Institution of MECHANICAL ENGINEERS

Improving the world through engineering

RATP

RATP - Engineering department – Railway Transportation Systems div.

Paris metro line 1, a story of migration to driverless operation

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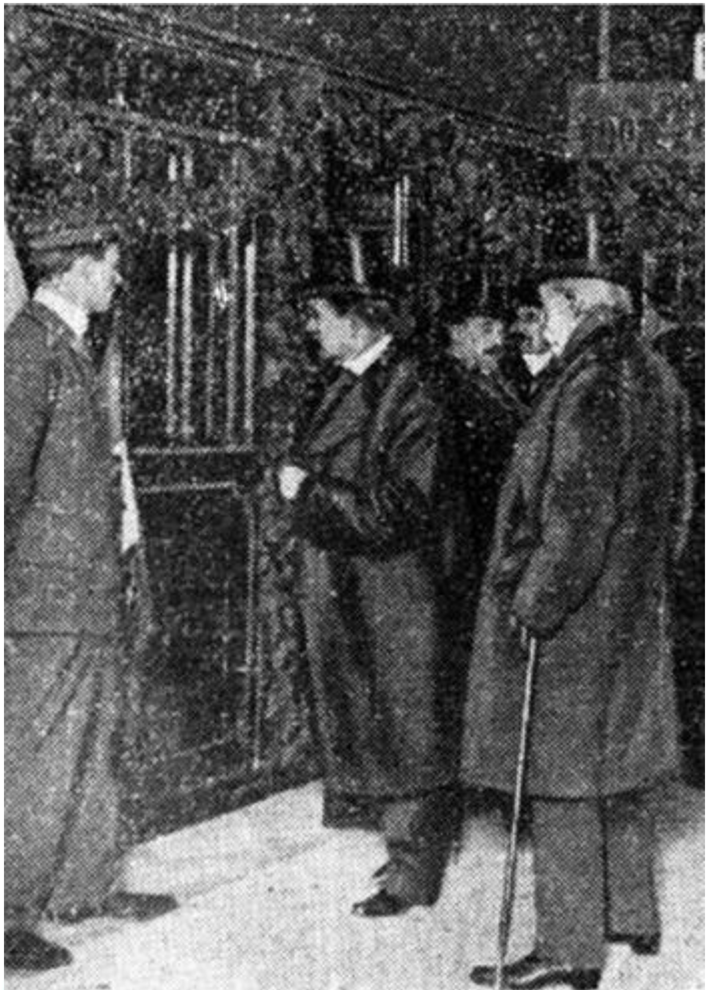


July 1900
Inauguration of Paris first metro line

111 years after

November 2011
First driverless shuttle running on line 1

© - RATP - Jean François Mauboussin 10825D03 - 03/11/2011

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:

