

The future of the metro

By SYSTRA and Usbek & Rica



SYSTRA

Next stop: the present

The metro is going over its century and half of existence in 2020. Having contributed to delivering half of the automatic metros in the world, we saw in this anniversary an occasion to pause and take a step back. It is with this ambition in mind that we imagined this notebook: to retrace the evolution of the metro and envision the possibilities for the next decades.

But to throw ourselves into prospective analysis in the midst of a pandemic, what an adventure! Independence of our will, the writing of this work has taken place straddled between two worlds: the one before-covid-19 and the one that we will name “the world after”. How to write something that will last in such an uncertain time? How to envision the future of public transportation when social distancing is becoming a new norm. But perhaps it’s this context that will give this document strength. This booklet—just like the metro—was thought out to adapt to all situations, to withstand all types of future. To bend itself to reality, without ever breaking.

And isn’t it when everything wavers that we clearly see the most stable elements? Everywhere, the crisis has shed light on the vital functions of our society: healing, feeding, educating. But also uniting.

By forcing half of the planet to be confined, the crisis reminded us how mobile we are in our professional and personal lives. And by depriving us momentarily of their use, it proved the importance of public transportation in all of our lives. For the metro belongs to the mundane, as French author Georges Perec once said, “what happens everyday and comes back the next day, the banal, the day to day, the obvious, the common, the ordinary, the infra-ordinary, the background noise, the usual”.

Tomorrow, when the metro is back on track, perhaps we will be amazed by this robust and resistant machine, fluid and without friction. Perhaps we will briefly realise how innovative it is, before reintegrating it back into our day to day, until we forget its presence. But until then, and starting now, the metro will have to learn to live in a world scarred by crises that are deeper and deeper and repeated. We will have to get used to reacting and finding answers. It will finally affirm its place in an ecosystem and contribute to structuring our collaborations with one another. In this way, it can continue to do what it knows best: being the backbone of our day to day, rigid enough to structure our lives, but supple enough to bend to all possible futures.

Pierre Verzat,
Chairman of the Board of SYSTRA

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Executive Director of Usbek & Rica

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Telling numbers

Familiar and daily, the metro actually conceals a lot of secrets.
Let's take a little tour of some numbers that show
its discreet and enormous exploits.

1863

The grand opening of The London Underground that became the 1st metro in the world. A real worldwide hit!

25 to 40 km / h

The average speed at which a metro transports its passengers. A speed that is far superior to the car in our global urban areas (13km/h in Paris, 16km/h in London).

180 cities

Around 180 cities in the world have their own metro networks. This represents more than 11000 metro stations.

14 000 km

The total length of all of the metro lines in the world.

40 years

The average technical lifespan of a metro train, which is almost 4 times more than the average lifespan of a car in Europe (11 years).

105 metres

The depth of the Arsenalna station in Kiev, the deepest metro station in the world.

90 out of 100

The number of metro stations decorated with works of art. This project, led by 150 artists began in 1950.

3,64 million

The busiest metro station, Shinjuku (Tokyo), sees 3,64 million passengers each day, which is the equivalent of the entire population of Uruguay.

1 metro out of 2

SYSTRA contributed to developing half of the automatic metros in circulation in the world.

A brief history of the metro

TEXT
Eric Senabre

The metro is such so commonplace in everyday town life that we take it for granted. However, it already has a long history, sparkling with innovations that were revolutionary in their time.

1863

Instant success

Although its history started in the second half of the nineteenth century, the metro was designed to solve problems that are still relevant today. When the London underground was opened on January 10 1863, its primary purpose was to relieve traffic congestion on the surface. There were no motor vehicles at that time of course. In a town with more inhabitants than the population of central Paris today, horse-drawn vehicles caused the same traffic jams. The pollution caused by horse manure was perceived as a real menace. Success was immediate. 30,000 passengers travelled from Paddington to Farringdon on the first day.

1890

Electrification

Until 1890, the London underground ran on steam. Despite the speed with which this solution was adopted (40 million travellers per year by 1880), we can imagine the discomfort of this form of locomotion in a confined space. Instead of using cable drive, as chosen by the New York metro, London chose electricity. This was a more modern solution that had featured in the Universal Exhibition of 1881. The metro preceded conventional railway by three years. When Paris built its own metro in

1900, electricity was preferred to some surprising alternatives (e.g. water cushion, inclined plane, compressed air). Three independent firms agreed to supply the electricity, until the dedicated power station was completed on Quai de La Râpée. Independent of the comfort that it brings to its passengers, electricity makes the idea of an underground network sustainable, while other cities have bet on the surface.

1903

Safety

In 1903, a train caught fire at Ménilmontant in Paris. The smoke asphyxiated 84 passengers on the platform at Couronnes station. The two villains of this catastrophe were the timber used to build the carriages, and the lack of emergencies in stations. Wood was replaced by metal. This gave birth to the legendary Sprague-Thomson in 1908, which remained in service until 1983. Of course, stations were upgraded to protect the safety of all.



Compressed air

After the opening of the London Underground, it was quickly acknowledged that coal and steam could not be considered long-term solutions. However, before relying on electricity, a number of projects were carried out. Among the alternatives: compressed air. If compressed air motors have indeed been put into service (notably on tramways in Nantes until the end of the first world war), there were also systems (in London then New York, from 1864) where a train was 'aired' in a tubular tunnel.

1906

Signalling

In the United States, the Hall semaphore signalling system was in general use from the end of the 19th century. It was adopted in France, but was quickly replaced by an automated electric system in 1906. This remained in use until the 1960s, when electronic and emerging computer technology took over. Now the metro relies on a signalling system as complex and efficient as the signalling used for mainline railways.

1952

- 1956

Articulations and tyres

In order to satisfy high demand during peak periods, Paris started to use articulated rolling stock (MA 1951) in 1952. Technically more advanced than the old Sprague-Thomsons, these trains could couple together two or three three-car units as needed, thereby adapting to cater for passenger influxes. However, success was limited. RATP decided to focus its efforts on tyre-borne trains (MP). Trains running on tyres can brake and accelerate more vigorously. As a result, the headway between two trains can be reduced. This was another way of satisfying increased demand while eliminating the rail squeal that offended sensitive passengers.

1980

- 2000

Automatic train control

In 1981, Osaka introduced the concept of the automatic metro system to the world with its Nankō



Ghost stations

Paris' metro has 16 ghost stations. While some of them were in reality merged with the neighbouring station (like Martin Nadaud with Gambetta) and remain de facto accessible under a different name, others are purely and simply abandoned (like the ghostly Saint-Martin station on line 9, whose platform can still be seen when you go from Strasbourg-Saint-Denis to République) or, even more strange, some never opened despite the construction of the platforme - like Haxo in the 19th.

