Paris metro line 1, a story of migration to driverless operation
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July 1900
Inauguration of Paris first metro line

111 years after

November 2011
First driverless shuttle running on line 1
Paris metro line 1, a story of migration to driverless operation

1. Overview of the Paris Metro Network, and RATP’s modernization programme
2. CBTC a modern railway technology, grades of automation
3. Main reasons for choosing line 1
4. Technical choices and challenges
5. Project milestones, and migration strategy
6. Main outcomes, lessons learnt and coming next
RATP, a national public service company

State-owned national company created in 1949 as a public service company

One of the worldwide largest public transport network:

- **RER (Suburban)**
  - 2 lines (A & B)
  - 115 KM (double tracks)
  - 67 Stations
  - 369 Trains
  - 469 million travels/year

- **Bus & Tramway**
  - 347 Bus routes
  - 3 Tramway lines
  - 3825 KM
  - 7388 Stops
  - 4490 Buses + 139 Trams
  - 1109 million travels/year

- **Metro**
  - 14+2 lines (1 to 14)
  - 205 KM (double tracks)
  - 302 Stations
  - 699 Trains
  - 1523 million travels/year

All figures 2012

RATP - Engineering department – Railway Transportation Systems div.
Traffic growth: +18% within the last decade

Traffic flow evolution 2001-2011
(base 100 in 2001)
Network extensions

Metro Lines extension:
- M13 in 2008, M8 in 2011, M12 in 2012 (then in 2017), M4 in 2013 (then in 2019)
- M14 in 2005, 2007 and then in 2018
- M11 (projected) in 2019

Tramway Lines extension:
- T2 in 2009 and 2012, T1 and T3 in 2012

New Tramway Lines
- 4 more tramway lines to come by 2015

Coming next
- “Arc-Express / Grand-Paris” project (200 Km with 72 stations, surrounding Paris, driverless mode)
An Answer: Technology Modernization

Rolling stock replacement
  • With better performances and improved diagram

Passengers Information Enhancement
  • With both trainborne and station side dynamic information

OCC New generation
  • For enhanced line management

Track Circuits replacement
  • Replacement with CVCM frequency based track-circuits

Signals replacement
  • Using LED bulbs

Interlocking renewal
  • With Computerized Interlocking

Passenger exchange control
  • With Platform Screen Doors

Automatic Train Control Performances Increase
  • With CBTC Technology  both GOA2 and GOA4
Main Objectives through Modernization

Obsolescence reduction
- Replacement of older systems, tricky to maintain (components & knowledge obsolescence)

Safety improvement
- Compliance with new safety standards (CENELEC)
- Continuous speed control (incl. in manual driving mode)

Passengers capacity increase
- Headway, Regulation, Trains diagrams

Quality of service increase
- Availability & maintainability of new systems
- Performance of degraded modes management
- Passenger exchange control (Platforms screen doors)

Operation Costs reduction
- Reduction of staff in terminus (centralized OCC)
- Less staff for line operation (when in driverless mode)
- Less trains (thanks to commercial speed improvement)
- Energy savings (with dedicated driving profiles in ATO mode)
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CBTC = Communication Based Train Control

- Train location determination to a high precision, independent of track circuits.
- Continuous, bi-directional RF (radio frequency)
  - communications between train and wayside, to permit the transfer of significantly more control and status data than is possible with conventional systems.
- Vital train borne and wayside processors to provide continuous Automatic Train Protection (ATP)
Typical CBTC System Architecture
CBTC Basic Functioning Principles

CBTC Basic Principles for Train Movement Control

• Trains localization:
  - Each train self-localizes on the track, using an odometer (various technologies exist), and synchronize with trackside beacons,
  - Each train transmits periodically its position to the ground,

• Trains follow-up:
  - Ground computers follow trains movements through a cartography of the track,
  - Ground computers compute safe targets for each train, according to their position together with interlocking conditions, and transmit them to the trains