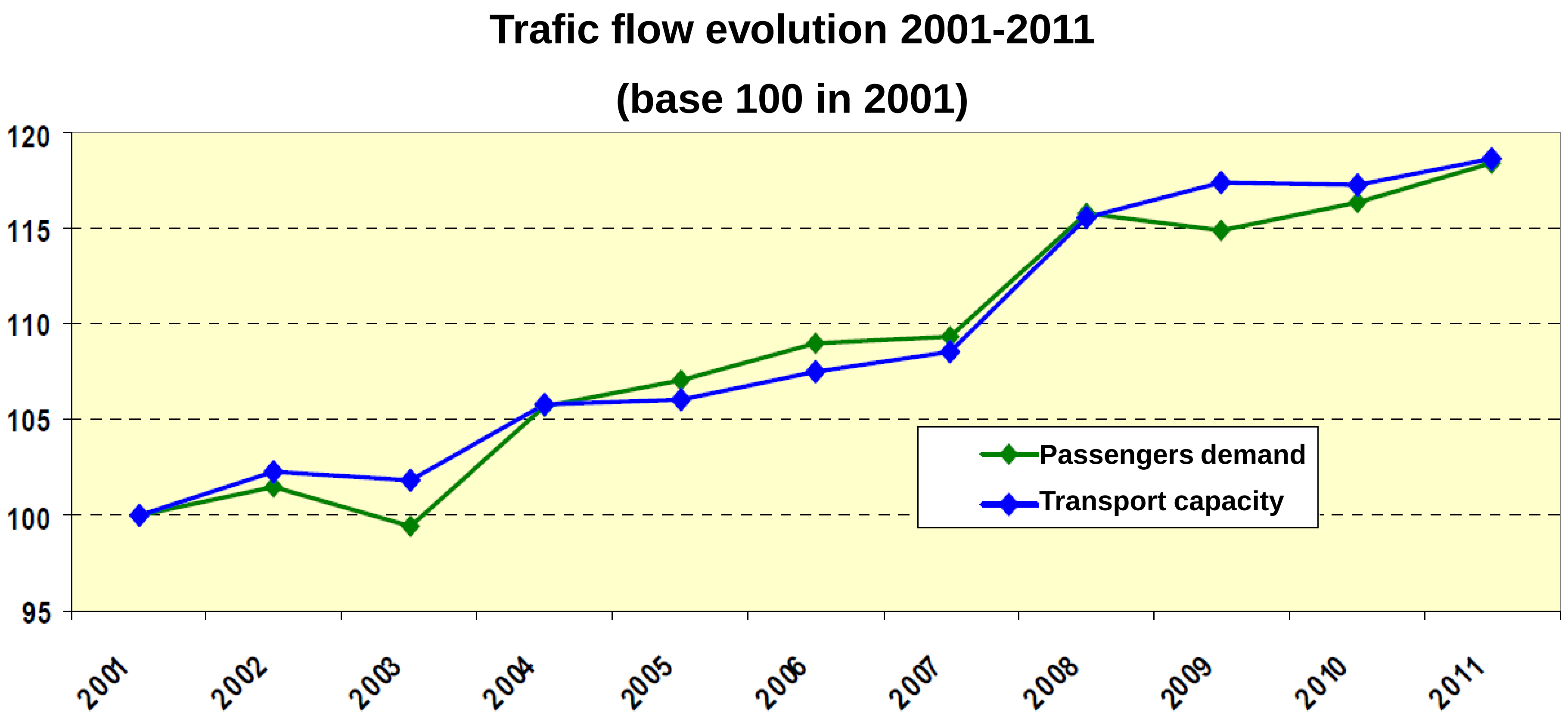
- **RER (Suburban)**
  - ✓2 lines (A & B)
  - ✓115 KMs (double tracks)
  - ✓67 Stations
  - ✓369 Trains
  - ✓469 million travels/year

- **Bus & Tramway**
  - ✓347 Bus routes + 3 Tramway lines
  - ✓3 825 KMs
  - ✓7 388 Stops
  - ✓4 490 Buses + 139 Trams
  - ✓1 109 million travels/year

- **Metro**
  - ✓14+2 lines (1 to 14)
  - ✓205 KMs (double tracks)
  - ✓302 Stations
  - ✓699 Trains
  - ✓1 523 million travels/year