Port Town line. Two years later, the city of Lille went even further with its Light Automatic Vehicles project that circulated without a conductor on lines 1 and 2. Germany quickly followed suite in 1984 with two lines in Nuremberg, followed by Canada and Vancouver. While it remained sporadic in the 1990's, the phenomenon spread across the planet in the 2000's in cities like Budapest, Barcelona, São Paulo, Dubai... and led to the automatization of existing lines (Paris' line 1 in 2013).

2003

Farewell to the ticket?

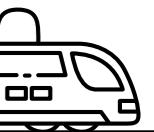
In London, the Oyster Card was launched in 2003. Based on RFID technology, it has simplified ticket transactions for the operator and passenger alike. In Paris, the Carte Navigo existed already in experimental form but did not enter general service until 2005 and 2006. Today, certain smartphones can already serve as super-tickets while more universal software and hardware solutions are being studied.

2010

- 2020

Passenger experience and sustainable development

At the end of the nineties, the metro started to focus on enhancing passenger comfort and the environment. Wi-Fi was gradually introduced (starting in 2009 in Seoul), while 4G spread to the metro (in Singapore, 4G and Wi-Fi cover the entire network). In Asia, contactless payment is becoming widespread through mobile applications. In 2017, Line S1 of the Beijing metro received magnetic levitation trains. Meanwhile, other towns were greening their transport. In Lausanne and Toronto (Victoria Park station), station exteriors were adorned with canopies of vegetation. And inside? In Paris, Gare de Lyon station on Line 14 had already shown the way. Although in 2016 the Chinese experiment in Hangzhou to vegetate a train interior did not last long, it did at least blaze a trail that the metro will probably seek to follow over the coming decades.



An itinerary under the open sky

TEXT
David Attié

ILLUSTRATION
Nelson Goncalves

2035 – the metro of the future has not set off any revolutions. It continues to deliver discreet innovations, fine-tuning its functioning and putting together its resilience.

Never forcing, Billie speeds ahead on her bike. A quick glance at her phone confirms that she is ahead of schedule. The screen saver shows the time of the next train, down to the second and the exact number of spaces available in the “multi-park”. It is referring to a garage, bookable on-line and now found at the entrance of all stations, with spaces that can be adapted to every type of micro-mobility. The open-air station appears on the horizon, on a small, lively square. Billie continues on the bike path that slopes down gently to the lower level, where shops and train connections can be found. On the lawn, some are soaking in the sun, but she pays them no attention. Having hung her bike up between a hoverboard and an electric scooter, she heads away from the multi-park and straight to the counter manned by Abel, who greets her with a big smile. Ever since ticketing became paperless, stations have freed up quite a few square metres by doing away with ticket checking lines. Abel has founded an association that sets up organic mini-farms in newly-freed technical rooms.

for me? I'll come back for them this evening.
- Yes, I've got oyster mushrooms just picked this morning...”

Suddenly, for a few seconds, the LEDs in the stand start shining and flickering as if there were no tomorrow. Billie squints into the light: “Whoa, what's that?”. Abel narrows his eyes mysteriously and looks towards the train that has just come in. Billie thrusts herself into the train. A ray of sunlight hits an empty seat: it's that time of day when the celestial body aligns with the station's slope. She sits down and writes a message. “Honestly, did you put up a disco light or what?” Raising her eyes, she looks around. Thanks to the new self-cleaning surfaces and self-contained mini-sweepers, the train is immaculate. Roomy and bright, it moves without a sound or vibration. A grandfather and his three grandchildren have settled in next to her with multiple shopping bags. The youngest of the three is faced backward, spying on a group of teenagers in cosplay a few rows away. Billie smiles knowingly. They're headed for UbiDream Station, no doubt about it. Her phone vibrates: it's Abel, answering.

- “Hey, look who's here! Is today the big day?”
- Yeah, I was just dropping by to say hi, then I've got to run! Could you put some mushrooms aside

- “Ha ha. Get this, yesterday, a technician came to check the electrical system of the stand. Apparently, they put in place a system that can retrieve the

energy released by the braking mechanism of the trains and supply the whole neighbourhood with electricity. Apparently when a metro arrives into a station, you can retrieve the energy produced (a free energy!) to fuel a ton of exterior equipment like electric heating, lighting, ventilation systems in public places and nearby housing.

- Well done! It gives it a magical touch.”

Further along, the teenagers are taking selfies with their costumes on. They are going to the Poplars' Station, which everyone calls UbiDream, after the famous video game company. It's one of the few stations in the system that has been co-financed by a property developer, who applied a porous approach to the tunnel and surface. Not only was the material excavated for the line used to construct the building, but a physical continuity was created between the two. One of the escalators offers direct access to the building shared by UbiDream and School 404, which is specialised in video gaming. Set up as an arcade open to the public, the ground floor of the building gives visitors the chance to test out different games, see the latest technologies for themselves and attend meet-ups. Professionals, students, gamers and just plain travellers meet there all year round in a gleeful atmosphere.

As the metro momentarily exits the tunnel, the lighting adjusts to the daylight and the ather-

mic windows regulate the sun's heat. Less energy-consuming than air conditioning, forced mechanical ventilation has become the norm. It offers optimal temperatures when inside.

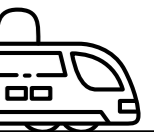
Thanks to a more frugal design, the weight of the trains has been reduced and they now consume less energy and emit less heat. They use new-generation high-albedo materials that are more insulating. Billie remembers last summer, when the metro became a heavenly icebox during the heat wave. Today, most stations are designed as climatic oases. In many cases, they can rely on bio-based materials such as clay and wood, which improve air quality and reduce stress.

Just before the train heads back underground, Billie recognises the poplars and the UbiDream building. Consistent with the concepts of Transit Oriented Development, the station was built in the middle of a working-class area in the heart of the city. A concerted effort by the community, residents and the developer helped to stem the rise in prices, and made it possible for residents to stay. Thanks to pedestrianisation, shops have moved in and the neighbourhood has gained a new lease of life. As the teenagers in the back start singing, the grandfather leans over to Billie.

- “They're so excited, you know what's happening today?”
- It's the launch of the latest UbiDream game, everyone's talking about it.
- Are you going too?
You're not dressed up!
- Actually, I'm leading a workshop.
I worked on the game, we developed an audio technology using super-immersive 3D.”

The children's eyes bulge in amazement as they turn to their grandfather, who bursts out laughing. He gives his go-ahead, but only on condition that they help him with the groceries first. In a single second, they all have their arms loaded with groceries.

