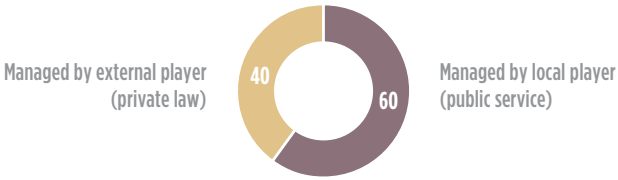
5 out of the 40 lines are operated by foreign players

87.5% of the lines are operated by national operators

OPERATORS OPERATING THE LARGEST NUMBER OF STATIONS



THE MAJORITY OF DRIVERLESS METRO LINES ARE OPERATED BY PRIVATE EXTERNAL PLAYERS



Vancouver is the only network with 1 line managed by an external player (SNC-Lavalin) and the other 2 lines by a public player (municipal council).

DRIVERLESS METRO LINES ARE CONSIDERABLY MORE COMPETITIVE THAN CONVENTIONAL METROS AND WILL BECOME MORE SO AS THEY ARE INDUSTRIALLY DEVELOPED

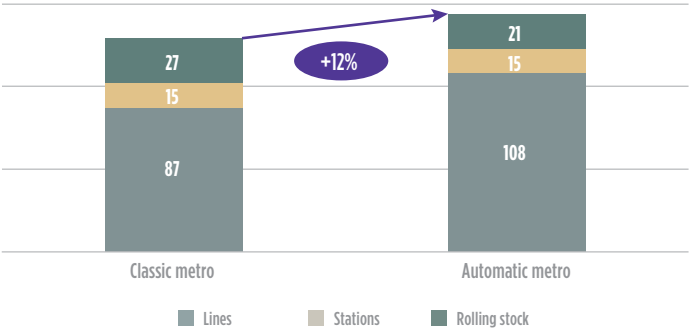
Highly competitive in terms of complete cost:

/ **Rolling stock:** the additional cost linked to the purchase of driverless trains is offset by **a gain in the sizing of the rolling stock**, since automatic systems have better performance (headways / commercial speeds). For the same service frequency, the driverless metro requires **33%* fewer trains**.

/ **Station:** the investments involved in implementing platform doors are offset by **smaller platform areas** for driverless metros and, consequently, **lower civil engineering costs**. This results from the higher-level service of the driverless metro in terms of headways.

/ **Line:** the costs of driverless lines are naturally higher than those of conventional lines. **This is largely due to communication and signaling**. However, the use of **CBTC communication is becoming more widespread for different types of metro**, thereby reducing the cost gradient involved.

Investment Costs per Km (in € million)

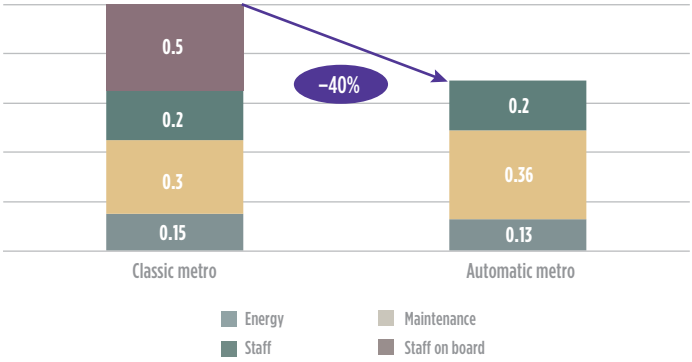


*Rolling stock manufacturers, Wavestone analysis.

/ **Operating costs:** the additional cost linked to the maintenance of platform protection systems is **offset by savings** on personnel costs and energy costs (15% lower for driverless metro lines).

In terms of global costs per km, the driverless metro is more competitive than the conventional metro for a depreciation of infrastructure and rolling stock of over 30 years.

Operating Costs per Km (in € million)



Hypotheses: Average line length of 14.5km, 30 trains per line, 22 stations on average per line, 200 drivers to operate a line.

Sources: LVMT Laboratoire ville mobilité transport, *The Economics of Urban Transportation 2007*,

TECHNOLOGICAL TRENDS AND CHALLENGES IN METRO AUTOMATION

OPERATORS NEED TO ADOPT THEIR KNOW-HOW TO THE GROWING USE OF CBTC TECHNOLOGY

CBTC technology is the preferred signaling **solution with a 68% share of the market**. This solution combines **safety and optimized frequency**.

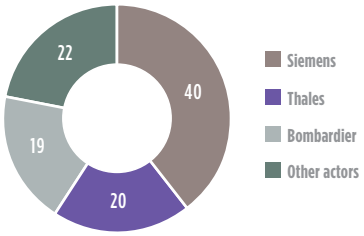
The market of CBTC solutions suppliers is highly **concentrated**: the **top 3 suppliers**, namely **Bombardier, Siemens and Thales**, have a 78% share of the market (including for non-automatic trains and metros).

The **convergence of manufacturers** towards CBTC, as well as **the investments involved** (Invensys was bought out by Siemens in 2013), indicate the **future widespread use of the technology** in the rail sector in general and driverless metros in particular.

All the metro systems analyzed in this study are equipped with **CBTC signaling and communication**. A wide range of suppliers are represented by the benchmark (see graph opposite).

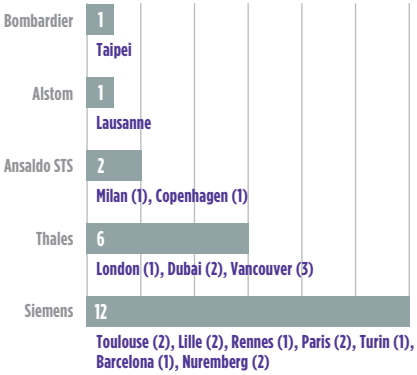
The Lille network is currently being redesigned and the new system is to be equipped with **Urbalis, supplied by Alstom**. But the delay in the project (estimated at 4 years) means that the current system (supplied by Siemens) will be maintained for the next few years.

Market Share* of Communication System Suppliers (in %)



*Frost & Sullivan data, Wavestone analysis.

Breakdown of CBTC Subcontractors in the Sample Studied (number of lines)



Sources: World Report on Metro Automation - July 2016, UITP.

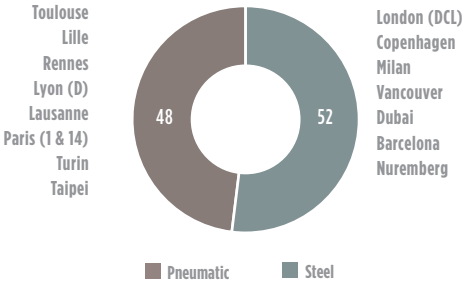
THE SHARE OF PNEUMATIC TIRES IS FALLING TO THE BENEFIT OF STEEL WHEEL-RAIL LINKS DUE TO THE SPECIFIC EXPERTISE AND MAINTENANCE CONSTRAINTS INVOLVED

10 manufacturers supplying rolling stock. **Bombardier, Alstom and Siemens are the leaders with 68% of total installed mileage**.

The preferred wheel-rail link in the mileage built in the **last decade is steel, accounting for 70%** of total mileage built. But pneumatic links have an **advantage in terms of sound levels and passenger comfort**.

The **know-how of the operator** and technological expertise are **decisive**. The two technologies have their specific characteristics in operation, with pneumatic systems requiring **know-how** in maintenance. In this respect, some **operators, such as Serco and ATM, appear to prefer steel links**.

Market Share of Steel vs. Pneumatic for Analyzed Sample (in %)



PNEUMATIC

\+
- **Better grip, system adapted to cities with sharp gradients**
- **Less noise inside and better passenger comfort**
- **Better adapted to automated system by avoiding wheel slip**

–
- Not particularly energy efficient (+1% to 3%)
- Leads to higher maintenance costs
- Makes the system heavier, which means it consumes more energy
- Higher fine-particle emissions than steel

STEEL

\+
- **Lower energy consumption owing to reduced rail friction**
- **Better adapted to metro systems in cities with difficult weather conditions (e.g. Dubai, Nordic countries, etc.)**
- **Lower maintenance costs**

–
- Recurring slip of train-rail link leading to control system problems
- Longer headways owing to longer breaking and acceleration times

WHAT DOES AUTOMATION INVOLVE FOR OPERATORS?

Technically speaking, operators need to:

/ Carry out the prerequisite work for the installation of platform doors necessary for optimizing **passenger safety**.

/ Roll out the automation system for train operation, which differs depending on the desired headways:

- For **long headways**, operators can opt for a fixed-block communication system (in which the position of the train is determined relative to a section of the line). This is a mature technique used by driverless and manual metro lines. However, because it is only moderately precise, it cannot be used for short headways.
- For **short headways**, operators are required to implement a mobile-block communication system (in which train position and speed are determined in a precise manner). This necessarily calls for the roll-out of additional technologies, namely ATP*, ATC* and ATO*. This in turn leads to additional risks (of a technical nature).

/ The possible creation of new maintenance workshops adapted to solutions that are often specific to driverless metro lines, such as platform doors.

Operationally speaking, operators need to:

/ Ramp up the driverless rolling stock during the transition phase operating in combined mode. Operators have to make this transition with as few interruptions as possible. The commissioning phase increases risks in service quality and requires specific expertise on the part of the operator.

Organizationally speaking, operators need to:

/ Redeploy driving staff to connected positions (line control and supervision).

/ Upskill existing staff or hire the new employees required to ensure the operation and maintenance of driverless lines.

*See glossary.

THE DEVELOPMENT OUTLOOK FOR DRIVERLESS METRO LINES

THE OUTLOOK FOR THE DEVELOPMENT OF DRIVERLESS METRO LINES LOOKS ROBUST THROUGH 2020, DRIVEN BY LARGE-SCALE PROJECTS

With more and more people living in cities, mass transit systems increasingly have to:

- **Optimize the existing urban infrastructure** as capacity can be extended only to a limited extent. The solution in this case is the automation of conventional lines.
- **Develop new infrastructure on the outskirts of cities** offering users high-quality service while keeping costs under control.

Automated technologies propose solutions **meeting both these requirements**.

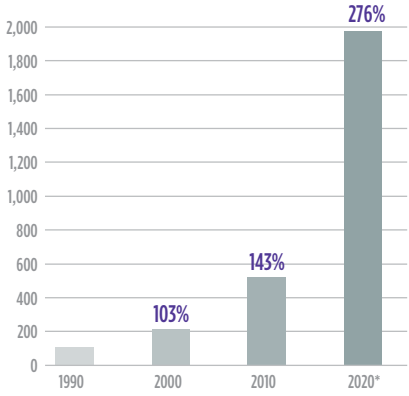
According to the UITP, **by 2025 some 2,300km** of driverless metro lines will be in operation, compared with around 800km today.

The increasingly widespread use of CBTC technology by all driverless metro lines together with **rising living standards in emerging countries** will boost the competitiveness of automation solutions and increase demand.

In 2025, Asia and Europe are expected to account for **33% and 30%** of driverless metro mileage, followed by the Middle East (25%) with ambitious projects such as the Riyadh metro.

China has announced the introduction of two new driverless lines between now and end-2017, one of them built exclusively with Chinese technologies.

Completed and Projected Driverless Metro Lines* in Km and Growth Over 10 Years



Source: World Report on Metro Automation - July 2016, UITP.

*The estimated number of kilometers by 2020 takes account of construction and/or automation projects confirmed as of July 2016.