• Trains safety:
  - Onboard computers ensure permanently the respect of safe targets and speed profiles (according to the track profile and fixed or moving blocks strategy),
  - Onboard computers activate emergency braking if any non-safe condition occurs
CBTC Train Protection Strategies: Fixed Virtual Blocks versus Moving Blocks

When in mixed fixed & moving block strategy
CBTC: a Market Trend for Train Control Technology

- Communication Based Train Control (CBTC) systems have been in service since 1985.
- CBTC has become the technology of choice for urban rail systems in the last 15 years.
- CBTC is the preferred choice for Unattended Train Operation (UTO) systems
CBTC Grades of Automation (UITP)

- **GoA 1**: ATP with driver
  - Setting train in motion: Driver
  - Stopping train: Driver
  - Door closure: Driver
  - Operation in event of Disruption: Driver

- **GoA 2**: ATP and ATO with driver
  - Setting train in motion: Automatic
  - Stopping train: Automatic
  - Door closure: Driver
  - Operation in event of Disruption: Driver

- **GoA 3**: Driverless
  - Setting train in motion: Automatic
  - Stopping train: Automatic
  - Door closure: Train attendant
  - Operation in event of Disruption: Train attendant

- **GoA 4**: UTO
  - Setting train in motion: Automatic
  - Stopping train: Automatic
  - Door closure: Automatic
  - Operation in event of Disruption: Automatic

**ATP** - Automatic Train Protection

**ATO** - Automatic Train Operation
**Expected Evolution in Automated Lines - in Km-UITP**

**UTO (GOA4) forecasted growth is mainly driven by new lines (Greenfield projects)**

*(less than 10 GOA4 migration projects identified so far)*
CBTC technology deployment in Paris metro network

RATP current CBTC Projects

- **GOA4 existing**
  - (SAET L14)
  - (SAET L1)

- **GOA2 existing**
  - (OCTYS L3 & L5)

- **GOA2 on progress**
  - (OURAGAN L13)
  - (OCTYS L9)

- **GOA4 projected**
  - (SAET L4)

- **GOA2 projected**
  - (OCTYS L11)

- **CBTC projected**
  - (all other M° lines)
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Line 1 Main Characteristics

Build in 1900, then extended to current configuration:
- 16.4 km and 25 stations (including 12 interchange stations from which 5 major multimodal)
- Heavy loaded line not only during rush hours but also off-peak hours, week ends & holiday periods

Oldest:
- 111 years old

Fastest:
- commercial speed over 27km/h

Busiest:
- 725 000 passengers per day

Crowdest:
- up to 24 000 pphpd
Line 1 facing recurrent regularity issues

Sources of service disruptions (2005):
- Operations: 72%
- Rolling stock: 13%
- Tracks & signalling: 6%
- Miscellaneous technical: 5%
- Passengers: 4%
Line 1 ageing infrastructure

Signalling 1956

ATO system 1972

OCC 1967

IXL 1964

A recent rolling stock (1989) but...

... line 4 stock (1959) to be replaced
Feasibility study carried out in 2003

Main conclusions:

Technically feasible but complex:
- Curved stations (40m radius…)
- No traffic disruptions
- Day to day works on existing line
- Daily interfaces management between suppliers and conventional maintenance
- Mixed traffic operation during handover
- Social transition from GOA2 towards GOA4

Financially advantageous
- The additional cost for automation is offset by the reduction in the rolling stock fleet and the operation cost without drivers

The project was launched in 2004
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Program organization

1 program; 5 projects:
1) CBTC, Signalling, OCC and PSD
2) Comm. and Passenger Info
3) Civil Engineering (platforms)
4) Rolling Stock
5) Operation and Social organization

System integration by RATP:
• system safety demonstration and sub-systems safety verification,
• Interfaces management,
• installation works coordination
• system test & commissioning