Following the smart guiding availed by their Smartphone, the teens decked out in cosplay have gathered in front of the door closest to the UbiDream escalator. The few seconds just before they open are spent in feverish silence. Billie winks at them, a magical beep sounds, and already, the metro's doors are opening.



The metro: between crisis and opportunity

TEXT
Millie Servant

ILLUSTRATION
Marine Benz
& Jan Siemen

Christelle Chichignoud,
Director of Sustainable
Development at SYSTRA

Maud Bernard,
Director of research in mobility
and innovative solutions at SYSTRA



Putting the metro at the heart of an ecological transition project also means envisaging its place in the social and economic context of our urban areas. Time to take a look into the future with Maud Bernard, Innovative transportation systems program director at SYSTRA, and Christelle Chichignoud, Group Sustainable Development Director.

→ **Our societies are going to experience increasingly unpredictable natural events. How can the metro prepare for this?**

Maud Bernard At SYSTRA, we already have a risk management culture that enables us to deal

with familiar events such as earthquakes for example... During the earthquake in Mexico in 1985, the core metro network resisted the shocks and operation was able to restart without major works. The consequences of a 100-year flood level can be integrated from the start to protect the sensitive equipment of fixed installations, with adaptations. These risks can also be the object of organisational measures for action in a crisis situation (e.g. obstruction of a metro tunnel by the rapid construction of a temporary wall). The challenge we are preparing to face today involves anticipating the unpredictable in order to be able to adapt instantly, but in retrospect, to an unprecedented event. Currently, there is much talk of resilience, a flexible concept which denotes 'the capacity of a system to deal with a shock'. According to its degree of intensity, resistance is associated with the capacity of a system's resilience (absorbative), with the implementation of changes to adapt the system and make it more resilient (adaptive), or even the radical transformation of a dominant model (transformative).

Christelle Chichignoud Whether for an existing structure or a new one, adapting the metro to the climate issues of tomorrow necessitates environmentally specific design and management. We integrate very early on in the design of an infrastructure project an analysis of the risks linked to exceptional climatic events and we propose structure dimensioning and adaptations according to this analysis. It is also the entire management of an exceptional event itself that must be taken into consideration. From the real time alert, the whole chain must be anticipated, planned and shared between the different actors.

→ **Could the metro become a solution in the face of risk?**

M.B. The metro as a structure can play a protective role. It can for example be designed as a protection against extreme temperatures, to resist fire or heavy rainfall. The Moscow metro was especially designed so that stations could become shelters in case of war.

However, for the metro to really take on this role it also must be considered that the system to be built must be as economical as possible in terms of resources, as much during the construction phase as during the operational phase. There is much to be explored here: one could for example play on the stations' architecture or their installation to regulate the temperature without recourse to air conditioning.

C.C. The metro is at once an object of performance and an object that is useful for communi- →



Total Luxury

The Moscow metro is not only the busiest in Europe, with its 365km of lines and 232 stations: it also has the reputation of being the most beautiful. In 1935 Moscow still had no metro and Stalin wanted to make it an example of Soviet brilliance. The project was colossal, and many of the stations are a testament to these incredible ambitions: Arbatskaya with its chandeliers, its marble; Elektrozavodskaya with its decorated vault and luminous circles, Barrikadnaya and its polished rock decor.



Non-stop

The First World War limited the activity of the Parisian metro system, but did not kill it: on average, between 1914 and 1918, 30% of the trains ran. After the Second World War, it went up to 40%, despite many stations being closed. Due the difficulty of finding gas (and tyres), the metro remains the safest means of locomotion of Parisians. In the end, the covid-19 crisis will have been more severe for the metro than armed conflict, with sometimes only 20% of trains running.

ties. Innovation is not only about futuristic projects such as Hyperloop or flying cars. We can develop the metro into an incremental innovation model: a useful and virtuous innovation.

→ **What will be the impact on the life of the city if the metro loses a part of its transport capacity?**

M.B. The covid-19 health crisis has led to a loss of 80% in capacity, corresponding at once to a drop in the level of service and a drop in the capacity of vehicles regarding the respect of physical distancing rules. In such a situation, the transport curve must be flattened by reducing the density of movements and by avoiding rush hours, moving commuter flows to other modes of transport, etc. It is clear here that resilience requires the activation of multi-scale systems combining everyone's strength to create a network.

This health crisis forces us to think about a 'global system' and the speeding up of certain changes already taking place gradually or still in gestation. This forces us to reconsider the place of bicycles, walking and micro-mobility in cities, and to recognise these as entirely separate ways of getting around.

C.C. Whether it is for a crisis, or more generally in the context of global warming and a zero emissions strategy, an ecosystems approach must be adopted instead of a narrower approach. It is not just the metro itself that is being considered but its place in a broader context, and the way it is integrated in the urban environment. A constant zoom in



and zoom out effect must be used. More than ever, the capacity of the metro, its added value in the service to communities and territories is to be envisaged in terms of synergy and complementarity with other services and modes of transport.

→ **Can a different distribution of passengers across different transport modes be considered according to their journey times?**

M.B. There is a huge number of ways to travel short distances. Private operators of micro-mobility have already understood this.. In urban zones, most short journeys (500m to 10km) are still made by car, and driving alone is

very common in the United States, 50% of journeys made by car are less than 10km in France, only 3% of journeys are made by bicycle, despite it being a very high capacity mode of transport. The problem in the case of a loss of transport capacity for the metro is that its number of passengers is difficult to match: a metro can carry 60,000 people per hour. The local authorities in Paris have thus estimated that if only 5% of the 600,000 daily passengers on line 13 took their car, four extra lanes would be needed on the road. Shifting journeys from public transport to cars is, however, neither viable nor desirable. The crisis should not act as a brake, a step backwards in the context of energy transition.

→ **How can public transport be made**

more desirable as a means of getting around?

M.B. First and foremost it is about simplicity, fluidity and comfort. Moving from A to B must be a pleasant experience. This requires a reliable and robust system of the right size, the taking into consideration of usage, and the interconnection of the metro with the other modes of transport (meaning intermodality). But one can go further: the urban anthropologist Sonia Lavadinho rightly said: "when we can say that our time spent on the street and on transport was pleasant and worthwhile, then we will have answered the challenges of mobility." Areas of the metro where the concept of time disappears thanks to design and what is beautiful and fun.