DESCRIPTION OF SCOPE AND METHODOLOGY

SCOPE OF THE STUDY

DATA ACCESS AND RELIABILITY ENABLED US TO ANALYZE 25 DRIVERLESS METRO LINES* OUT OF THE TOTAL 40 EXISTING IN FEBRUARY 2017 WITHIN THE SCOPE OF THE STUDY

Criteria Used to Define Scope

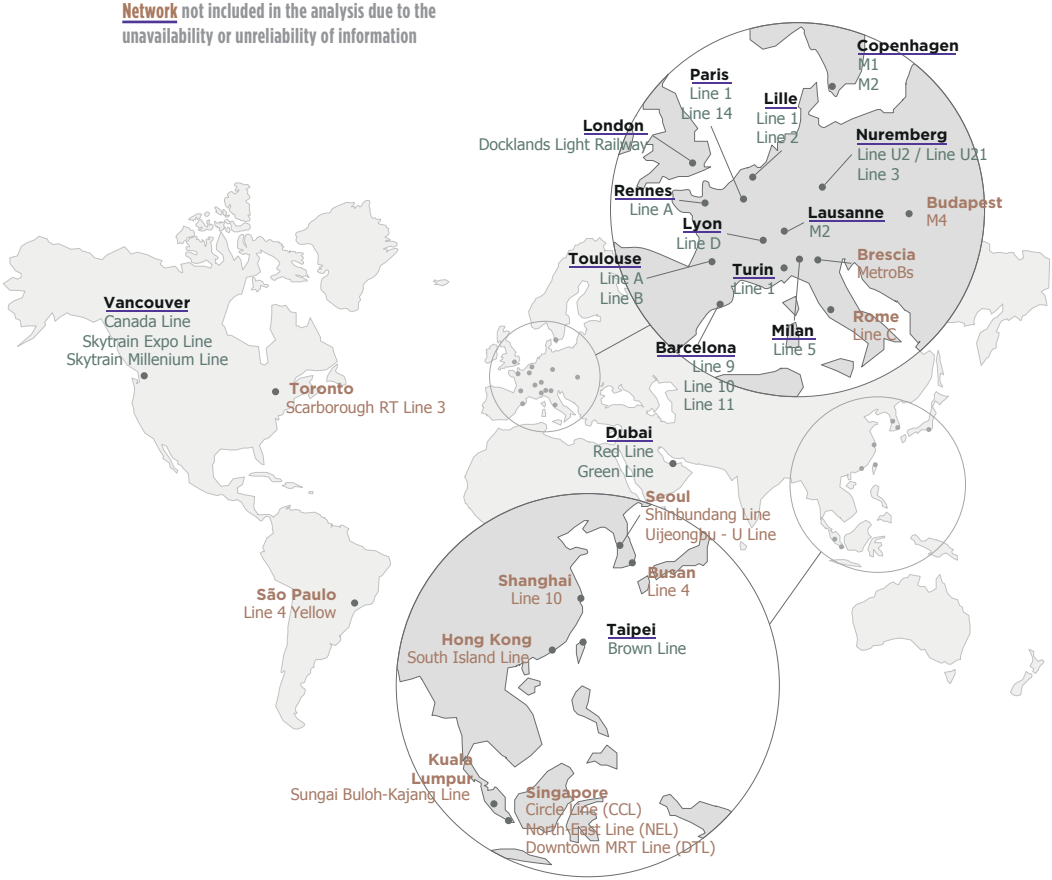
- ☑ **Driverless metro*:** a dedicated, rail-powered circuit mainly used for commutes, with several carriages (up to 6 or 8), raised access and a capacity of over 400 passengers
- ⊟ *Not including automated people-mover*, light rail transit* and automated guideway transit* systems*
- ☑ **Pneumatic or steel rail link**
- ⊟ *Excluding Maglev and Hyperloop rail links*
- ☑ **Dual-rail or third-rail systems**
- ⊟ *Excluding monorail*
- ☑ **Automation level GoA 3 and 4***
- ⊟ *Automation level GoA 1 and 2* excluded*

*The terms used in the study are defined in the glossary.

List of Driverless Metro Lines Worldwide

Network included in the comparative analysis

Network not included in the analysis due to the unavailability or unreliability of information



BENCHMARK METHODOLOGY

Performance Fields Selected for the Benchmark

		PERFORMANCE FIELD
1		Performance of infrastructure and rolling stock
2		Service reliability and quality
2		Auxiliary or innovative services

The difference in performance between 2 driverless metro lines can be attributed to a great extent by the operator's ability to effectively operate the lines in question. Infrastructure and rolling stock are key to the performance of a network but with room for maneuver in the much longer term.

Icons denoting the fields to which the analysis of each page refers

INDICATORS CONCERNED	PROPOSED WEIGHTING
Commercial speed Distance between stations Headway Accessibility Intrusion rate in network	1
Punctuality and/or availability and/or regularity Cleanliness Passenger information Passenger safety	1.5
Available communication networks Innovative mobility service (route planner, etc.) New technologies (NFC, IoT, mobile)	Field assessed but not included in the final grade attributed to each metro line


山手線(外回り)
Yamanote Line
2
2

SUMMARY OF THE COMPARATIVE ANALYSIS OF DRIVERLESS METRO LINES

PERSPECTIVE

The **performance** of a transport system – including driverless metros – **is impacted by a set of factors external to the organization of the operator or transport authority**

This means that the **distinctive characteristics** of each network have to be taken into account in order to contextualize the analysis

Consequently, the **following characteristics or factors** need to be considered when comparing performance:

* **The age of the network:** entailing growing obsolescence costs with the age of the infrastructure and rolling stock, as well as the corresponding adapted processes for maintaining the line in operational condition.

* **The requirements included in the delegation contract (headways):** involving an operational strategy on the part of the operator capable of delivering performance consistent with contractual requirements.

** **The architecture and geography of the network:** involving the uneven exposure of rolling stock to its environment (underground, overground) and specific needs for fulfilling transport demand (air conditioning, heating).

** **The "load curve"** (breakdown of passenger use over the day): involving peaks of varying extent that may have an impact on punctuality (passenger incidents, etc.).

** **The socio-cultural characteristics of the user population:** involving the uneven use of public services, with particular impact on cleanliness and safety.

*Factor taken into account in the grade attributed to the metro line.

**Factor not taken into account in the grade, but assessed in the analysis of the results.

THE PERFORMANCE OF THE WORLD'S DRIVERLESS LINES: A PERFECT BALANCE BETWEEN INFRASTRUCTURE AND OPERATION AT THE SERVICE OF PASSENGERS

The performance of driverless metro lines is assessed through a complex equation of the **operational ability** to deliver a transport service adapted to mobility behavior and the optimization of **the transport conditions** of the journey experience.

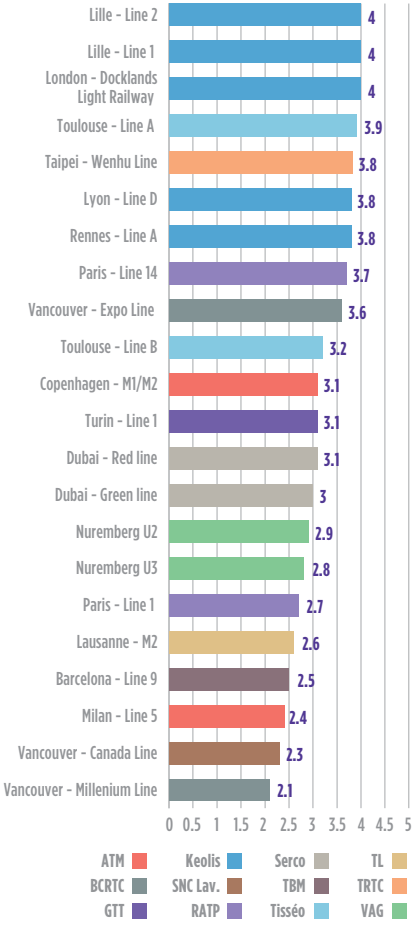
- The correlation between the **strong constraints imposed** by transport authorities (short headways) and the punctuality of the service is vital to performance.
- **Ageing networks** require **operational overperformance** on the part of operators.
- The **experience** operators have of a network and their length of service **are decisive to the performance** of an driverless metro line.

The design, construction and commissioning of an driverless metro line present **value added** for the city and its population, as vital as it is a **difficult activity** for transport authorities and operators.

The **most recent** driverless lines and networks demonstrate **high levels of reliability** that need to be **maintained over the long term** if they are to become world leaders.

Grades for the Performance of Driverless Metro Lines (out of 5)

Infrastructure x Operation / Network age



Sources: Wavestone grades and modeling.

The grade being the weighted sum of infrastructure performance (weight=1), operational performance (weight=1.5) and the network age indicator (weight=0.5).

THE HIGHEST-PERFORMANCE DRIVERLESS METRO LINES SHARE THE SAME CHARACTERISTICS OF EXCELLENCE

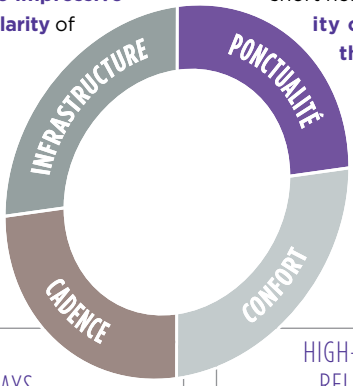
The best driverless metro transport services all score high on 4 key points related to infrastructure and operation:

THE ABLE MANAGEMENT OF AGEING INFRASTRUCTURE

These operators **demonstrate** excellence in the management of old assets. **As confirmed by the impressive availability and regularity** of their networks.

STRONG PUNCTUALITY

This is a defining characteristic of driverless metro lines. But combined with short headways it confirms the **ability of an operator to respect the requirements imposed by the transport authority**.



SHORT HEADWAYS

The strong punctuality of the lines managed by these operators confirms their commitment to demanding **transport authorities**.

HIGH-LEVEL USER SATISFACTION RELATIVE TO CLEANLINESS AND SAFETY

Globally speaking, the surveys led by these operators confirm **a good level of user satisfaction**, knowing that ageing infrastructure has a **negative impact** on passenger perception in this area.

INFRASTRUCTURE AND ROLLING STOCK PERFORMANCE

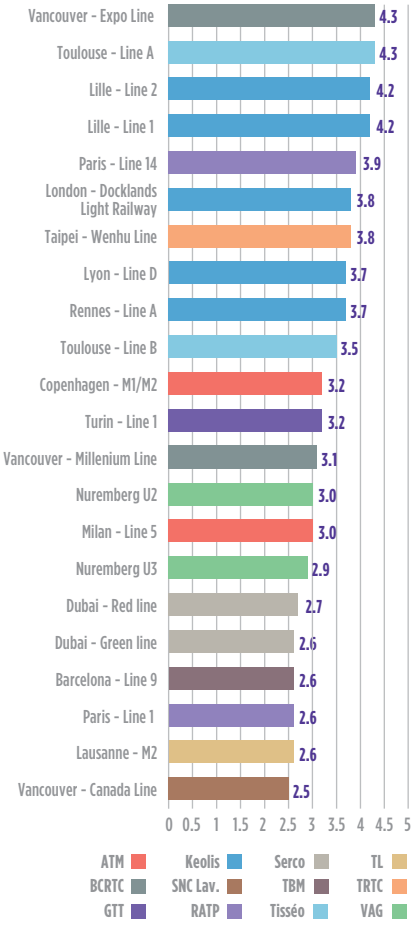
THE PERFORMANCE OF THE INFRASTRUCTURE AND ROLLING STOCK OF THE WORLD'S DRIVERLESS METRO LINES UNDERPINS THEIR SAFETY AND COMFORT

Infrastructure and rolling stock performance involves:

- **Strategies on urban mobility flow management:** the design of a driverless metro line, from upstream research to the layout of the line and the choice of stations, determines the relevance of a line and its utilization success.
- **Network access:** an infrastructure that makes access easier for people with mobility issues or harder for fraudulent users contributes to overall quality.
- **Matching operating requirements and expected use:** the optimization of infrastructure and rolling stock hinges on aligning service levels with use.

Infrastructure operation and maintenance serve to maintain performance levels over the long term. This challenge tests the operational performance of operators.

Grades for the Performance of Infrastructure and Rolling Stock* (out of 5)



*The sum of the grade attributed to the performance of the network and stock (weight=1) and the grade attributed to the aged of the infrastructure (weight=0.5) (5 corresponds to very old infrastructure).