All figures 2012

Trafic growth: +18% within the last decade



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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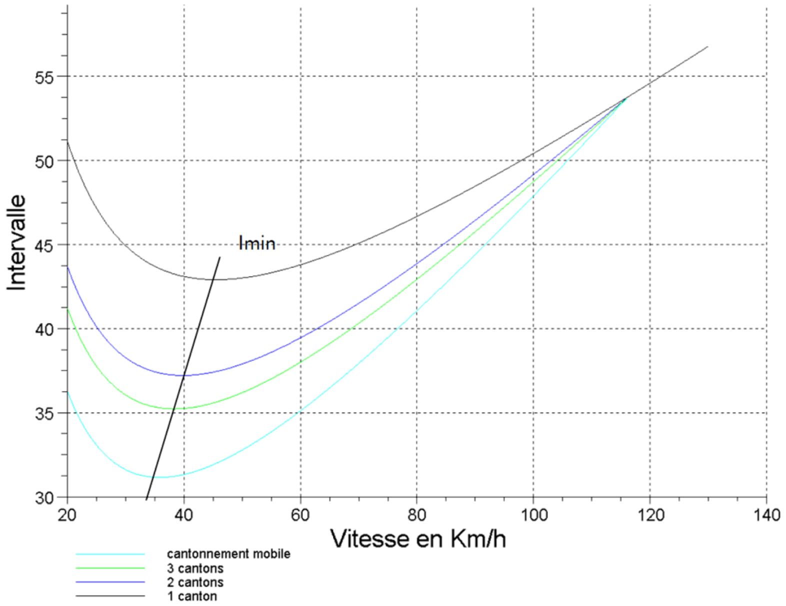
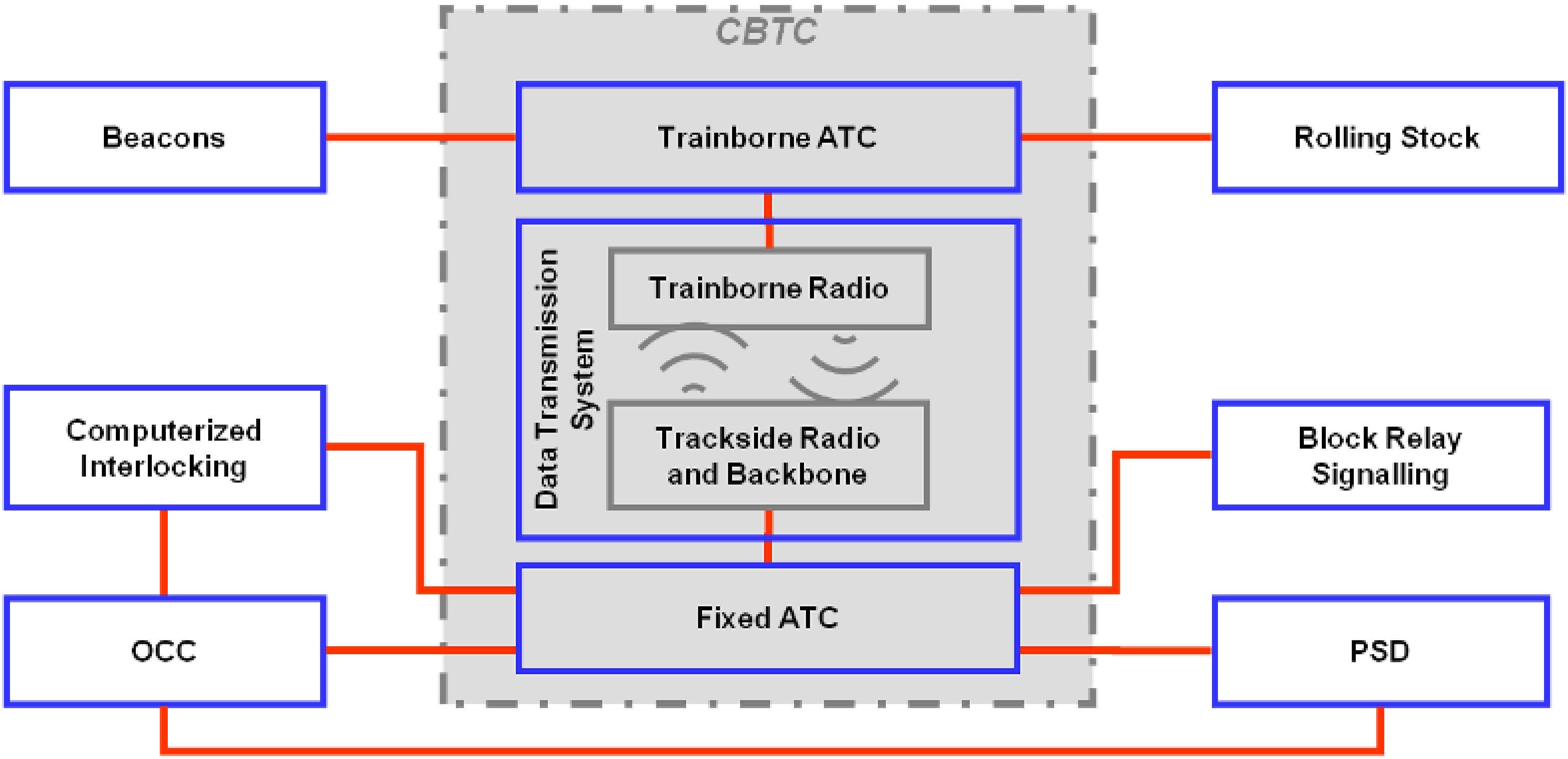
CBTC: technical definition as per IEEE 1474