→ **The metro also has negative externalities: how can they be limited, or even put to good use?**

C.C. At SYSTRA, we envisage the potential but also the impacts in their entirety, at the project level and throughout the lifecycle of the infrastructure. We pay great attention to optimising the lifecycle of the infrastructure and its interactions with the environment. For example, we monitor the carbon footprint of our different design scenarios very closely, we encourage our clients, as soon as it is possible, to accept technical solutions (choice of equipment, constructive methods) that enable impacts to be limited. On certain projects, we are for example capable of proposing savings of

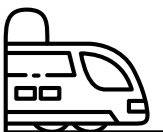
Dialogue

10% on concrete for a 20km viaduct, which could avoid emitting 6,000 tonnes of greenhouse gases, or the equivalent of 600 individuals in one year (11.9 tonnes CO₂ equivalent per person and per year, according to the figures of the French Government for the year 2016). We also seek to benefit from the system's potential, from its design to its maintenance, via its operation, but also from the functioning of the stations and administrative buildings. The ambition is to be able to build a metro tomorrow while mastering all its energy requirements. We could also propose related functions that generate added value for the environment and cities. It is thanks to this approach that the metro will soon be more than just a line but also an essential component in our cities and for society.

→ **Journey times will change in the cities of the future: how could this impact use of the metro?**

M.B. Transport exists because there is activity. If we change the way in which we localise our activities, we change the way in which we build cities. There is much talk today about the concept of short distance cities: the 15-minute city, the poly-centric city... This opens an interesting realm of possibilities on the use of land resources and the recycling of the urban space (multiplication of uses, reversibility of spaces). These future possibilities raise questions about distance, proximity, but also about connectedness - links between the different places. More than short

distances, it is the composition of scales that we need. We also need to consider urban planning in line with the transport offer. In their academic work on 'La ville cohérente' (the coherent city), the researchers Emre Korsu, Marie-Hélène Massot and Jean-Pierre Orfeuill have shown that, in the case of Greater Paris, if assets are less than 30 minutes from offices, car traffic linked to work could be reduced by 10% and that of public transport by 47%. If this vision is utopian, the study presents difficulties linked to the specialisation of zones and a concentration of employment that is too high. As Jean-Marc Offner points out in his work 'Anachronismes urbains' (Urban anachronisms), the future will see the establishment of a mobility system based on three principles: walking for short distance journeys; public transport for scalable movements, and on-demand transport modes and car-sharing for other movements. In such a system, the networks feed each other, and work together to meet the expectations of users.



In praise of voids



→ **When we think of architecture, we think spontaneously of materials, masses, surfaces and solids. But your vision focusses on voids. What does the void stand for, in your approach?**

Philippe Rahm The first duty of an architect, which we tend to forget, is to create a space, a void where it does not rain when it is raining outside, which has less sunshine when there is too much outside. We take portions of the world and its atmosphere, and we transform them so that the climate inside is acceptable to people. External walls are built to delimit this void. It interests me to tell myself "this void is not something neutral. It is a material in itself". We can adjust the real parameters of this material, in terms of temperature, humidity and quality of air, quantity of light, radiation. There is also a chemical parameter and an electromagnetic one too. Architects use bricks, concrete and steel. Why shouldn't they use air pollution, temperature and the type of light? This is how I approach my work. I consider the void as a raw material for the architect.

The Swiss architect Philippe Rahm advocates a form of architecture that features physiology and meteorology. He has agreed to tell us about a future metro, that is in harmony with the natural needs of individuals and the climate.

TEXT
Eric Senabre

→ **Quite so. And how do you consider the voids created by spaces in the metro, in terms of climatic comfort and energy efficiency?**

P.R. In Paris, you just need to go 5 metres underground, to reach the mean annual temperature of the town, between 11° and 12°C. It's a bit like the wine cellars in Reims where they mature champagne. Renaissance churches have a thermal value too, just like Roman basilicas. Today, the metro is primarily functional. Tubes joining one station to another. But it might be worth endowing it with an 'urban' value, like the semi-underground shopping malls in Canada. This thermal value could take on a public role. In winter, there is a huge loss of heat from the metro. We ought to recover the air coming out of metro station entrances, to stop it from going to waste.

→ **Do you think that growing plants in the metro could be a good way of regulating the temperature? At least it could build a link**

between the underground and the overground, couldn't it?

P.R. Vegetation needs certain qualities of air, light and moisture. That creates a degree of technical dependence which can be hard to control. Take irrigation, for a start. And the consequences would be more psychological than anything else. It takes 300 trees to compensate the average person's annual carbon footprint. A few shrubs won't do much for the thousands of people in the metro. They won't be much use as air fresheners, or at least no better than a pool or a fountain.

→ **What else could be done to make the metro more resilient, or at least a bit nicer?**

P.R. First and foremost, the quality of the air and the light. The lighting devices in the metro emit standard spectra of light. However, we ought to choose them to satisfy the metabolic needs of travellers, and we could even adjust them to suit the time of day. For instance, we could make the lights go yellow in the evening, to respect circadian rhythms. The quality of air is still quite hard to control. Intrinsicly, these two notions could become aesthetic considerations. Light and air could create the beauty of the metro.

→ **The problem today is that the covid-19 crisis has questioned**

the very concept of air circulation.

P.R. We do not yet fully understand how the virus circulates. Studies show that if Milan has been so severely affected, it is due to the air pollution. The virus attaches itself to fine particulate matter. In the metro, we should certainly expect the virus to circulate more actively, using the high density of fine particulates. The solution might be to dilute this concentration, just as we can attenuate pollution above ground level.

→ **You mentioned the cool temperatures of Renaissance churches. Could we pursue this line of thought, to reconsider the materials used for the metro?**

Yes, these are major questions about emissivity and effusivity. Highly emissive material opposite us would absorb our heat, because it would be constantly cooled by the earth at 11°C. In the metro, everything we touch should be made of highly effusive material, and the materials opposite us should be highly emissive.

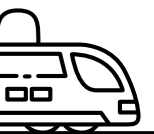
→ **How could geothermics influence the future metro?**

I think that geothermics could be used widely to cool down the air blown into the metro, acting as an earth-to-air heat exchanger. If outdoor air was blown directly into the metro tunnels during a heatwave, it would be stifling. But if you blew the air through heat exchanger coils, it would be cooled. Of course, it is a bit complicated to make the air move naturally but it is possible. The upper sections of a solar chimney are black. They get hot and create an updraft. Such thermal chimneys could replace mechanical ventilation.



De profundis

The Arsenalna metro station in Kiev had the funny idea of setting up at the top of the valley. Consequently, the metro platforms are 105 meters lower and require a long journey on escalators: between 5 and 10 minutes. Of course, this is not about gratuitous cruelty on the part of the engineers: the following station is indeed in the valley, and it would have been a lot more complicated to make it up the hill for the train.



A virtual metro at the service of reality

The metro of the future will also be virtual ! The creation of its digital double will offer an exact multidimensional model of the network, which will evolve in real time thanks to connected sensors deployed on the field. From research to maintenance, and from constructions sites to the operation of the infrastructures, this virtual metro will have real impacts and allow digital continuity...The goal ? Saving time and energy, being more reliable and renewing the experience for users.