FOUR MAIN CATEGORIES OF INFRASTRUCTURE AND ROLLING STOCK PERFORMANCE FOR DRIVERLESS METRO LINES

The entities in this category operate infrastructure and rolling stock that are **several years old**. Their strong performance reflects their **optimal use** of these assets, which requires **good operating conditions** on the part of the transporters.

The players operate infrastructure and rolling stock that are **generally recent and even new**. Their strong performance may be considered as resulting from the newness of the network. At this stage, the good performance of the rolling stock **cannot be correlated** to any operator input.

The input of operators in this category is clearly a factor in the performance of the assets. The advanced age of the rolling stock suggests **considerable maturity** on the part of the operator in terms of **maintenance** and **operations**.

The entities in this category have **difficulties** maintaining their **rolling stock in optimal operating condition**, independently of the fact that their stock is new. As such, the **ageing** of the infrastructure and the rolling stock will have a **considerable impact** on performance.

LINE DENSITY IS A FACTOR IN THE REDUCTION OF TRAVEL TIMES, THE IMPROVEMENT OF THE PASSENGER EXPERIENCE AND THE OPTIMIZATION OF INFRASTRUCTURE

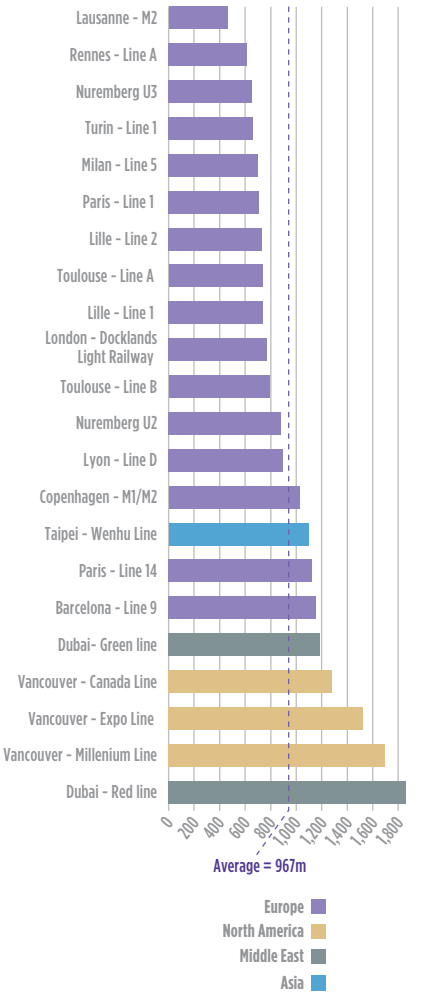
Driverless metro networks are characterized by **short distances** between stations.

European lines are **denser** in this respect than international lines, mainly because European cities have **smaller surface areas** and **users prefer** public transport to walking.

Adding more stations to a network or line involves additional operating constraints (the more stations, the higher the punctuality risk). **The operators of European networks** appear to be **more exposed** to this type of constraint.

Short distances between stations help operators to maintain reasonable travel times between stations at **low speed**. They also limit infrastructure wear and **reduce the resulting maintenance costs**.

Average Distance Between Stations (in m)



COMMERCIAL SPEED, A KEY CHARACTERISTIC IN TRANSPORT SERVICE, IS A CORE PERFORMANCE ASSESSMENT ITEM

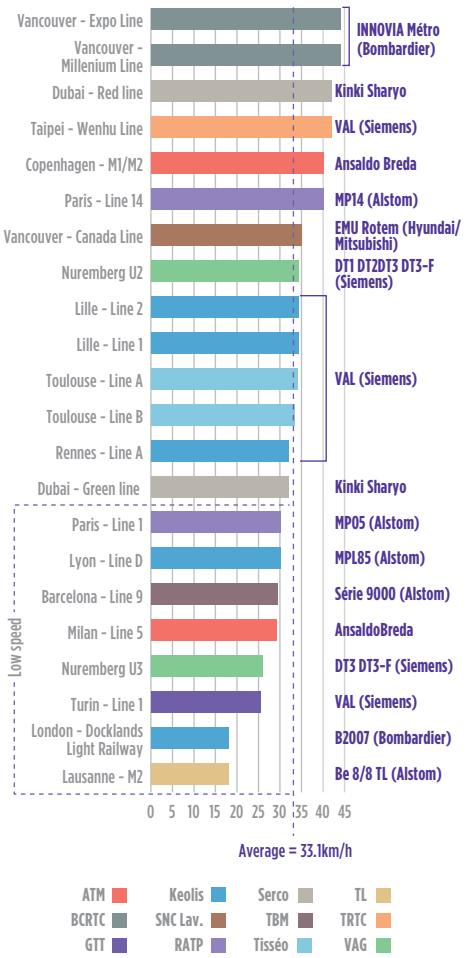
VAL rolling stock is the most represented in the study sample, accounting for **35% of lines**. It is operated at low speeds on some lines (such as Turin) and high speeds on others (Lille and Taipei). In addition, some operators appear to have **experience** with and a preference for a **single type** of rolling stock (Ansaldo Breda for ATM, for example).

End-to-end **line times** depend mainly on **station stop times**. Commercial speed is thus **inversely proportional** to the density of stations on a given line (see previous slide vs. graph opposite).

By optimizing acceleration and braking times, **driverless metro** lines increase the average **commercial speed** of **"dense"** lines.

High commercial speed entails **additional operating constraints**. Operators managing **low-speed lines** only may find it **difficult** to effectively operate **high-speed lines**.

Average Commercial Speed (in km/h)



DRIVERLESS METRO LINES GENERALLY PROVIDE IMPROVED ACCESS FOR PASSENGERS

Low Accessibility	Average Accessibility	High Accessibility
10% of the lines surveyed have limited accessibility: **fewer than** 80% of the stations are equipped for people with reduced mobility	**3% of the lines** analyzed have average accessibility: more than **80% of the stations are equipped** for people with reduced mobility	**87% of the metro lines** analyzed have high accessibility: **more than 90%** of the total number of stations are equipped for passengers with reduced mobility

Station accessibility is generally related to infrastructure and thus to the transport authority's approach to the issue. However, the availability of the implemented solutions results from the performance of operators. Besides the fact that this availability remains difficult to measure, the metro lines analyzed have high accessibility as a whole, resulting from standardized construction compliant with new standards and good rolling stock access (reduced distance between platform and train).

THE CHOICE OF INFRASTRUCTURE ACCESS IS CRUCIAL TO FRAUD RATES. OPEN SYSTEMS* FOSTERING AN ENHANCED CUSTOMER EXPERIENCE LEAD TO POOR RESULTS IN THIS RESPECT

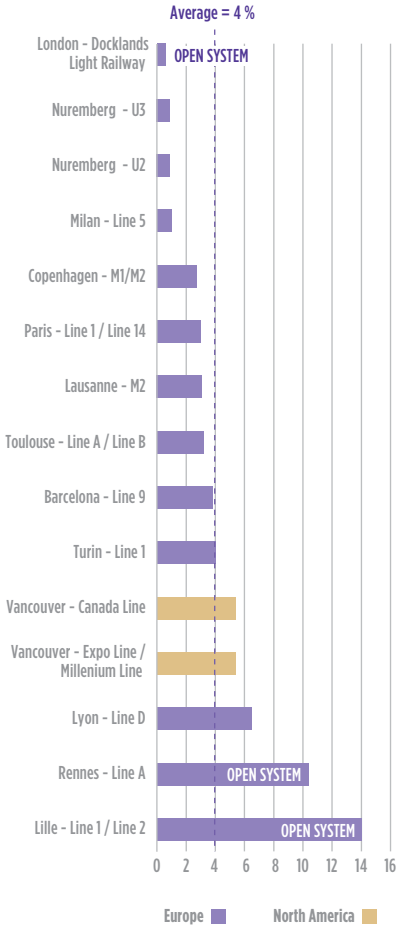
Platform **access gates** are decisive in the fight against fraud.

The two networks **still without these gates** (Lille and Rennes) have fraud rates of over 10%, compared with 7% for networks with gates. However, the DLR line in London remarkably has the lowest fraud rate despite lacking access gates.

The installation of access gates is often a **joint decision** by the operator and the transport authority. Access gates appear to be much **more effective** at **limiting fraud** than an increase in (often random) ticket inspections by the operator.

The **socio-economic characteristics** of the cities and neighborhoods served by the metro line are also **a key factor** in this respect, with the fraud rate varying on the same line from one station to the next. Operators are **powerless** against this variable but it does **negatively impact** their operations over the long term.

Estimated Fraud Rate (in %)



* A system is considered as “open” if access to the metro network is not controlled by gates.

SERVICE RELIABILITY AND QUALITY PERFORMANCE

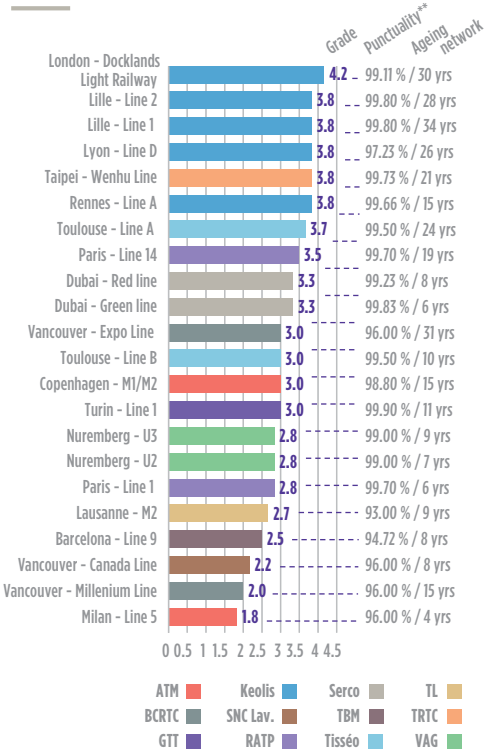
FRENCH DRIVERLESS METRO LINES ARE EXTREMELY RELIABLE, A QUALITY REINFORCED BY EXPERTISE IN THE OPERATION OF AGEING NETWORKS

Reliability and service quality are key factors in driverless metro line operational performance, determining:

- **The passenger experience**
- **The rhythm of the service**

Performance in this area is an operational signature that also creates the relational signature of the network: a memorable mass transit experience or, on the contrary, an unpleasant experience encouraging customers to use other transport modes.

Grades for Reliability and Service Quality Performance* (out of 5)

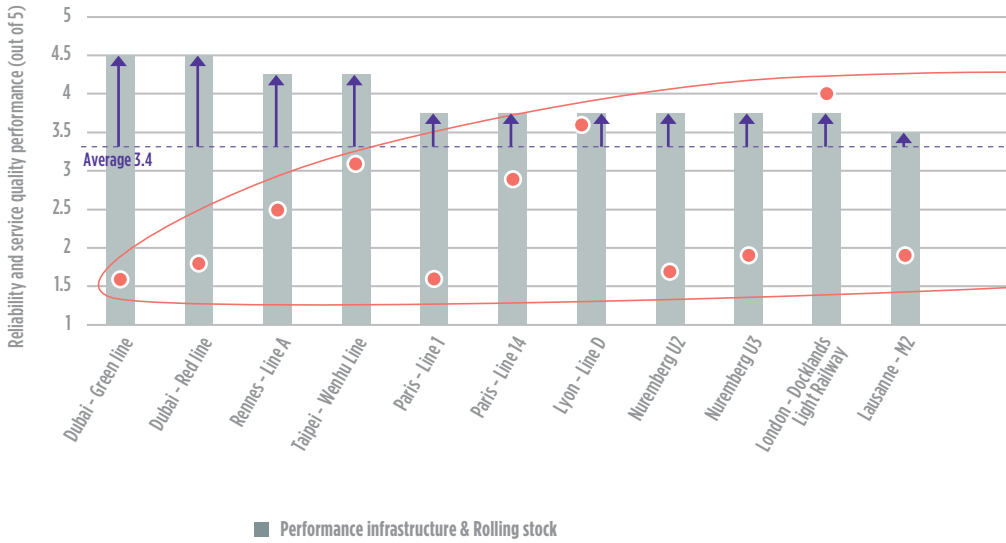


*The sum of the grade attributed to reliability and service quality (weight=1) and the grade attributed to the age of the infrastructure (weight=0.5) (5 corresponds to very old infrastructure).