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)



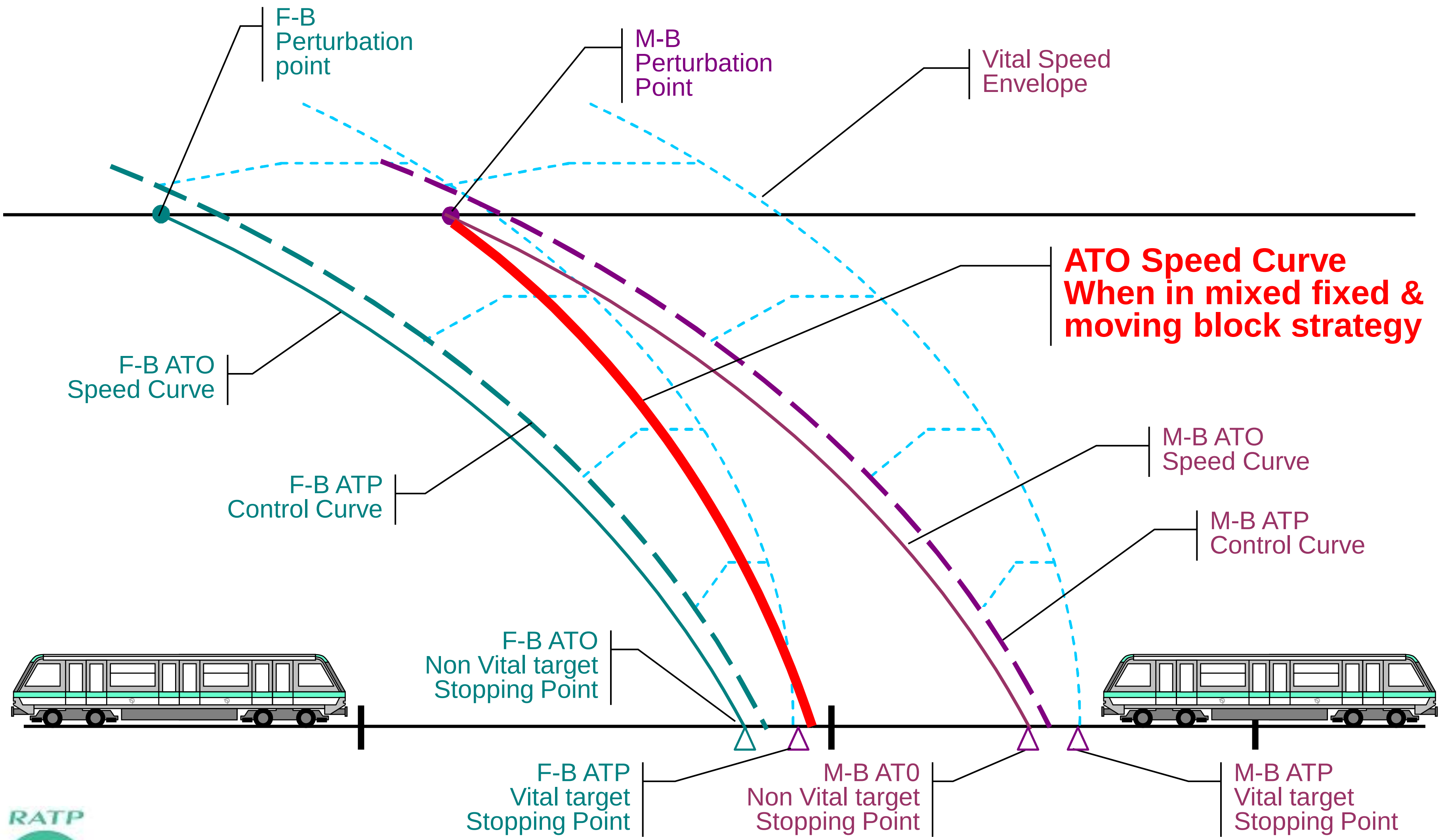
Typical CBTC System Architecture



CBTC Basic Principles for Train Movement Control

- Trains localization :
  - Each train self localize 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 trains, 