TEXTE
Benoit Zante

ILLUSTRATION
Johan Papin



The visualisation of the network is no longer science fiction

The visualisation of the metro is well underway: the creators of the metro of tomorrow are already working on digital models by using the platform BIM ("Building Information Modeling"), which aggregates all of the data. This tool is crucial for coordinating the different parties in order to limit the risk of error or delay on the different sites. Already in its conception phase, these visualisation tools already allow you to simulate, organise and efficiently plan construction, exploitation and maintenance.

"By working in a virtual environment, it is possible to identify problems that until now were invisible. By investing more means into the design, we can better anticipate the future: spending more time thinking about the conception will always cost less than correcting errors during construction." adds Sandra Lang, the Technical Director at SYSTRA Scott Lister, Australia.

Modeling in order to better collaborate and control the impacts

BIM turns out to be just as useful on the field, during the construction phase, by facilitating the collaboration between the different pro-

Thomas Juin, Chief Digital Officer, SYSTRA

"The metro is a complex system to master and we need a rigorously deterministic conception in order to ensure the security of its passengers. The emergence of new sources of data bring us tools to observe and measure real behaviours that help us better organize our deterministic models of simulation. This data invites humility by bringing to light phenomenons that are unpredictable or that we cannot yet explain. We must not turn the use of data into a statistical revolt in a deterministic dictatorship. Statistics and determinism must work hand in hand at the service of a metro that saves more energy, is more reliable and more efficient."

fessions that have to work together, in often restricted spaces.

"Before, everyone came into the meetings with their own tools. Today, thanks to the cloud, we can all have access to the same model, test, exchange and chose the best solutions together" explains Vladana Darras, the Deployment Manager of BIM in the SYSTRA Group.

These digital models also pave the way for longer-term gains that are significant, on the entire lifespan of the network, by virtually simulating the performance of the entire transportation system right from the conception phase, before the trials. By virtually simulating the infrastructures, it is also possible to model their environmental impact and determine in advance their carbon footprint, which turns out to be particularly useful in identifying the most economic configurations in terms of energy.

Sensors for a real time report

BIM and its digital models are not the only digital incursions on construction sites: drones, satellite images, IoT sensors provide precious data that, depending on the case, monitor the storage capacity of the site, guarantee the security of the workers or ensure that the schedule is respected by following the advances in construction on a day to day basis.

"We now complete the traditional topographic measurements with data that is much more precise thanks to drones, sensors and satellites." explains Eric Pruvost, Director of the BIM Transformation Plan at SYSTRA.

Once the infrastructure is delivered, the digital plans, connected sensors and virtual models are not abandoned, on the contrary: they start a new life, at the service of the maintenance and the exploitation of the infrastructures. The network thus becomes stronger thanks to its "digital twin", a true virtual control center.

The digital twin facilitates the integration of future evolutions on the existing metro lines

Marc Seffacene, Operations Director, SYSTRA, Dubai

"In tropical cities, the quantity of energy dedicated to metro stations is equivalent to the amount consumed by the trains. The challenge for energetic optimisation is a reality. All of these systems must function perfectly with a perfect reliability, and adapt to the flow of passengers, thanks to constant supervision that has become finer and finer as the technology progresses: in the most modern metros, hundreds of thousands of points of measurement of temperature, tension, lighting, noise are collected each second."

(extensions, the adaptation of the tracks, the arrival of new material, the switch to automation...) and of its direct environment (buildings, other systems of transportation).

Maintenance reinvented by artificial intelligence

Sensors are progressively finding a place on the equipment between stations and on the rolling material, for a monitoring to the millimeter: associated to artificial intelligence algorithms, the data collected paves the way for predictive and preventative maintenance rather than corrective or planned. We therefore speak of Asset Management.

"Thanks to the data, predictive maintenance aims to reduce the risk of the most critical breakdowns as well as the number of interventions. The material can roll longer each day, with a reduced down time, which allows for increased frequency with better reliability" explains Jessica Smith, the Director of Mobility Research at SYSTRA Scott Lister, Australia.

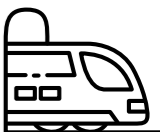
The digital twin also allows you to better prepare the heavy maintenance and renewal operations (the renewal or changing of the tracks, the circuit of tracks ...) by reducing the impact on the exploitation.

A better experience for users

The virtual control center also ensures better reactivity for the network and guarantees a better daily experience for its users. Passenger flow, the temperature and the lighting can be optimised in real time.

"Sensors both inside and outside the station can be used to analyse the temperature, the brightness or the number of passengers present, in order to optimize the lighting, the sound levels, the air conditioning or the information for passengers like the positioning of the trains" explains Alan Trestour, General Manager, Advisory, SYSTRA Australia & New-Zealand.

Whether it be the latest metro lines above ground or the more ancient ones, the progressive instalment of sensors provides precious data about the use of the infrastructures. Enlightened by this unprecedented information, the operators of the networks can optimise the existing...and plan for the next extensions.



The metro in all its ordinary beauty

ARTICLE
Eric Senabre

ILLUSTRATION
Jan Siemen
& Kouzou Sakai

Buying a ticket, getting off, getting on, waiting on the platform, slipping into the train...In appearance, the potential amazement that a metro trip can procure is relatively low. But the illusion of its simplicity is in reality underpinned by a multitude of discreet innovations, sometimes old, sometimes recent, that we would never suspect – and a fortiori, of an exceptional character.



A train without a conductor

An automatic metro, without a conductor and without personnel onboard, doesn't surprise anyone anymore. And yet, the deployment of completely automated trains is not that easy. There are five levels, from 0 to 4, in terms of automatization; the first designates a system that handles the switches automatically, while level 4 applies to the exploitation of the trains without personnel onboard. The first steps in terms of automatisisation were done in the 70's, with level "2" lines that still significantly alleviated the conductor. After the development of the electronic and then the digital, it was possible to reach, in the 80's, level 4.

Furthermore, while certain "historic" lines are capable of welcoming automatic trains and classically conducted trains (this is the case with line 1 in Paris that simultaneously welcomed the two types during the migration phase), other more recent ones are created

only for 100% automatic circulation. On most of these automatic lines, it was decided to put a system of automated doors to prevent access to the track and avoid intrusions even when the train is not in the station. The idea was of course to regulate the flow of passengers and prevent accidents. Having someone on the tracks is a mortal risk, with delays across the board as a consequence. Are there any risks? On September 18th 2019, an automatic train of the line 1 in Paris scared its passengers to death, by skipping multiple stops before ending its journey at Palais Royale. The incident—which resulted in a series of disfunctionments—illustrated that each "automatic" train benefits from a sort of "invisible bubble" making it impossible to catch up to the train ahead. The collision with another train was therefore, de facto, impossible.