** According to data availability and/or reliability, the figure may concern punctuality, availability or regularity (see glossary for definitions).

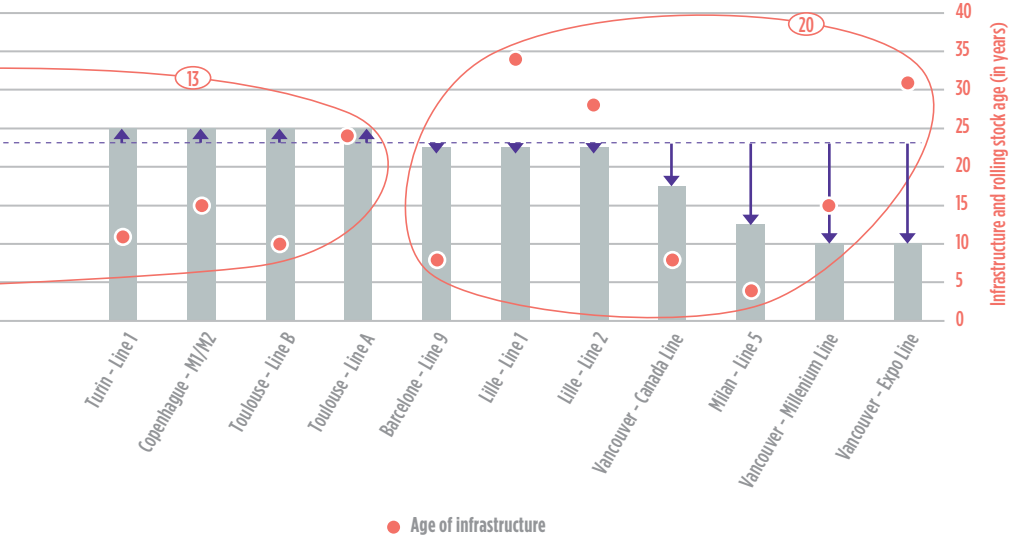

TDK

THE AGE OF THE NETWORK AND ROLLING STOCK HAS A STRONG IMPACT ON OPERATIONAL RELIABILITY



Infrastructure age is **key** to the reliability of service. The **deterioration** of service quality is **correlated** to the ageing of assets (see graph above).

For example, the **ageing** of rolling stock and stations has a **direct impact** on how passengers **perceive cleanliness**.



As it ages, infrastructure becomes less robust and **limits the commercial speed** of the line.

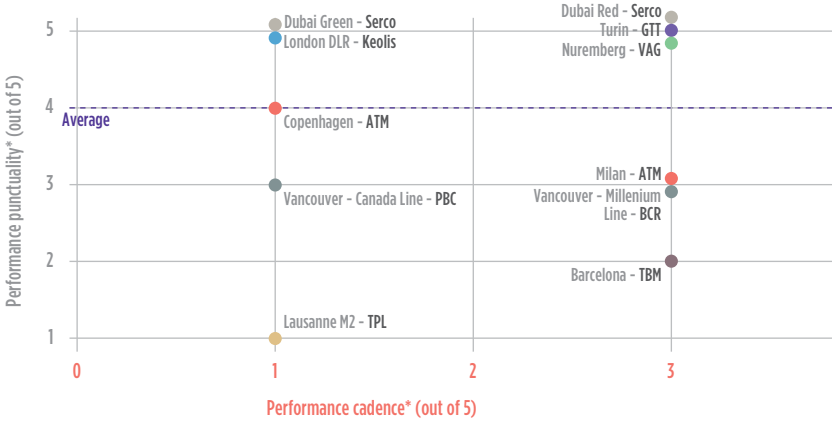
To ensure **short headways**, ageing infrastructure and rolling stock require substantial **experience** on the part of the operator. Failing which, maintenance **costs** rise drastically.

HIGHLY STRONG VARIATIONS IN CUSTOMER AUTHORITY STANDARDS FAVORING THE PERFORMANCE OF CERTAIN LINES AND ERODING THAT OF OTHERS

Punctual operators are able to deliver punctuality performance only when headway requirements are longer. Any pressure to shorten those headways may considerably worsen their performance.

PUNCTUAL

Punctual



Under-performers

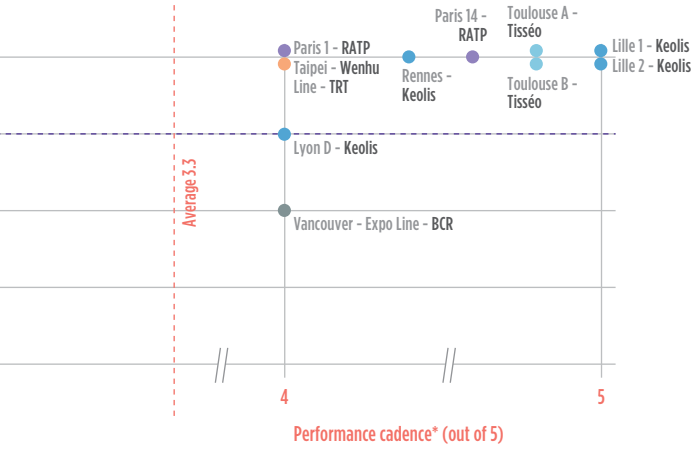
"Under-performers" are unable to ensure decent punctuality, even for long headways. Any transport-authority demands to shorten headways will significantly impact service levels.

UNDER-PERFORMERS

*Assessment method: the assessment is made comparatively between the lines analyzed. The maximum grade of 5 corresponds to the best headway/punctuality identified, the minimum being 1. Distribution within this range of grades is made in a proportional manner.

SUPER-PERFORMERS

European operators, and French operators in particular, lead the way in terms of punctuality performance. Their experience, built on the margins of the high-level requirements of their respective transport authorities, brings them a major advantage over other operators.



Super-performers

Trying to perform

TRYING TO PERFORM

The short headways required by the transport authority appear to put the operators in the "trying to perform" category under pressure. BCRTC is currently struggling to deliver punctuality for short headways.

While headways are generally the responsibility of transport authorities, their respect as part of a punctual service shows the ability of some operators to deliver high-level service under strong constraints. This is the case with the "Punctual" and "Super-performing" categories.

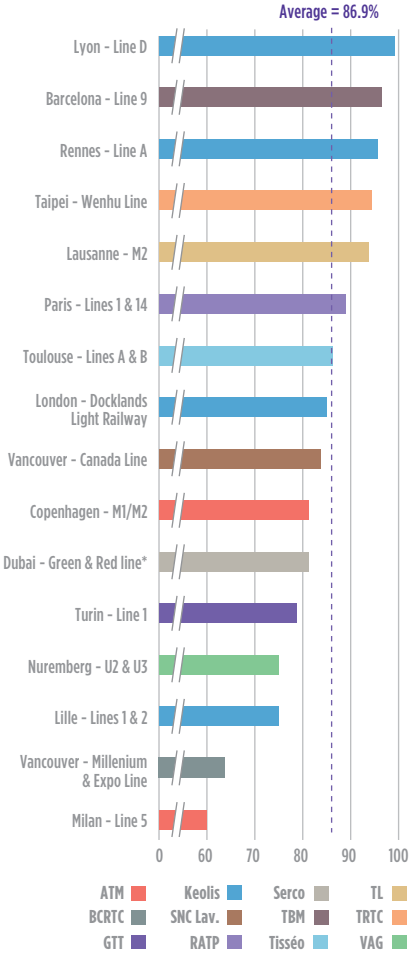
ALTHOUGH DIFFICULT TO ANALYZE OWING TO ITS SUBJECTIVE NATURE, SATISFACTION WITH CLEANLINESS PLAYS A CRUCIAL ROLE IN THE EXPERIENCE OF PASSENGERS

The **satisfaction rate** of users relative to the cleanliness of the network and rolling stock **varies**. It is **closely linked** to the (often subjective) **perception of users**.

While the satisfaction rate used in this study corresponds to people having reported a **positive opinion**, the comparison cannot be exact. This is because customer surveys are not the same for all the lines, which can **bias comparisons** to a **certain extent**.

Ageing infrastructure and rolling stock can play an **important role** in the perception of users. But the performance of operators on cleanliness remains decisive, as shown by the mediocre satisfaction ratings of certain lines (including Turin and Milan).

Cleanliness Satisfaction Rate
(positive opinion in %)



*Satisfaction rate estimated via observations and comparisons between metro lines.

THE SAFETY OF A METRO LINE REFLECTS USER PERCEPTIONS OF THE NETWORK AND THE SOCIO-ECONOMIC SITUATION OF THE URBAN AREAS SERVED

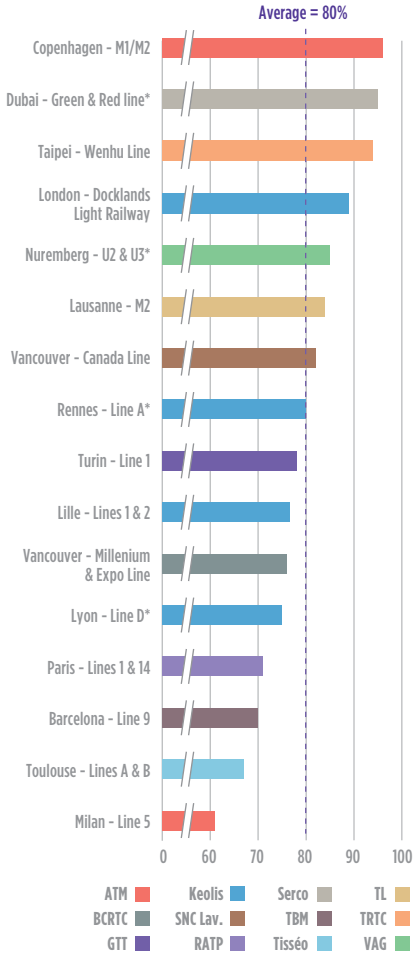
The **safety of a metro line** depends **directly** on the surrounding environment. The safety performance of a metro line is directly related to that of the **city in question**, and more specifically the **different areas of that city**.

Lines in cities such as Dubai, Copenhagen and Taipei benefit from the high levels of **safety** existing **outside the metro in the city itself**.

Safety quality is often judged by users in terms of the **entire network**. The grades of metro lines such as lines 1 and 14 in Paris, reputed to be the city's safest, are lowered by the **poor perception of the network as a whole**.

Some lines serving areas far from the center with **sensitive socio-economic situations** appear to be **more exposed** to a drop in the overall safety level and, hence, a drop in user satisfaction (for example, Toulouse, Lyon and Lille).

Safety Satisfaction Rate
(positive opinion in %)



*Satisfaction rate estimated via observations and comparisons between metro lines.