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

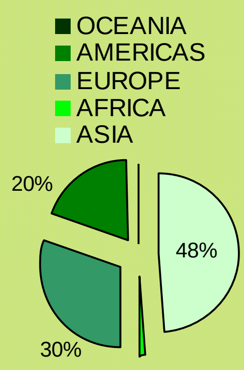
CBTC Train Protection Strategies: Fixed Virtual Blocks versus Moving Blocks

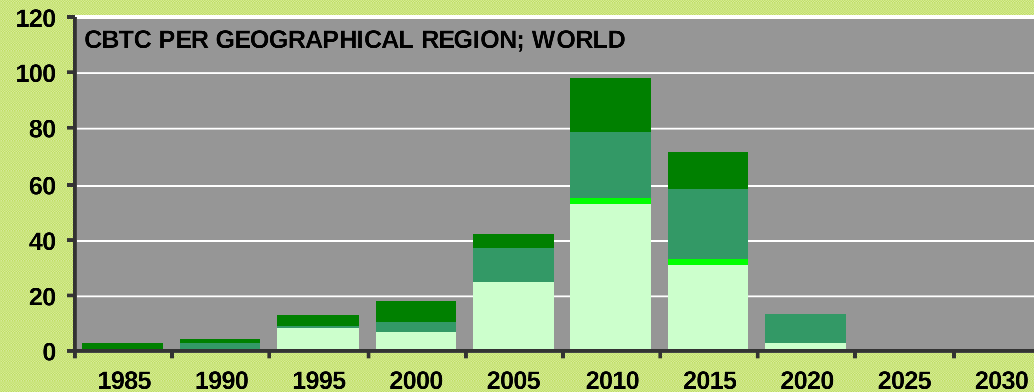


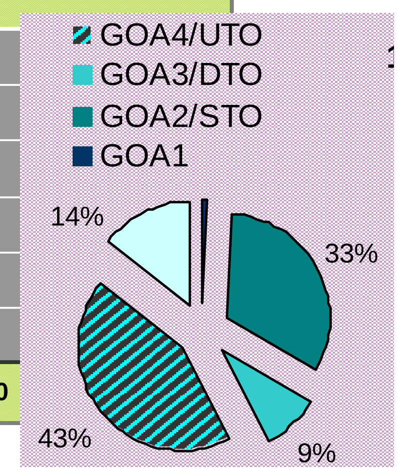
CBTC: a Market Trend for Train Control Technology