Infrastructures: pushing back the impossible

Except for the cities that recently came out of the ground (on the scale of industrial civilisation at least), metros around the world were built within the existing urban landscape, which presented innumerable challenges for the engineers in charge of the infrastructure. Also, what we take for granted—connecting point A to point B transparently—sometimes conceals a true headache for yesterday and today's engineers.

And so, just recently, the city of Kolkata launched enormous construction projects to make its East to West metro line under the Hooghly river bed. On the surface, indeed, the ground did not have the required conditions for the extension of the line—starting with the lack of space one can imagine in a city with a population of 14 million people. In total, the underground section should run along 10km, with 520m under the river itself. This is a first for the country, and should be finished in 2021.

Such technical exploits are not new, →



Mysterious facades

In the early days of the European metro, the lines were generally not very deep: they would dig a hole in the pavement, "stuff" a box inside and close it up, or not! The houses located at 23-24 Leinster Gardens in London appear to be the same as their neighbours, but in reality, they are mere facades, without any depth, that are just there to hide the "open" line from the public.

Façal Chaabane, Senior Vice President, International West Operation & Egypt Managing Director, SYSTRA

"The metro of the future should no longer be perceived as merely a means of transportation for individuals from point A to point B because it will be developed in a way that reflects the new way of life of urban communities in terms of security and respect of the environment, passenger comfort, simplicity in usage and the resort to digital. The metro of the future will be an integral part of the great transformations of our way of life."



even if for many passengers, they have become part of the landscape. In Paris—whose land, like all “historical” cities, is full of surprises, and holes—the Danube station is supported by enormous pillars of over 30 meters high that are dug into embankments. Between the ground of the station and this embankment, despite the pylons, there is emptiness. Who would think of this during their daily commute?

In recent construction, like the metro in Dubai, other structural findings have been put in place. Rather than turning to metallic structures and rivets for the overground parts, like you can see in New York, Paris and London, prefabricated U-shaped concrete viaducs have been put in place. The concrete opens the way for more bold and modern architecture that is better integrated in the urban landscape, and limits the ground use (use of mo-no-piles as opposed to pairs of pillars). Braking is producing

Braking is producing!

A metro that brakes, if it is a “tyre material” is not a problem, but if it’s metal, it can be very painful for the ears! In both cases, this braking action, which occurs tens of thousands of

times a day, conceals a technological prowess. In the beginning, the braking action of a metro was like basically any other vehicle: iron “skates” put pressure on the wheels to slow down the train. Since the 80’s however, it has changed: the motor becomes a sort of dynamo (like a bicycle) that not only acts on the brakes, but also converts the mechanical energy lost in electricity. This electricity is then used by the train itself, or injected into the electrical system by the lateral rail to fuel another train for example... if it is close-by. If this condition is not fulfilled, the energy is dissipated in the form of heat, and thus lost. Indeed, reinjecting electricity in the power rail sets off an electrical surge, which thus needs to be used or regulated (the storage is not yet possible).

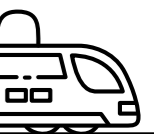
In September 2015, however, the London metro made a huge advancement by using electricity to make, not just a train, but an entire metro station work (lighting, etc). In practice, a station like Holborn could be fueled for two days a week this way. On a daily basis, that represents 1MWh of energy that could be recuperated, which equals the electrical consumption of 104 homes.

Behind this exploit lies an ingenious device. It consists of supply sub-stations that are “reversible”, capable of retrieving 99% of the energy of the braking action and reinjecting it into the electrical network without setting off a power surge. The metros in London, Milan, Riyadh, Panama and Dubai as well as the trams in Sydney are already equipped with this.



Visions of the future

The metro in Dubai, in the United Arab Emirates, is right out of a science-fiction movie. Launched in 1997, the project was inaugurated 12 years later, on September 9th 2009 (at 9:09:09, you can’t make that up!) At the time, it was the longest automatic metro system in the world: it now gets third place after Vancouver and Singapore. But its red line, with 52 km long, remains the longest automatic line in the world.



Three killer questions

ARTICLE
David Attié

Is the metro lying to itself? We asked three killer questions to Maud Bernard, Director of research in mobility and innovative solutions, Hervé Mazzoni, Transportation expert, and Tristan Vandeputte, Directeur of Innovation, at SYSTRA.



Maud Bernard



Hervé Mazzoni



Tristan Vandeputte

Ashish Kumar, Head of Operations – Infrastructure, SYSTRA, India

“The term ‘metro’ is relatively new in India. The first fast transportation system was inaugurated in 1984 in Kolkata. It took 23 years to build the first line.

Then in 1998, Delhi gave itself the ambitious objective of building a network of over 300 km in 15 years. Today, India has about 700 km of functioning metros and 600 km are in construction, while the government is thinking about other alternative and complementary modes of transportation. With over 50 cities in India with a population of over 1 million people, the need for urban transportation systems is huge. Finding the right system and the best way to implement is a necessity.”

Frédéric BANA, VP West Coast – Operations & Business Development, SYSTRA, USA

“The metro must be integrated in a greater transportation policy. This multi mobility relies on a structural backbone, like a metro network, that allows to cater to the needs in terms of urban transportation. Due to the sprawling urban landscapes of certain cities with multiple city centers like Los Angeles, Lagos and São Paulo, the transportation offer must adapt in consequence and must both target occasional, short and non-planned trips, for which the individual transportation services are relevant, just as much as recurrent trips (home to office trips) for which the metro networks offer an ideal solution with high transportation capacity and a very strong integration into the urban landscape without creating barriers between neighbourhoods.”

Is a future without big transportation structures possible?

Today, the metro, the ultimate public transportation in terms of capacity, is asked to compose with new transportation devices. Will they make it obsolete?

In recent years, car manufacturers and the general public have become excited about the progress made in autonomous cars, which indicates a future door-to-door transportation system rid of parking lots. These taxis-robots promise great transformations. Should we see in this the end of urban transportation infrastructures, for the benefit of individual mobility?

This is unlikely, at least in big cities. The metro's infrastructure is synonymous with capacity. *“A 3,5 km long line of moving cars represents 1000 people per hour. A metro represents 50 000 people per hour. Even by increasing the occupation rate, we are not in the same playing field.”* Maud Bernard explains.

On the scale of a city, the metro network makes passengers converge towards major transportation corridors and acts as a backbone. This performance has a price that not all cities can afford: they thus resort to installing a BRT (Bus Rapid Transport) network. While it has less capacity, it does help the population and makes it possible to open up certain neighbourhoods.