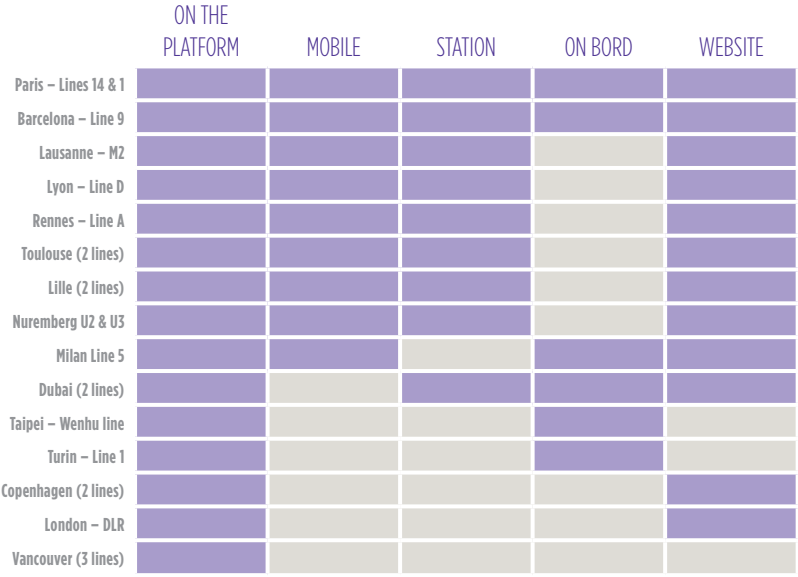
CHANNELS FOR SHARING INFORMATION (ON TRAVEL TIMES AND TRAFFIC) IN REAL TIME ARE WIDESPREAD, SERVING TO ENSURE THE QUALITY OF THE PASSENGER EXPERIENCE

All the networks studied **shared** passenger information **on platforms**. This remains a **preferred dissemination channel** for operators.

However, operators are seeking to extend traffic information to other places, including station interiors and even **throughout the passenger experience**.

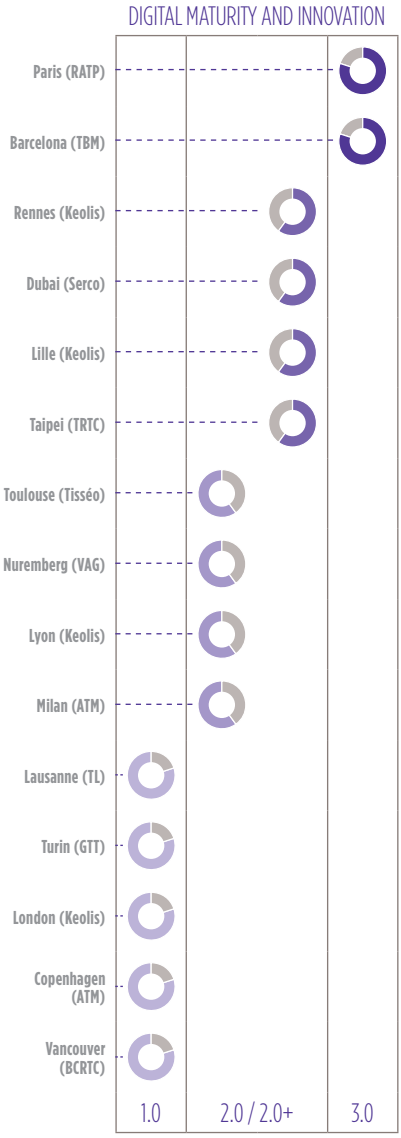
It is important for operators to **multiply** passenger information media as these last are vital to a **successful passenger experience**.

To that end, **open data** are an ideal way of transmitting information (e.g. social media, airport displays, chatbots, etc.). Some operators are working on this issue (see following slide).



Traffic information is a pillar of the passenger experience in urban environments. Providing this information in real time and ensuring its reliability are both key to gaining the loyalty of customers through an augmented transport experience. In addition, opening metro lines up to competition and the arrival of new transport modes will require operators to differentiate. Providing multi-channel passenger information in real time is a way of doing just that.

THE DIGITAL TRANSFORMATION AND INNOVATION ARE CENTRAL TO THE GROUP STRATEGY OF SOME OPERATORS



The driverless metro line benchmark identifies **five trends** in innovation:

- The reliability and sharing of **passenger information** and traffic news. This data is decisive to the passenger experience.
- Bringing passengers a **mobile app** with increasingly **extensive** functionalities and using it as a sales channel.
- The implementation of a **reliable connection** network (with a clear shift to 4G rather than WiFi given the interest shown by telecom operators in this area) covering **all stations and the entire journey**. Most of the time spent by the passenger being on the train.
- **Open data**, bringing operators a unique opportunity to boost innovation by opening systems up to the outside world.
- **Big data** for "transport as a service" (TAAS). Operators that know more about their customers can bring these last a **new**, multimodal and personalized **passenger experience**. Analysis of passenger flows in stations can be used to more finely adjust supply to demand.

A DETAILED BENCHMARK OF THE DRIVERLESS METRO LINES UNDER REVIEW

BARCELONA: LINE 9

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (29km/h) and long distances between stations (>1,000m) • Long headways, with 3-min intervals at rush hour • Accessibility: good for PWRM (>80% of stops accessible) • Fraud rate: <4%	3.4
2	Service reliability and quality	• Regularity: 94.72% (this is the contractual objective) • Cleanliness: 9.9 / 10 satisfaction rate for trains and stations • Passenger information: information in real time disseminated in stations, scheduled times and traffic info on mobile app, on board and the TMB website	3.25
3	Auxiliary and innovative services	• Route planner app with real-time information (TMB app) • 4G coverage for entire line 9 • The operator, TMB, has rolled out an open-data platform with 6 interfaces. In this respect it remains less mature than operators such as RATP and Keolis • TMB already uses big data to model passenger flows in stations and adapts line operation in consequence and in a predictive manner • In 2015 TMB introduced NFC and mobile payments for the entire urban network	

KEY POINTS

- Line 9 is the first driverless line in Spain. It comprises 2 sections (L9 North and L9 South). Once these two sections have been joined up, it will be the longest driverless metro line in Europe.

*Raw grades out of 5, not weighted for age of network.

Age of network	8 years

City, Country	Barcelona, Spain
Line	Line 9
Wheel type	Steel
Degree of automation	GoA4
Operator	Transports Metropolitans de Barcelona
Transport authority	Metropolitan Transport Authority
Passengers per hour and per direction (PPHPD)	38,500
Signaling	TrainGuard MT CBTC - Airlink
Network length in km	30
Number of stations in operation	24
Date commissioned	2009
Passengers per car	895 (passengers per train)
Manufacturer / model	Alstom Série 9000
Average commercial speed	29km/h

*Age of network in number of years of driverless line operation.

COPENHAGEN: LINES 1 AND 2

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (40km/h) and average distances between stations (>1,000m) • Average headways, with 2-min intervals at best at rush hour • Accessibility: good for PWRM (>80% of stops) • Fraud rate: 2.7%	3.8
2	Service reliability and quality	• Respect of departure numbers: 98.7% • Cleanliness: more than 80% of users say they are satisfied or very satisfied with the cleanliness of the stations and trains • Passenger information: real-time information on platforms and planned hours on the Metro Services website (80% of people say they are satisfied or very satisfied with information updates) • Passenger safety: more than 95% of users say they feel safe	3.5
3	Auxiliary and innovative services	• 3G available on entire metro line, including the 22 stations • The Copenhagen network doesn't have a dedicated mobile app	

KEY POINTS

- The operator, Metro Service, is a joint venture between ATM and Ansaldo STS.
- The manufacturer is thus likely to provide ATM with strong support in rolling stock maintenance. The current operating and maintenance contract terminates on December 31, 2018 and the new contract covers the 2019-2024 period.
- The Copenhagen metro won the "World's Best Driverless Metro" award in 2008, 2009 and 2010.
- The Copenhagen metro runs 24-7.

*Raw grades out of 5, not weighted for age of network.

Age of network*	15 years	
City, Country	Copenhagen, Danemark	
Line	M 1	M 2
Wheel type	Steel	
Degree of automation	GoA4	
Operator	Metro Service	
Transport authority	Movia	
Passengers per hour and per direction (PPHPD)	12,000	
Signaling	Ansaldo STS driverless solution - CBTC	
Network length in km	21.5	
Number of stations in operation	22	
Date commissioned	2002	
Passengers per car	200 - 34 trains, 3 cars per train	
Manufacturer / model	Ansado Breda	
Average commercial speed	40km/h	

*Age of network in number of years of driverless line operation.

DUBAI: LINE RED

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (42km/h) but long distances between stations (>1,800m) • Long headways, with 3-min intervals at rush hour • Accessibility: 100% for PWRM • Fraud rate: unknown • Free park-and-ride at three stations	3.6
2	Service reliability and quality	• Strong punctuality (>99%) • RTA does not disclose passenger satisfaction levels regarding cleanliness, but numerous opinions point to high levels of cleanliness • Passenger information: real-time information disseminated in stations, on platforms, on board; scheduled times on the RTA website	4.5
3	Auxiliary and innovative services	• Network fully covered by mobile phone network • WiFi access across entire network • NFC payments by mobile phone available since 2013 • The Dubai metro stands out through its high levels of in-train connectivity: Very high quality WiFi and 4G connectivity end-to-end	

KEY POINTS

- Serco has obtained the renewal of the operating and maintenance contract (terminating in 2019) for two additional years
- In addition to offering a more competitive offer, SERCO has committed to making a skills transfer, in particular by recruiting more nationals in operations, maintenance and supervision

*Raw grades out of 5, not weighted for age of network.

Age of network*	8 years

City, Country	Dubai, UAE
Line	Red Line
Wheel type	Steel
Degree of automation	GoA4
Operator	Serco
Transport authority	RTA
Passengers per hour and per direction (PPHPD)	26,000
Signaling	SelTrac CBTC - UTO
Network length in km	52.1
Number of stations in operation	29
Date commissioned	2009
Passengers per car	110 - 62 five-car trains (550 pass cap)
Manufacturer / model	Kinki Sharyo
Average commercial speed	42km/h

*Age of network in number of years of driverless line operation.

DUBAI: LINE GREEN

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (32km/h) and long distances between stations (>1,100m) • Very long headways, with 6-min intervals at rush hour • Accessibility: 100% for PWRM • Fraud rate: unknown, estimated on the basis of observations	3.4
2	Service reliability and quality	• Strong punctuality (>99%) • RTA does not disclose passenger satisfaction levels regarding cleanliness, but numerous opinions point to high levels of cleanliness • Passenger information: real-time information disseminated in stations, on platforms, on board; scheduled times on the RTA website	4.5
3	Auxiliary and innovative services	• Network fully covered by mobile phone network • WiFi access across entire network • NFC payments by mobile phone available since 2013 • The Dubai metro stands out through its high levels of in-train connectivity: Very high quality WiFi and 4G connectivity end-to-end	

KEY POINTS

- Serco has obtained the renewal of the operating and maintenance contract (terminating in 2019) for two additional years.
- In addition to offering a more competitive offer, SERCO has committed to making a skills transfer, in particular by recruiting more nationals in operations, maintenance and supervision.

*Raw grades out of 5, not weighted for age of network.

Age of network*	6 years
City, Country	Dubai, UAE
Line	Green Line
Wheel type	Steel
Degree of automation	GoA4
Operator	Serco
Transport authority	RTA
Passengers per hour and per direction (PPHPD)	26,000
Signaling	SelTrac CBTC - UTO
Network length in km	22.5
Number of stations in operation	20
Date commissioned	2011
Passengers per car	110 - 25 five-car trains (550 pass cap)
Manufacturer / model	Kinki Sharyo
Average commercial speed	32km/h

*Age of network in number of years of driverless line operation.

LAUSANNE: LINE M2

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Low commercial speed (18km/h) – major gradients with an incline as steep at 12% – but short average distance between stations (<500m) • Average headways, with 2.5-min intervals at rush hour • Accessibility: high for PWRM • Fraud rate: ~ 3% • One park-and-ride facility	3.4
2	Service reliability and quality	• The operator has no quantified data on punctuality but does disclose a user satisfaction rate, of 93/100 • Cleanliness: user satisfaction rate of 95/100 • Passenger information: real-time information in stations, on platforms, via mobile apps, and scheduled times/traffic info on the TL website (satisfaction rate with information: 94%) • Passenger safety: satisfaction rate of 84%	3.5
3	Auxiliary and innovative services	• Route planner app with real-time information (TL Live app) • TL has chosen SMS payments rather than NFC technology	

KEY POINTS

- Line M2 is the first and only driverless metro line in Switzerland, opened in 2008. In 2012 Métro Lausanne-Ouchy SA, concession-holder and long-standing operator, was struck off the Commercial Register and its assets taken over by Transports Publics Lausannois. This change in operator was made following congestion problems resulting from an under-estimation of user numbers in preparatory studies.
- A project has been initiated to increase capacity by upgrading the line's automatic systems.