- 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 PER GEOGRAPHICAL REGION; WORLD												S/TOTAL
ASIA			8	7	25	53	31	3	1			128
AFRICA						2	2					4
EUROPE	1	3	1	3	12	24	25	10		1		80
AMERICAS	2	1	4	8	5	19	13					52
OCEANIA												





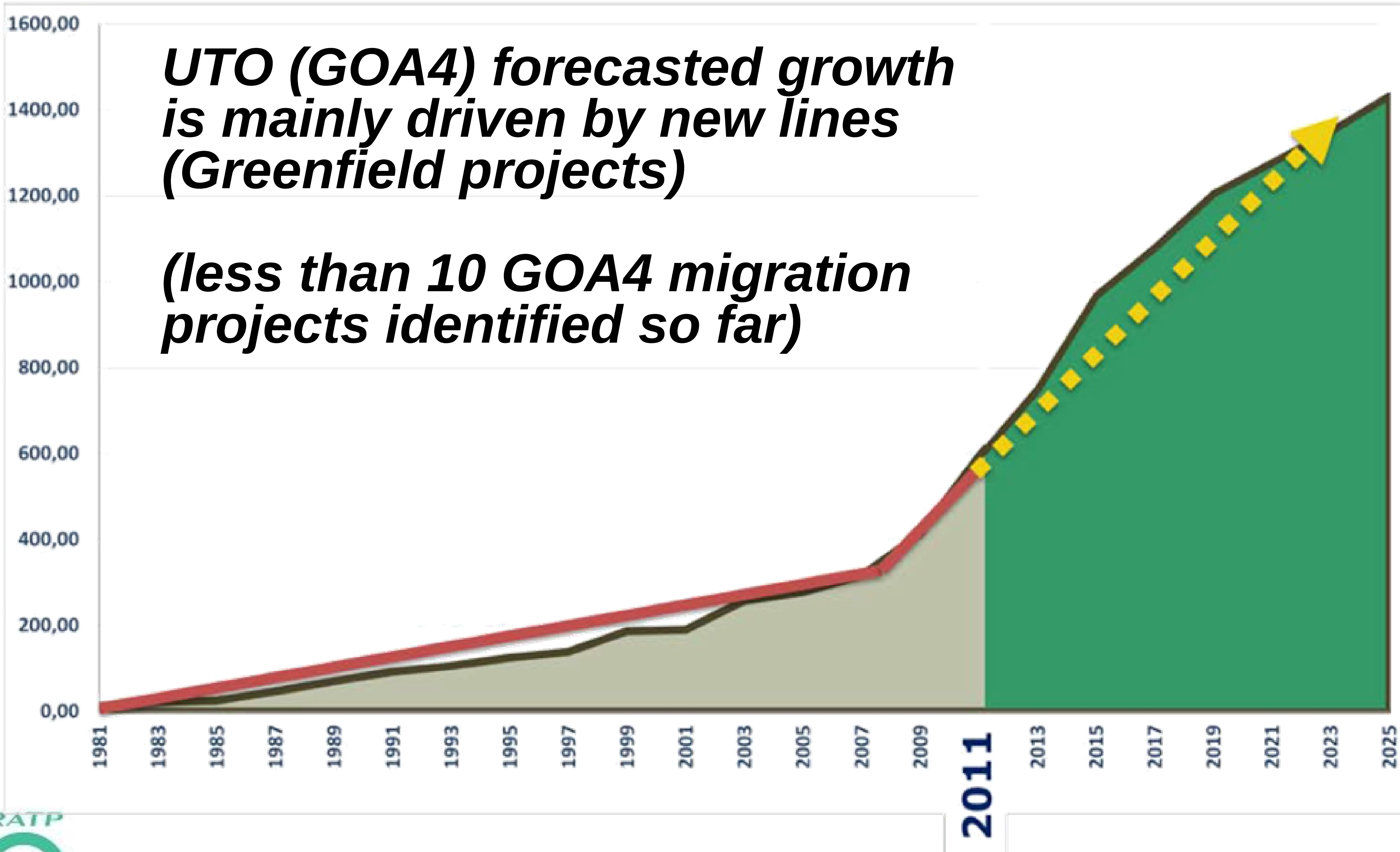


CBTC Grades of Automation (UITP)