Operational constraints:
• No traffic interruption
• Work shifts of 3 hours per night
• Maintenance works “as usual”
Major choice : Rolling Stock

Decision to buy new Rolling Stock
- transfer the current one (MP89) to line 4 whose Rolling Stock (MP59) needed to be renewed (Network opportunity)
- Rolling Stock functional requirements for line 14 and line 1 are identical

Trains characteristics evolution:
- New Interior fitting (diagram)
- New passenger information system (with video based on WIFI radio transmission and voice communication through TETRA)

Contract awarded in 2006 to ALSTOM
Major choice: Interlocking

Same level of performance (headway)
- Needed for mixed operation period
- Additional functions for driverless operation (interlock inhibition in case of trackside components failures: track circuits, point position controls)

Signals equipped with LED bulbs

Computerized interlocking in terminus
- Implementing “RATP’s generic signaling principles”
- Application Engineering by RATP teams
- Introducing the new “formal proof” safety demonstration method

IXL Contract awarded in 2003 to THALES (global contract for 6 lines)
Major choice: track protection

72% of the regularity issues are related to the passengers.

- Passengers using the tracks as a “shortcut” (once a day per line)
- Passenger falls (one a month per line)
- Passenger blocking the closing doors and being entrapped
- …

RATP’s rules and local regulation

- To stop the operation and shut off the third rail until people are safe
- To get the ready to proceed from the head of police
- To check no one is entrapped
- …
Major choice: junction track protection

The entire tracks to be protected for all kind of intrusion:

- Need for junction tracks protection
- With interlocked closing grids

RATP - Engineering department – Railway Transportation Systems div.
RATP started a benchmark in 2002 to evaluate the solutions for platforms. Two alternative systems were analyzed:

- **Guideway Intrusion Detecting System (GIDS)**
  - Systems based on electronic sensors (laser, IR, radar, pressure mat)
  - Used in Vancouver, Copenhagen, Lyon, Nuremberg
  - SIL 2 only and does not stop the people entering onto the tracks

- **Platform Screen Doors (PSD)**
  - Systems based on glass or aluminum doors and gates
  - Used in London, Paris, Asia
  - SIL 3 achievable and stop the people entering onto the tracks

**PSD solution chosen for the safety level and the improvement on the availability**
Three kinds of Platform Screen Doors evaluated:

- **Full screen**
  - Mostly used in Asia, due to air conditioning requirement. Most expensive.

- **Full height**
  - Most common system at that time (Jubilee Line, Paris L14…)
  - Provides full protection but requires strong and heavy platforms

- **Half height**
  - New system, used in Asia in retrofits on existing lines
  - Easier and quicker to install on existing lines, cheaper and less intrusive

Half height doors seemed to be the most suited for Line 1; RATP launched an experimentation with 3 suppliers to validate technical solutions
Major choice: platform/track protection

Kaba – Invalides
Major choice: platform/track protection

Faiveley – St Lazare dir. St Denis
Major choice: platform/track protection

CNIM – St Lazare dir. Chatillon
Major choice: platform/track protection

Contract awarded to KABA (GILGEN) in 2006

- Half height doors (1.7m)
- Important platform enabling works (both for structure consolidation and height alignment)
- PSD installed during revenue service at night, without disturbing the normal operation of the line
Major choice: platform/track protection

PSD: at the heart of the system
PSD need to be deployed first (before arrival of the 1st shuttle):

- Need for an interim PSD control system (DOF1):
  - Compatible with current rolling stock, manual driving mode and legacy ATO
  - DOF1 provides doors control sequences (SIL3) and trains departure authorization (SIL4)

Contract awarded to CLEARSY in 2007
Major choice: platform/track protection
Major choice: platform/track protection

Important gaps remaining on some curved stations

- The gap has been reduced using mechanical means:
  - For the narrower gaps: a passive horizontal aluminum bar at 1m height
  - For the medium gaps: an active horizontal aluminum bar at 1m height, interlocked
  - Flexible steps for lower gaps (under the level of platforms) entering the KE of the trains
Important gaps remaining on some curved stations