*Raw grades out of 5, not weighted for age of network.

Age of network*	9 years

City, Country	Lausanne, Switzerland
Line	M2
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	Transports publics lausannois
Transport authority	-
Passengers per hour and per direction (PPHPD)	5,600
Signaling	Urbalis 300 CBTC
Network length in km	6
Number of stations in operation	14
Date commissioned	2008
Passengers per car	222 - 15 x 2-car trains
Manufacturer / model	Alstom
Average commercial speed	18km/h

*Age of network in number of years of driverless line operation.

LILLE: LINES 1 AND 2

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (35km/h) given the age of the rolling stock. Short average distance between stations (750m) • The shortest rush-hour headways in the world: ~ 66 seconds • High fraud rate (~14%) owing to open network. This is expected to fall with the installation of access gates throughout the network, to be completed by 2020. • Accessibility: 100% for PWRM	3.8
2	Service reliability and quality	• Availability: 99.8% / Respect of journey time: 99% • Cleanliness: satisfaction rate of 78% for stops and 82% for trains • Passenger information: real-time information in stations, on platforms, via mobile apps, and scheduled times/traffic info on the Transpole website. Satisfaction rate of 86% for availability of information and 66% for information on line disruptions • Passenger services: stores, Internet connection to public services • Passenger safety: satisfaction rate of 73% for stops and 80% for trains	3.25
3	Auxiliary and innovative services	• Route planner app with real-time information (Transpole app) • Launch of Moodi, an app designed to generate real-time mapping of the "emotional climate" of passengers (passengers can express how they feel and report on incivility or violence) • 3G/4G will be available in 2018 throughout both lines • The operator favors NFC technology, providing customers with an app that can recharge travel passes via mobile phone. This is a further step towards 100% electronic travel • Passengers have access to a "PlanBookTicket" app as part of a multi-modal transport approach	

KEY POINTS

- Lille was the world's first urban driverless metro line, commissioned in 1983.
- Transpole has received excellent feedback on its rolling stock, this last serving to optimize maintenance processes.
- Maintenance costs are falling steadily, while the Mean Kilometer Between Failure (MKBF) rate has risen constantly in the last few years (currently at 5,600km).

*Raw grades out of 5, not weighted for age of network.

Age of network*	Line 1: 34 years Line 2: 28 years	
City, Country	Lille, France	
Line	Line 1	Line 2
Wheel type	Pneumatic	
Degree of automation	GoA4	
Operator	Transpole	
Transport authority	Métropole Européenne Lilloise	
Passengers per hour and per direction (PPHPD)	11,000	
Signaling	TrainGuard MT	
Network length in km	12.6	31.5
Number of stations in operation	18	44
Date commissioned	1983	1989
Passengers per car	156	
Manufacturer / model	Alstom/Siemens - VAL 208 / VAL 206	
Average commercial speed	34km/h	

*Age of network in number of years of driverless line operation.

LONDON: DOCKLANDS LIGHT RAILWAY

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Short average distance between stations (750m) • Long headways, with 5-min intervals at rush hour • Accessibility: good for PWRM (>80% of stops) • Fraud rate: 0.6%, down sharply since Keolis Amey took over the franchise	3.2
2	Service reliability and quality	• Punctuality: 99.11% • Cleanliness: the composite cleanliness indicator is 88/100 • Passenger information: real-time information on platforms, and scheduled times/traffic info on the TFL website • Passenger safety: 89%	3.75
3	Auxiliary and innovative services	• Monthly reporting available on the performance of the network, disseminated by TFL • Traffic information and travel times available in real time via the TFL transport authority	

KEY POINTS

- The concession was recently taken over (2014) by the Amey group and the French urban transport player Keolis. Consequently, the performance indicators for the line could soon change in the future.

*Raw grades out of 5, not weighted for age of network.

Age of network*	30 years

City, Country	London, UK
Line	Docklands Light Railway
Wheel type	Steel
Degree of automation	GoA3
Operator	KeolisAmey Docklands
Transport authority	Transport for London
Passengers per hour and per direction (PPHPD)	6,000
Signaling	SelTrac CBTC (Thales)
Network length in km	34
Number of stations in operation	45
Date commissioned	1987
Passengers per car	284
Manufacturer / model	Bombardier
Average commercial speed	18km/h

*Age of network in number of years of driverless line operation.

LYON: LINE D

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (30km/h) and relatively short average distance between stations (890m) • Average headways, with 2-min intervals at rush hour • High accessibility rate for PWRM (superior to contractual objectives) • Fraud rate: ~6.5% (closed network)	3.6
2	Service reliability and quality	• Regularity: 97.23% (superior to contractual objective) • Cleanliness: Metro stations: 99.54% / Metro cars: 99.20% (superior to contractual objective) • Passenger information: information in real time and disruptions communicated in stations, on platforms, and on mobile phones; scheduled times and traffic info on the Sytral website (Metro stations: 99.54% / Metro cars: 99.20% (superior to contractual objective) • Passenger safety: estimated at 75%	3.75
3	Services auxiliaires et innovants	• Route planner app with real-time information (TCL app) • Implementation of WiFi by end-2017 in stations (but not on entire line) • More than 15 APIs available via the Greater Lyon open-data platform	

KEY POINTS

- Line D was the world's first driverless driverless metro line with train intervals managed by a CBTC system. The operator is planning to increase rush-hour capacity by 15% by 2020 (to this end, in 2015 Sytral and Keolis Lyon tested the operation of a train with 4 cars as opposed to the current 2).
- The principle of full automation for metro line B in 2019 has been accepted by Sytral.

*Raw grades out of 5, not weighted for age of network.

Age of network*	26 years

City, Country	Lyon, France
Line	Line D
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	Keolis Lyon
Transport authority	SYSTRAL
Passengers per hour and per direction (PPHPD)	15,000
Signaling	TrainGuard MT CBTC
Network length in km	12.5
Number of stations in operation	15
Date commissioned	1991
Passengers per car	291
Manufacturer / model	Alstom MPL 85
Average commercial speed	30km/h

*Age of network in number of years of driverless line operation.

MILAN: LINE 5

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Modest commercial speed (30km/h) but short distances between stations (>1,000m) • Relatively long headways, with 3-min intervals at rush hour • Accessibility: good for PWRM (>80% of stops) • Low fraud rate (~1%) due to ticket access gates at network entrances and exits	4
2	Service reliability and quality	• Strong punctuality (>99%) • No contractual commitment to cleanliness in delegation contract. Cleanliness levels are measured by a satisfaction survey that must respect a minimum threshold. The latest known and available rates are particularly low. • Passenger information: real-time information on platforms, in-train, via mobile apps, and scheduled times/traffic info on the ATM website. • Passenger safety: 61% for latest known and available rates	2.25
3	Auxiliary and innovative services	• Route planner app with real-time information (ATM app) • 3G is available on all the metro lines • Electronic travel pass via mobile app (non-NFC)	

KEY POINTS

- Line 5 is subject to a concession contract between the City of Milan and the Metro 5 SpA company, whereby the City concedes the financing, design, production and operation/maintenance to Metro 5 SpA. For the account of Metro 5 SpA, ATM operates and maintains Line 5 via a gross-cost contract applying for the entire duration of the concession through end-2040.
- ATM is responsible for all regular maintenance of rolling stock (Ansaldo's activity is limited to exceptional work as provided for in the warranty).

*Raw grades out of 5, not weighted for age of network.

Age of network*	4 years
City, Country	Milan, Italy
Line	Line 5
Wheel type	Steel
Degree of automation	GoA4
Operator	Azienda Transporti Milanesi
Transport authority	Azienda Transporti Milanesi
Passengers per hour and per direction (PPHPD)	10,700
Signaling	Ansaldo STS driverless solution - CBTC
Network length in km	12.6
Number of stations in operation	19
Date commissioned	2013
Passengers per car	134 - 21 trains, 4 cars per train (536 passengers per train)
Manufacturer / model	Hitachi Rail Italy (formerly Ansado Breda) / Driverless Metro
Average commercial speed	30km/h

*Age of network in number of years of driverless line operation.

NUREMBERG: LINE U2

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (34.4km/h) and relatively short average distance between stations (880m) • Relatively long rush-hour headways: ~3-min • Very low fraud rate of 0.9% (ranking in the top three networks in this study) • Accessibility: 100% for PWRM	4
2	Service reliability and quality	• High punctuality rate of 99% • Cleanliness: satisfaction rate of 80% for stations and rolling stock • Passenger information: widely available. VAG even provides an interface providing the real-time geolocation of the trains • Passenger safety: passengers are generally satisfied with the safety level of the Nuremberg network, though there are some incidents	3.75
3	Auxiliary and innovative services	• Route planner app with real-time information • VAG is working with T-System on a big data project to analyze passenger flows across the entire transport network • WiFi is available in stations and on trains	

KEY POINTS

- Line U2 has high-level punctuality and a very low fraud rate, characteristic of German networks.

*Raw grades out of 5, not weighted for age of network.

Age of network*	7 years

City, Country	Nuremberg, Germany
Line	Line U2
Wheel type	Steel
Degree of automation	GoA4
Operator	VGN / VAG
Transport authority	Nuremberg Public Transport
Passengers per hour and per direction (PPHPD)	12,800
Signaling	TrainGuard MT
Network length in km	13.2
Number of stations in operation	16
Date commissioned	2010
Passengers per car	128
Manufacturer / model	Siemens Munich A
Average commercial speed	34.4km/h

*Age of network in number of years of driverless line operation.

NUREMBERG: LINE U3

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Low commercial speed (26km/h) and relatively short average distance between stations (650m) • Relatively long rush-hour headways: ~3-min • Very low fraud rate of 0.9% (ranking in the top three networks in this study) • Accessibility: 100% for PWRM	3.8
2	Service reliability and quality	• High punctuality rate of 99% • Cleanliness: satisfaction rate of 80% for stations and rolling stock • Passenger information: widely available. VAG even provides an interface providing the real-time geolocation of the trains • Passenger safety: passengers are generally satisfied with the safety level of the Nuremberg network, though there are some incidents	3.75
3	Auxiliary and innovative services	• Route planner app with real-time information • VAG is working with T-System on a big data project to analyze passenger flows across the entire transport network • WiFi is available in stations and on trains	

KEY POINTS

- Line U3 has high-level punctuality and a very low fraud rate, characteristic of German networks.

*Raw grades out of 5, not weighted for age of network.

Age of network*	9 years

City, Country	Nuremberg, Germany
Line	Line U3
Wheel type	Steel
Degree of automation	GoA4
Operator	VGN / VAG
Transport authority	Nuremberg Transport Public
Passengers per hour and per direction (PPHPD)	12,800
Signaling	TrainGuard MT
Network length in km	6.5
Number of stations in operation	11
Date commissioned	2008
Passengers per car	128
Manufacturer / model	Siemens Munich A
Average commercial speed	26km/h

*Age of network in number of years of driverless line operation.