Grade of Automation	Type of train operation	Setting train in motion	Stopping train	Door closure	Operation in event of Disruption
GoA 1	ATP with driver	Driver	Driver	Driver	Driver
GoA 2	ATP and ATO with driver	Automatic	Automatic	Driver	Driver
GoA 3	Driverless	Automatic	Automatic	Train attendant	Train attendant
GoA 4	UTO	Automatic	Automatic	Automatic	Automatic

ATP - Automatic Train Protection ATO - Automatic Train Operation

Expected Evolution in Automated Lines - in Km- (UITP)



CBTC technology deployment in Paris metro network

RATP current CBTC Projects

GOA4 existing
(SAET L14)
(SAET L1)

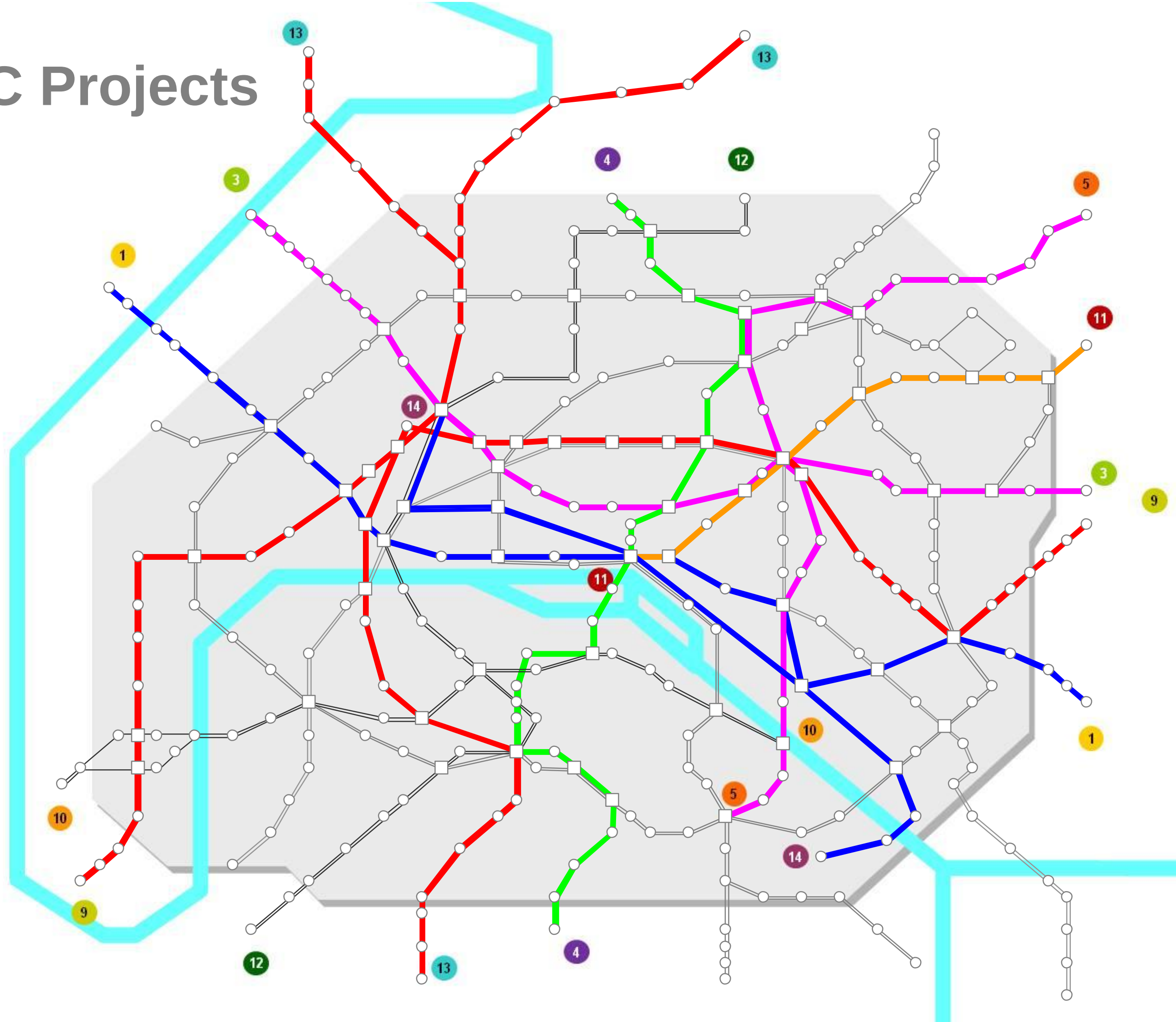
GOA2 existing
(OCTYS L3 & L5)