- For the wider gaps, need for an innovative entrapment detection system (DIL) using laser scrutinizers:
  - interlocked with PSD system to stop train departure
- Installed in 3 stations (18 doors)

Contract awarded to CLEARSY in 2009
Re-use of line 14 specifications with functional adaptations:

- **Better performance:**
  - Introducing moving blocks, commercial speed improvement, PSD controls, …

- **Additional features:**
  - Energy savings, trains preparation/depreparation management, degraded modes management …

- **Line 1 specifics requirements:**
  - Outdoor train operation, reduced trains sidings length, PSD gaps management,…

- **Mixed operation constraints**
  - Trains spacing, movements in sidings,…

**Technical evolutions**

- Radio train to track transmission @5.9 GHz
- Video projected overhead control panel
- System test bench for validation tests

**Contract awarded in 2006 to SIEMENS**
Independent from CBTC

- **On board functions**
  - Passenger emergency communication (w/ OCC), Passenger audio information system & discrete listening via TETRA
  - CCTV, passengers information messaging and Maintenance data transmission via WiFi 802.11 a (5.2Ghz)

- **Stations functions**
  - Platforms audio information system
  - Platforms & PSD CCTV
  - PSD local control panel intercom.

- **OCC functions**
  - Intercom. with trains passenger (PEC) or roving staff (w/ portable device)
  - Passenger Information System (PIS) control
  - Video surveillance display (both on board and station)
  - Recording of all communications

**Contracts awarded in 2006 to various suppliers**
- AMESYS, ALSTOM, ALCATEL LUCENT, GE, TELINDUS, CAP GEMINI, NEXTIRA-ONE
Basic safety approach: GAME (vs. ALARP)
• Globally Equivalent to Previous Similar Systems

Overall System safety case produced by RATP
• RATP acting as « integrator »

Safety critical systems using « formal methods »
• IXL (CBI): formal proof method developed by RATP (model checking approach)
• ATC (CBTC): B method initiated with SACEM in 1989 and developed for METEOR L14 in 1998

RATP’s double check as per internal policy 1993
• Independent from ISA assessment
• Covering systems, software and hardware levels
## The systems in figures

<table>
<thead>
<tr>
<th>Category</th>
<th>Quantity</th>
</tr>
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<tbody>
<tr>
<td>49x6 cars trains</td>
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<tr>
<td>On-bord Safety Computers</td>
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<tr>
<td>Controllers</td>
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<tr>
<td>Remote Safety I/O Modules</td>
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<td>5 Operating Positions in OCC</td>
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<td>Technical Rooms</td>
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<td>Beacons on track</td>
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<td>Video Projectors in OCC</td>
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<td>Access Points</td>
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<td>Trainborne Video Displays</td>
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<td>Comm. Servers (12 Operating Positions)</td>
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<td>2268 Platform Screen</td>
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<td>Doors</td>
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<td>Entrapment Detection Systems</td>
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<td>Interlocked Routes</td>
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<td>Signal Boxes</td>
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<td>Track Circuits</td>
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6. Main outcomes, lessons learnt and coming next
Paris metro line 1, Overall schedule & project milestones

Feasibility studies
Writing of specs
Call for tender
Detailed design
System installation
Track works & Signalling renewal
System test & commissioning at night
Legacy system removal


Project launch
Contracts awards

PSD installation
Shadow mode testing
Mixed fleet op.
1st shuttle in driverless mode
100% driverless
Occ renewal
Final system release
Migration Principles in 6 steps
Initial situation

- 16.4 Kms, 25 stations from which 12 interchange stations
- 52 trains fleet (6 cars consist)
- 105 seconds headway peak hours (24 000 pphpd)
- Manned train operation with “speed code” ATC (early 1970’s)
Migration Principles in 6 steps
Step 1: Signalling and trackside enabling works