PARIS: LINE 1

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (30km/h) and short distance between stations (660m) • Short maximum headways, with 2-min intervals at rush hour • Accessibility: low for PWRM (<70% of stops) • Fraud rate: 3% for entire network (closed network)	3.4
2	Service reliability and quality	• Availability: >100% (% of real number of metro trains in circulation in rush hour relative to service ordered) • RATP does not disclose information on passenger satisfaction concerning cleanliness but STIF reports that 89.6% of the stations comply with the reference service level • Passenger information: real-time information in stations, on platforms, in-train, via mobile apps, and scheduled times/traffic info on the RATP website	3.75
3	Auxiliary and innovative services	• Route planner app with real-time information (RATP app) • Most of the stations on Line 1 have 3G and 4G coverage • An API console with more than 20 interfaces • Big data and IoT are strategic topics for RATP and central to the group's overall strategy • RATP is carrying out tests on the simulation and projection of passenger flows in stations, using big data	

KEY POINTS

- Line 1 was one of the world's first metro lines to be automated, in 2011.
- Line 1 demonstrated its adaptability in summer 2015, absorbing the increase in passengers when the RER A line was shut down for work. To achieve headways of 100 seconds, Line 1 benefited from the temporary use of 4 shuttles intended for use on Line 14.

*Raw grades out of 5, not weighted for age of network.

Age of network*	6 years
City, Country	Paris, France
Line	Line 1
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	RATP
Transport authority	STIF
Passengers per hour and per direction (PPHPD)	25,000
Signaling	TrainGuard MT CBTC
Network length in km	16.5
Number of stations in operation	25
Date commissioned	2011
Passengers per car	120 (6 cars per train)
Manufacturer / model	Alstom
Average commercial speed	30km/h

*Age of network in number of years of driverless line operation.

PARIS: LINE 14

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (40km/h) and average distance between stations (1,000m) • Short maximum headways, with 85-sec intervals at rush hour • Accessibility: good for PWRM (>80% of stops) • Fraud rate: 3% for entire network (closed network)	4.4
2	Service reliability and quality	• Availability: >100% (% of real number of metro trains in circulation at rush hour relative to the service ordered) • RATP does not disclose information on passenger satisfaction concerning cleanliness but STIF reports that 89.6% of the stations comply with the reference service level • Passenger information: real-time information in stations, on platforms, in-train, via mobile apps, and scheduled times/traffic info on the RATP website	3.75
3	Auxiliary and innovative services	• Route planner app with real-time information (RATP app) • Most of the stations on Line 1 have 3G and 4G coverage • An API console with more than 20 interfaces • Big data and IoT are strategic topics for RATP and central to the group's overall strategy • RATP is carrying out tests on the simulation and projection of passenger flows in stations, using big data	

KEY POINTS

- The first large-size 100% driverless line in the world when it went into service, Line 14 is to be extended to link up the center of the capital with the Saint-Denis Pleyel business hub to the north and Orly airport to the south.
- These extensions will be made while maintaining the current characteristics of the line, with a speed of over 40km/h.

*Raw grades out of 5, not weighted for age of network.

Age of network*	19 years
City, Country	Paris, France
Line	Line 14
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	RATP
Transport authority	STIF
Passengers per hour and per direction (PPHPD)	25,000
Signaling	TrainGuard MT CBTC
Network length in km	9.2
Number of stations in operation	9
Date commissioned	1998
Passengers per car	720 (passengers per train)
Manufacturer / model	Alstom
Average commercial speed	40km/h

*Age of network in number of years of driverless line operation.

RENNES: LINE A

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (32km/h) and short distance between stations (610m) • Short headways, with 100 sec intervals at rush hour • Accessibility: 100% for PWRM • High fraud rate (~10.4%) due to open network, to be closed in 2019/2020	4
2	Service reliability and quality	• Punctuality: 99.66%, system availability rate: 99.72% • Cleanliness: satisfaction rate of 94.4/100 • Passenger information: real-time information in stations, on platforms, via mobile apps, and scheduled times/traffic info on the Star website. Satisfaction rate of 95/100 relative to the condition and the availability of information • Passenger safety: estimated at 80%	4.25
3	Services auxiliaires et innovants	• The 4G system of mobile telephony operators will be available from June 2017 on the entire Line A • A customer mobility solution (mobile app) is available. It brings users a route planning resource and real-time traffic information • In collaboration with OpenDataSoft, Keolis provides a comprehensive open-date platform with over 30 APIs for third-party developers	

KEY POINTS

- The construction of a second driverless metro line (using the CityVal variant of Neoval) is under way, with service planned to begin in 2020.
- The current delegation contract expires at end-2017 and will need to be reviewed before the inception of the second metro line, which will significantly change the Rennes transport offering.

*Raw grades out of 5, not weighted for age of network.

Age of network*	15 years

City, Country	Rennes, France
Line	Line A
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	Keolis Rennes
Transport authority	Rennes Métropole
Passengers per hour and per direction (PPHPD)	6,000
Signaling	TrainGuard MT CBTC (Siemens)
Network length in km	8.56
Number of stations in operation	15
Date commissioned	2002
Passengers per car	156
Manufacturer / model	Siemens
Average commercial speed	32km/h

*Age of network in number of years of driverless line operation.

TAIPEI: WENHU LINE (BROWN LINE)

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (42km/h) and long distances between stations (>1.100m) • Maximum headway of 2-min at rush hour • High level of accessibility for PWRM • Fraud rate: unknown	4.2
2	Service reliability and quality	• Punctuality: 99.73% • Cleanliness: satisfaction rate of over 95/100 • Passenger information: real-time information on platforms and in trains, and 24-7 customer hotline	4.25
3	Auxiliary and innovative services	• WiFi accessible in all stations • NFC contactless technology was rolled out across the network starting in 2012 • The Taipei metro has an open-data platform but does not communicate real-time data. The interface is mainly used to share monthly statistics • MRT provides a mobile app with offline information, with no route-planner function	

KEY POINTS

- The Taipei metro is considered by several local press sources to rank among the top 4 most efficient networks in the world (with Hong Kong, Seoul and Singapore). This is a result of top-level punctuality, very good condition infrastructure and high-level cleanliness.

*Raw grades out of 5, not weighted for age of network.

Age of network*	21 years

City, Country	Taipei, Taiwan
Line	Wenhu line
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	Taipei Rapid Transit
Transport authority	-
Passengers per hour and per direction (PPHPD)	28,400
Signaling	Bombardier CityFlo
Network length in km	25.2
Number of stations in operation	24
Date commissioned	1996
Passengers per car	114
Manufacturer / model	Alstom-Bombardier / VAL
Average commercial speed	42km/h

*Age of network in number of years of driverless line operation.

TOULOUSE: LINES A AND B

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Average commercial speed (33km/h) but relatively short distance between stations (740m) • Short headways, with 80 sec intervals at rush hour • Low fraud rate of ~3.2% (closed network) • Accessibility: good for PWRM (over 80% of stops accessible)	**4.4** Line A **4.2** Line B
2	Service reliability and quality	• The operator does not share quantified data on punctuality, cleanliness or passenger information • But these indicators are compliant with the quality commitment established with AFNOR, which has awarded Tisséo with NF Service certification • Passenger information: real-time information in stations, and scheduled times/traffic info on the Tisséo website • Passenger safety: Estimated at 67%	**3.5**
3	Services auxiliaires et innovants	• Route planner app with real-time information (Tisséo app) • The 4G system of mobile telephony operators will be available from October 2017 throughout lines A and B • An open-data platform is available. But the number of APIs remains low (10 interfaces)	

KEY POINTS

- The line is operated by Tisséo-Réseau Urbain, a public undertaking of an industrial and commercial nature (EPIC).
- Given the demographic and economic growth of the Toulouse agglomeration and its mobility needs, the plan is to double the capacity of line A between now and 2019.

*Raw grades out of 5, not weighted for age of network.

Age of network*	Line A: 24 years Line B: 10 years	
City, Country	Toulouse, France	
Line	Line A	Line B
Wheel type	Pneumatic	
Degree of automation	GoA4	
Operator	Tisséo	
Transport authority	Tisséo-EPIC	
Passengers per hour and per direction (PPHPD)	7,000	
Signaling	TrainGuard MT CBTC	
Network length in km	12.5	15
Number of stations in operation	18	20
Date commissioned	1993	2007
Passengers per car	200	
Manufacturer / model	Siemens (VAL 206 and VAL 208)	
Average commercial speed	34km/h	33km/h

*Age of network in number of years of driverless line operation.

TURIN: LINE 1

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• Low commercial speed (25.5km/h) but relatively short distance between stations (660m on average) • Long average headways, with 3-min intervals at rush hour • Very high level of accessibility for PWRM • Fraud rate of 4%, moderately high for a closed network	3.8
2	Service reliability and quality	• Service availability is very high, close to 99.9% • Passenger information: available on platforms and in-train	3.5
3	Auxiliary and innovative services	• A mobile app is available. It has route-planner functions but no real-time traffic information	

KEY POINTS

- The Turin metro network is recent and the infrastructure is new and well maintained. This explains in part the reliability of the service and the strong satisfaction of customers regarding cleanliness.
- The fraud rate is considered as moderately high for a closed network. This rate does not fall within the average in Italy, which appears to vary between 1% and 3%.

*Raw grades out of 5, not weighted for age of network.

Age of network*	11 years
City, Country	Turin, Italy
Line	1
Wheel type	Pneumatic
Degree of automation	GoA4
Operator	Gruppo Trasporti Torinesi
Transport authority	-
Passengers per hour and per direction (PPHPD)	23,000
Signaling	TrainGuard MT CBTC
Network length in km	13.2
Number of stations in operation	21
Date commissioned	2006
Passengers per car	200
Manufacturer / model	Siemens / VAL 208
Average commercial speed	25.5km/h

*Age of network in number of years of driverless line operation.

VANCOUVER: CANADA LINE

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (35km/h) but long average distance between stations (1,300m) • Long headways, with 6-min intervals at rush hour • Accessibility: good for PWRM (>80% of stops) • Fraud rate: 5.4%	3.2
2	Service reliability and quality	• The operator does not disclose figures on punctuality, but this last is judged as satisfactory or very satisfactory by 92% of passengers • Cleanliness: 87% of passengers give a good to excellent rating of cleanliness in trains and in stations • Passenger information: real-time information disseminated on platforms; scheduled times on the Translink website • Passenger safety: 82% of passengers give a good to excellent rating of on-board safety	2.75
3	Auxiliary and innovative services	• No dedicated app, but a route planner developed for mobiles	

KEY POINTS

- The Canada Line was built as part of a public-private partnership. SNC Lavalin is the operator for a 35-year period, with minimum frequency guaranteed by Translink.

*Raw grades out of 5, not weighted for age of network.

Age of network*	8 years

City, Country	Vancouver
Line	Canada Line
Wheel type	Steel
Degree of automation	GoA4
Operator	Protrans BC
Transport authority	Greater Vancouver Transport Authority
Passengers per hour and per direction (PPHPD)	15,000
Signaling	SelTrac CBTC - UTO
Network length in km	19.2
Number of stations in operation	16
Date commissioned	2009
Passengers per car	334
Manufacturer / model	Hyundai Rotem
Average commercial speed	35km/h

*Age of network in number of years of driverless line operation.

VANCOUVER: EXPO LINE / MILLENIUM LINE

		CHARACTERISTICS	EVALUATION*
1	Infrastructure and rolling stock	• High commercial speed (45km/h) but long distance between stations (>1,500m) • Average headways, with 2-min intervals at rush hour • Fraud rate: 5.5%	4 Expo Line 3.6 Millenium Line
2	Service reliability and quality	• The operator does not disclose figures on punctuality, but this last is judged as satisfactory or very satisfactory by 81% of passengers • Cleanliness: 71% of passengers give a good to excellent rating of cleanliness in trains and in stations • Passenger information: real-time information disseminated on platforms; scheduled times on the Translink website • Passenger safety: 76% of passengers give a good to excellent rating of on-board safety	2
3	Auxiliary and innovative services	• No dedicated app, but a route planner developed for mobiles	

KEY POINTS

- British Columbia Rapid Transit Company Ltd (BCRTCTC) operates and maintains the two Skytrain lines on behalf of TransLink.

*Raw grades out of 5, not weighted for age of network.