The example of Bogota is emblematic. Due to its lack of financial resources to build metro lines, the city invested in BRT. A victim of its success, it is now saturated and cuts the city into boulevards that are impossible to cross and has 100 meter stations that are jam packed. The will to reproduce the metro's capacity provoked heavy negative effects on the urban landscape.

As structuring as it may be, the metro's goal is not to make door-to-door transportation possible, but to solve the problem of passenger volume. Starting with walking, it is necessarily accompanied by other modes of transportation that are complementary.

Does transportation still need big disruptive innovations?

The Hyperloop systems, flying cars, the new generation PRTs or other high-speed systems on air cushions...These projects of innovative transportation systems continue to mobilise research and our imagination. And yet, few of them will have the privilege of being deployed on a large scale.

“In the innovation sector and in case of technological rupture, the person who will be able to say how much the response in terms of safety and availability will cost will be the winner.” explains Hervé Mazzoni. In other words, a technological concept is not enough, you also have to anticipate the infrastructures, the logistics, the breakdowns, etc. By running after performance, certain projects lose touch with reality.

After all, the railway networks work. Some dream of removing the rail/wheel contact. Trains with magnetic levitation, air pillows and reduced pressure tubes are proof of this. *“Whatever the outcome, there will always be interesting technological derivatives to explore”,* explains Maud Bernard. By mobilising our imagination, these totems bring together desires and capital that allow us to break through certain barriers. Hidden innovations in the autonomous car or flying car will eventually find a use in a transportation system.

In fact the metro went through this. Since the first steam-powered locomotives, it has benefited from technological innovations from elsewhere, whether it be in terms of braking systems, contactless control access or techniques of ground freezing. *“If the metro benefited from a favorable environment for its development, such an environment seems more difficult to create for current innovations, event though they are relevant”,* remarks Tristan Vandeputte.

In any event, innovations must ask themselves the question of their horizon. In a time of environmental crisis, should it privilege speed or simplicity?

Is the metro a colossus with feet of clay?

A complex system, the metro had been forged by time to be robust. But is that not its weakness? Too heavy, too technical, too expensive, will it survive tomorrow?

For over a century, the metro has bent, but never been broken. Built to last, it builds its resilience, meaning its capacity to absorb shock, to adapt and to transform itself. *“We respect construction norms that correspond to an ambition of robustness.”* summarises Hervé Mazzoni.

Absorbing a shock is to envisage a breakdown. *“The global concept of our system plans for degraded modes of operations.”* Each device plans for multiple duplications to guarantee continuity in service. The automatic metro trains are for example equipped with an emergency manual control console.

The adaptability of the metro consists in adjusting the service to outside needs. The automation for example, allows you to increase the offer almost in real time. It thus helps absorb big variations in passenger flow, just like in the evacuation of a stadium.

And finally, the metro is transforming itself: it welcomes materials and technologies that make it better and maintain it constantly. Replacing wood by metal for the construction of the trains first reduced the risk of fires; then the transfer to aluminium offered better compression performances in case of a collision, all the while reducing the weight of the trains.

But the metro cannot do everything or predict everything. *“It has its role to play, we can prepare it for certain situations but it is not alone, it functions on a network.”* Maud Bernard reminds us that the local systems are a major factor of resilience, in the sense where the solutions that need to be mobilised in the case of a crisis are above all organisational. A systemic approach must take into account the additional offers of transportation, and on a larger scale, it must also be able to be linked to the question of urban planning, the localisation of our activities and land use.



The metro in 2035: three scenarios for a station of the future

The metro is destined to remain a pillar of urban mobility. As a quick and practical mode of transport, it is the best option for serving the development of large conurbations, particularly to meet the challenges of climate change. Public transport powered by electricity is the most obvious way of reducing the greenhouse gas and particle emissions generated by traffic congestion. Its underlying principles correspond to the main objective of sustainable development. Making the metro attractive, now and in the future, will rely heavily on improving access, signage and information systems. New technology will play an important role and will streamline travellers' journeys. Likewise, with more efficient operating and maintenance, the equipment is becoming increasingly available. But the metro is not just a means of transport. It is also a space that embodies the town, expressing part of its identity. Stations evolving at the pace of urban evolution and the changing rhythm of life could change the face, and even the very definition of the metro. Illustration in three scenarios.

TEXT
Benoît Hervieu

ILLUSTRATION
Nelson goncalves

1. From station to multimodal transport hub

By 2035, underground stations will look completely different. Traditional turnstiles will have disappeared. Personalised signage will be everywhere, using real-time connectivity. More accurate information about the density of passengers in trains, along with suggestions for alternative routes, will improve the management of traffic. Passengers will not be so frightened of succumbing to thrombosis during the rush hour. Accessibility for persons of reduced mobility will improve, with special ramps, reserved lanes and above all, better laid-out trains. Passengers will not mind lingering in stations featuring retailers and cultural amenities. Some of these stations will be turned into multi-service hubs, featuring libraries, exhibitions, and cultural offerings. Others will be converted into art galleries, laid out like the Stockholm metro to cater to travellers' physical and psychological comfort. Stations that are multimodal hubs will become the norm. They will ease connections between metros and other means of transport, both vertical (lifts, flying taxis) and horizontal. All hubs will offer parking space for human powered and electric bikes. Traffic management systems will control these exchange nodes, coordinating the various transport fleets.

2. Bio-inspired stations, to mark a new era

2035 will be the start of a new era. The ecological and energy transition, oft announced, obstructed or delayed, will have finally greened our towns. The metro station will become a symbol of the decarbonised paradigm and the circular economy. Designed as a town within the town, it illustrates the 'cradle to cradle' process. All materials are recycled and recyclable, and even the functions of the station can be modified in the long term. The

**Paola Arellano, Head of the Architecture
Department at SYSTRA, France**

"In the future, people will no longer need to be mobile on a daily basis or follow a routine. People will travel more by pleasure than by necessity. And thus, the success of the metro of the future, like all other modes of transportation, will depend on its capacity to offer a rich experience for the passenger. Stations, the first interface between the passenger and the system, will thus need to meet all the passengers' expectations in terms of society and sustainable development. In order to make it, they will have to be more flexible and adapt to the new practices that have yet to be invented."

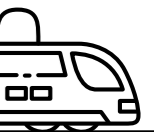
station will become the launchpad for the innovative town, booting the new green metro further upstairs. It will contribute to the power-saving effort for the line, using the energy recovered by regenerative braking to power its activity.