- Modernization with computerized interlocking in terminus
- Signals with LEDs bulbs, Beacons & Optical barriers inst.
- Additional signalling functions
- Modernization of HV controls
Migration Principles in 6 steps
Step 2: PSD deployment

- Installation of a remote PSD control on board trains and reception loops in stations (DOF1 system)
- Then, installation of PSD
Migration Principles in 6 steps
Step 3: Operation under supervision of new OCC

- DCS Installation (Backbone Network + Radio Access Points)
- Installation of Trackside Remote I/Os
- Replacement of OCC with integrated ATS/ATR
Migration Principles in 6 steps
Step 4: System Deployment

- Installation of System Trackside Zone & Line Controllers
- System Test and Commissioning at Nights (with first Driverless Train)
Migration Principles in 6 steps
Step 5: Mixed fleet operation

- Driverless Trains Operation together with Conventional Operated Trains
- Headway Remains the same (105 secs)
- Operating Staff still in terminus (as long as there is train drivers)
- System Tests continuing at night for advanced UTO commissioning
Migration Principles in 6 steps
Step 6: Driverless operation, full performances mode

- All Driverless Trains on line
- Whole operation from OCC (no more staff in terminus)
- Removal of DOF1 PSD Control System
- Removal of former Trackside ATC
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Paris metro line 1, Main outcomes

A successful social & technical challenge

- On planning (+9 months) and cost (+5%)
- No major impact on operation while migrating the systems (<1% passengers affected with stations closure)
- Improvement of operation staff role in a new organisation focusing on « passengers service »

Improvement of passengers service

- Transport production (in vehicle-kms) increased by 10% (with 3 less trains)
- Peak hour production from 92% to 98% (still growing)
- Immediate transport adjustment offer, ex:
  - Jan 2012: double train traffic from 20h15 to 22h due to line A major disruption
  - Jun 2012: service extension up to 2h15 due to presidential election
- Lowering impacts due to traffic incident

Return on investment estimated within 15 years
Key issues and lessons learnt

Key Success factors

• Involvement of L1 operating staff in the project
• Consider social reorganisation as a full project
• Development of passengers communication toolkit during the works
• Re-use of L14 METEOR system specifications (limited innovation)
• “Long nights” testing (up to 9:30 am on Sundays)
• Use of test track and system test benches
• Interface management at the heart of system integration
• Mixed mode operation
  ■ Automatic shuttles in « precaution mode » (respectful of signals)
  ■ Special operation in sidings (“safe zones” for drivers walking to reach their train)
• Coordination of installation works
  ■ With conventional maintenance works “as usual”
  ■ 13’500 work yards during 2007-2011 period (up to 350/week)

Main difficulty: curved stations

• Too many mechanical constraints with mid-height PSD
• Gap issues between train and platform screen doors
Paris Metro Line 4 in figures

North/south backbone of the Paris metro network

- Connected to all metro lines (13) and suburban lines (5)
- Complementary line to RER B and D in Paris (high density of passengers)
- South extension (3 stations) and future connection to Greater Paris network

Poorly predictable traffic demand

- Touristic areas, 3 major railway stations (TGV to France, Belgium, UK, …)

Operating key figures

- 29 stations – 13 km
- 105 s headway during peak hour
- Low regularity: 91.6% mainly due to passengers incidents

Project launched in 2013

Delays due to passengers disruptions
Comparison

Line 1
Line 4
Grand Paris project

Full driverless mode
- 200 Km double track (including extension of Paris lines 11 & 14)
- Steel wheels rolling stock (3-6 cars train consist)
- 72 stations
- Revenue service from 2018 to 2035

A dedicated project organization
- Capital program management by « Société du Grand Paris »
- Systems engineering by SYSTRA/RATP
- Infrastructure management by RATP
- Operation in competitive market
Thank you for attention