Age of network*	Expo Line: 31 years Millenium Line: 15 years	
City, Country	Vancouver, Canada	
Line	Skytrain Expo Line	Skytrain Millenium Line
Wheel type	Steel	
Degree of automation	GoA4	
Operator	British Colombia Rapid Transit Company	
Transport authority	Autorité des Transports du Grand Vancouver	
Passengers per hour and per direction (PPHPD)	16,000	15,000
Signaling	SelTrac CBTC - UTO	
Network length in km	28.9	15
Number of stations in operation	20	
Date commissioned	1985	2002
Passengers per car	500 (passengers per train)	200
Manufacturer / model	Bombardier Transportation	Siemens (VAL 206 and VAL 208)
Average commercial speed	44km/h	33km/h

*Age of network in number of years of driverless line operation.

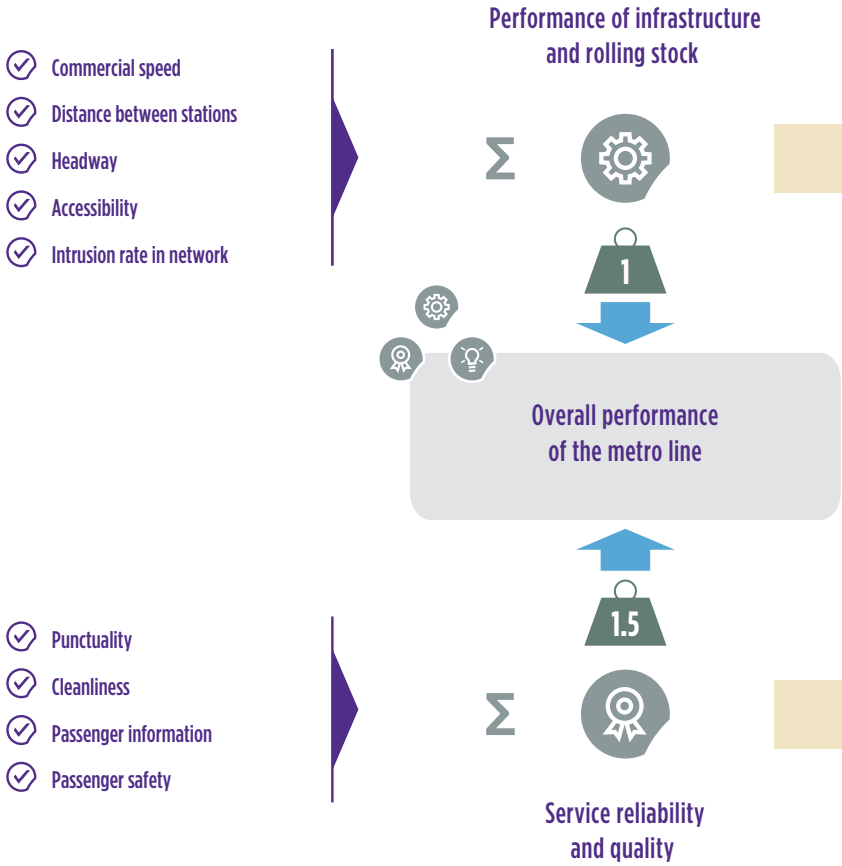
APPENDICES

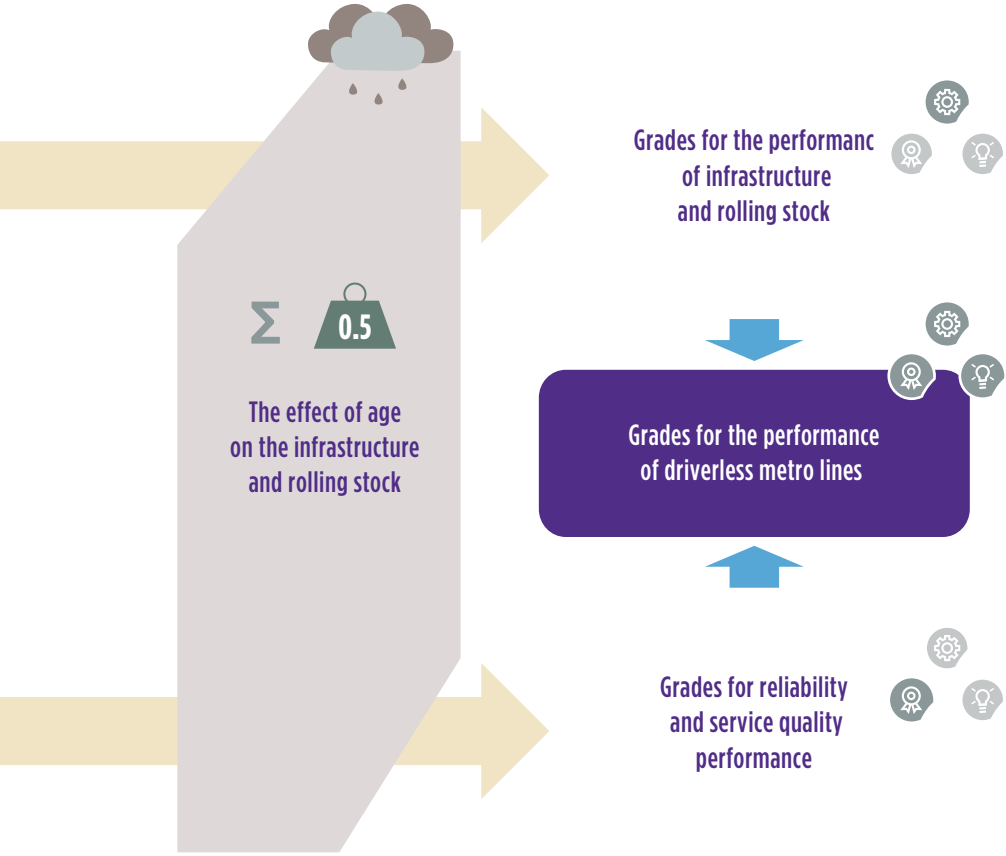
INDICATOR ASSESSMENT METHODOLOGY

Performance is graded in 5 levels so as to determine
for each indicator the relative performance of each network in the benchmark

PERFORMANCE LEVEL	SCORED OUT OF 5	ATTRIBUTION OF GRADE
Mediocre performance The least efficient network in the scope	1	**Grade** attributions are **systematically objectified** on the basis of the **quantitative data** compiled Where quantified data are not available, the **grade** is based on all the **supplementary qualitative items** liable to enlighten the analysis
Insufficient performance	2	
Average performance	3	
Good performance	4	
Excellent performance The most efficient network in the scope	5	

THE COMPARATIVE ANALYSIS OF THE METRO LINES IS BASED ON INDICATORS TAKING ACCOUNT OF INFRASTRUCTURE, SERVICE QUALITY AND THE AGE OF THE ASSETS

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The effect of age
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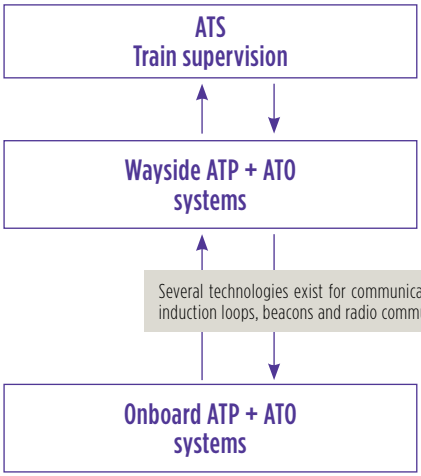
Grades for the performance
of driverless metro lines
Grades for reliability
and service quality
performance

COMMUNICATION-BASED TRAIN CONTROL (CBTC) ARCHITECTURE

The main characteristics of the CBTC system are:
- the localization of trains independently of track circuits;
- high-speed dual-direction transmission between ground equipment and trains;
- a system comprising computers located both on ground and in trains.



Automatic Train Supervision (ATS) serves as an interface between the operators and the system. It can be used to control and globally supervise the system and manage train flows in respect of theoretical service.

Wayside ATP: manages communications with the trains in its area and calculates the movement limits to be respected by the trains

Wayside ATO: controls the destination of trains and the parameters for regulating their movement (station stop times)

Several technologies exist for communications between onboard systems and ground systems, including induction loops, beacons and radio communication. This last technology is the most widely used

Onboard ATP: continuous control of train speed consistent with safety criteria (braking management where necessary). Serves to communicate the data necessary to operations with the Wayside ATP

Onboard ATO: automatic control of the acceleration and braking of the train, consistent with theoretical service

ATP: Automatic Train Protection
ATO: Automatic Train Operation

GLOSSARY

Automated guideway transit (AGT): a system similar to the metro, in that it runs on a dedicated circuit which does not interfere with other modes of transport. It differs from a metro by often being composed of one car per train, with a maximum capacity of 100 passengers. Through its simple design, AGT does not have the same limitations as a metro.

Automatic train protection (ATP), automatic train control (ATC), automatic train operation (ATO): onboard systems serving respectively to prevent collisions, control route setting and train regulation, and control train acceleration and deceleration.

Automation level: the level of automation is defined according to the division of responsibilities between the system and human resources of the activities relating to the operation of the service.

- **GoA 1 (Grade of automation 1):** 100% manual operation in which the driver is responsible for starting and stopping the train and controlling the doors and operating incidents.
- **GoA 2 (Grade of automation 2):** semi-automatic operation in which the train is started and stopped automatically but the driver is responsible for controlling the doors and operating incidents and is called on to drive the train where necessary
- **GoA 3 (Grade of automation 3):** driverless operation in which the train is started and stopped automatically but an operator (not a driver) is responsible for controlling the doors and operating incidents and is called on to drive the train where necessary
- **GoA 4 (Grade of automation 4):** operation with no human resources on board, in which the train is started and stopped automatically and the control of the doors and operating incidents are fully automated.

Availability: an indicator quantifying the difference between the actual number of kilometers traveled and the number of theoretical kilometers. Availability is calculated as the ratio between the actual number of kilometers traveled and the number of theoretical kilometers.

Communication-based train control (CBTC) system: an automatic rail transport control system (train or metro) based on continuous communication between the train and the computers used to coordinate traffic.

Conventional metro (as defined for the study): a metro (see definition above) whose running is entirely or partially ensured by a driver (grade 1 and grade 2)

Driverless metro (as defined for the study): a mass transit system operating on a dedicated underground or overground circuit powered by rail and transporting passengers essentially making back-and-forth journeys/commutes. Generally speaking, the train is made up of several cars (up to 6 or 8), comprises a raised access level, and has a capacity of over 100 passengers. The train is operated entirely automatically without driver input (grade 3 or grade 4). The LTR, AGT and people-mover systems defined in this glossary do not fall within this category.

Driverless metro operators: TL (Transports Publics de la Région Lausannoise), ATM (Azienda Transporti Milanesi), BCRTC (British Colombia Rapid Transit), GTT (Gruppo Torinese di Transporte), TMB (Transports Metropolitans de Barcelona), TRTC (Taipei Rapid Transit).

Light rail transit (LRT): a system operating on a circuit that may be shared with other modes of transport (such as cars), often powered by a catenary, the trains of which have a limited number of cars (1 or 2). Trams are included in this category.

Metro: a mass transit system operating on a dedicated underground or overground circuit. Generally speaking, the train is made up of several cars (up to 6 or 8) and comprises a raised access level.

People mover: a fully automated light transit rail system. The term is generally used only for raised, single-rack shuttles operating over short distances at airports, leisure parks or compact urban areas.

PPHPD: the number of passengers per hour and per direction is a measurement of the capacity of a public transport system. PPHPD is used to determine the capacity requirements of the rolling stock (and thus the CAPEX and OPEX of the project).

Punctuality: an indicator quantifying the difference between the actual time of arrival at a station and the theoretical time of arrival. Regularity can be calculated as the percentage of trains respecting the theoretical time of arrival.

Regularity: an indicator quantifying the difference between actual headways and theoretical headways. Regularity can be calculated as the percentage of trains respecting theoretical headways.

Urbanization: population movements from rural areas to urban areas, or the transformation of rural areas into densely populated urban areas.

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