Now stations will combine aesthetics, technical quality and high green ambitions. Zero waste will be an integral part of its design and operation. Vegetation will no longer be used as greenwash, but it will offer a shared access to biodiversity in new areas. Bio-inspired stations will also use optimised natural ventilation, to resolve the sensitive problem of particles in stations, and their repercussions on people's health. Good collective hygiene will be a high-priority requirement. Dematerialised access controls and automated door opening on trains will reduce tactile interaction. Anti-bacterial materials will be specified in building standards. Bio-inspired stations will be linked to the digital era. The digital footprint of services will be factored into the carbon neutrality calculation.

Will there be enough political determination to back such an ambitious transformation?

3. Access and stops, the end of stations

By 2035, the station mall will be firmly established as a cornerstone of the metropolitan tissue. The growth of this model will mark an even more radical step than the creation of multi-service areas. Underground space will have been transformed following the example of 63,000 sites in Tokyo (of which 40% is connected to the metro) and the famous Montreal RESO, extending over 32 kilometres of tunnel. In Paris, the Hôtel de Ville metro station has set an example by offering direct access to the BHV department store in Rue de Rivoli. The metro moulds itself to match the town it serves. The traditional barriers between urban and transport areas will be abolished. Travellers will choose between walking along underground corridors and taking the metro, according to how much time they have to spare. The number of accesses to a single place will question the very concept of the station. Once again, this prospect will raise the major topic of financial investments. Such a project will change the role of underground urban space, independently from the metro to which it owes its existence. Will travellers adapt to it?



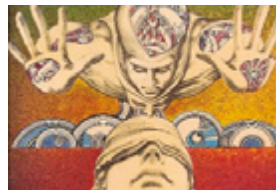
The metro in SF

Science fiction, after the twenties, probably would have been more interested in spatial vehicles than underground trains. And yet, whether it be as a matrix symbol or an elegant alternative to other modes of ground transportation, the metro has continued to stimulate the imagination of the creators of alternative worlds.



The Cristal Age, Michael Anderson (1976)

Both a utopia and a dystopia, this film depicts a society living an idyllic existence in the 24th century (until the age of thirty at least) in a world under a bell jar. People circulate in a sort of monorail metro, composed of transparent and tubular aerial sections, foreshadowing some very realistic projects like the Dubai metro.



Steal caverns, Isaac Asimov (1954)

This novel by the master of SF talks about an underground world where humans live for the most part in fear of what can be found on the surface. Their preferred mode of transportation, oddly, is not the metro that we imagine, but what allows us, in "real life", to change metros faster at Montparnasse or Châtelet: very sophisticated conveyer

belts with different speeds, whose usage is quickly mastered and becomes second nature to its users.



Batman Begins, Christopher Nolan (2005)

In this "reboot" of Gotham's super-hero saga, a flashback scene shows us millionaire Thomas Wayne and his wife with the young Bruce—the future "Dark Knight"—on a retro-futurist above-ground metro. "Did you build this Dad?" asks the young boy. "The city has suffered and needs something to reunite" explains the philanthropist. As an ironic answer, the metro becomes the matrix of evil—or at least, of social discomfort—in the recent *Joker*.



A Metro Named Möbius, Armin Joseph Deutsch (1950)

We owe this intriguing short-story to astronomer Armin Joseph Deutsch. It depicts the

strange disappearance of one of the subway cars in Boston after a new interconnection was inaugurated. Impossible to find the train, even if the latter keeps on pulling electricity from the network and activating signalling. What if the topologic complexity of the network had generated an "infinite interconnection", beyond the rules known to space and time? A beautiful premise, transposed in Buenos Aires in the movie *Moebius* in 1996.



The Matrix Trilogy, Les Wachowski (1999-2003)

The Wachowski sisters' trilogy managed to introduce clever discrepancies in a seemingly ordinary environment that allows one to slip into a virtual world. During the saga, we meet Trainman, who rules as a demi-god in a metro station called Mobil Avenue. The station appears like a sort of landing, an intermediary between worlds, and you can only get out if the Trainman decides so. The choice of the metro to introduce this idea of interconnection in space and time is probably not fortuitous.



Quadrail series, Timothy Zahn (2005-2012)

The novel series is a considerable step away from the concept of the metro as we know it, but pays a very nice tribute to it. The "Quadrail" which gave the saga its name is a transportation device on rails, which allows trains to travel in tubes where absolute emptiness reigns: we discover here, in broad terms at least, the concept of the metro with compressed air. However, here, the Quadrail allows one to do interstellar travel. It is a sort of metro on the scale of the universe.

We would like to thank...

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...For having imagined together the metro of tomorrow

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The future of the metro lies between the lines

A lot has happened since the first metro hit the rails 150 years ago. It looks as though the best is yet to come. Let us read between the lines, to find out what the future has in store, mixing surprising anecdotes and major evolutions.

2022



More people telecommute, travelling on foot and by bicycle. Thanks to chrono-urbanism and diversified office hours, rush hours and jam-packed commuting have become things of the past. Since the epidemic, metros have become *health friendly*.

2023



Dematerialised payments and free transport make contactless access to metros the norm. Metro stations begin their transformation, opening up to their surroundings. Inspired by termite mounds, Zimbabwean architects help European engineers to bring more light and air to the underground. The Guardian headlines 'More light and speed for

underground transport. Forget about travelling at the speed of light!

2027



The World Metro Congress hosted the launch of a new range of trains made of super materials to cope with extreme weather conditions in southern countries. Among other features, they are sheathed in an ultralight organic coating to resist saline groundwater, they have a mud and sand discharge device, and a king-size gyroscope guaranteeing zero vibrations during an earthquake.

2029



Regenerative braking has been installed and optimised in most metros, and any

excess power is fed into the neighbouring electricity grid.

2030



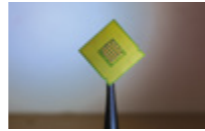
160 years after its creation to relieve horse-drawn traffic jams, metros are expanding worldwide to alleviate traffic pollution. Great metropolises gradually reduce access for motor vehicles. *Le Monde* headlines: 'Quit your car, catch a metro', the *New York Times* proclaims: 'Metro goes mainstream.'

2034



People shelter from freak weather in metro tunnels. Concrete tunnel walls offer geothermal cooling in hot weather and warmth in winter.

2045



Inspired by the Brazilian invention of 'Ticket Books', novels containing travel passes on embedded RFID chips, companies compete to invent the next must-have in metro tickets. After tickets inserted in shoes, ticket tattoos compete for the limelight with implants and biometric identification.

2060



Mini-trains glide along slim steel viaducts from station to station, bringing to life scenes from science fiction in our town centres. Perhaps those flying cars they used to make such a fuss about were actually metro trains.

SYSTRA