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 :

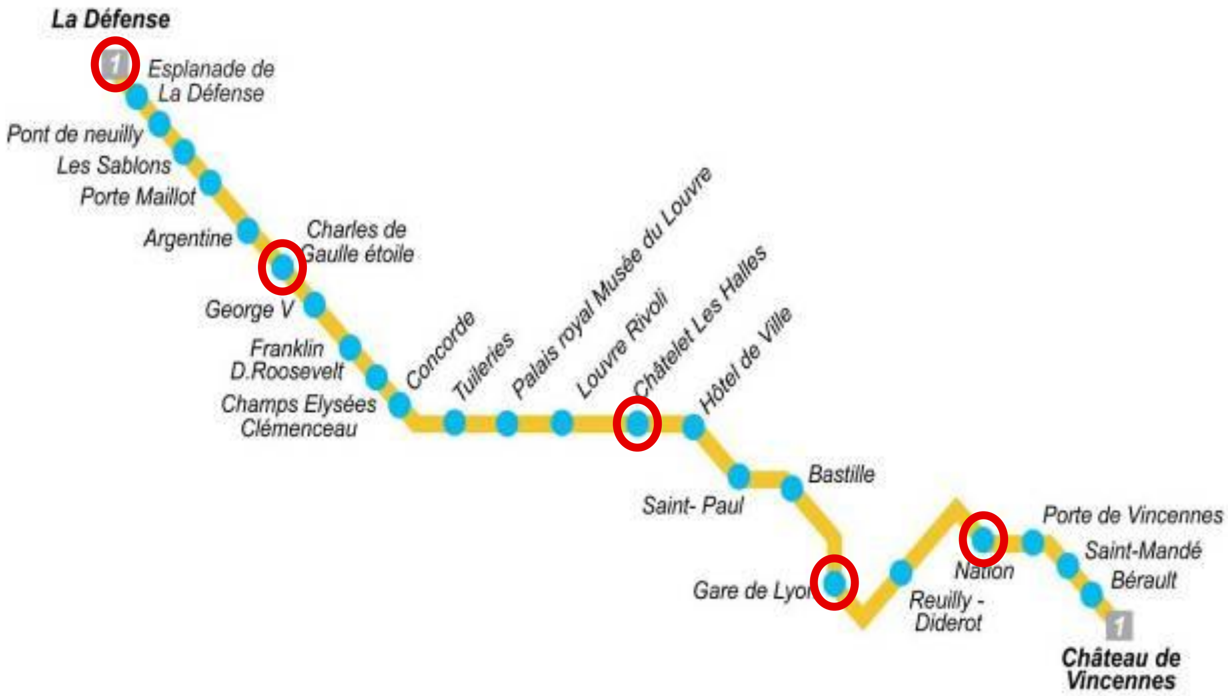
- commercial speed over 27km/h

Busiest :

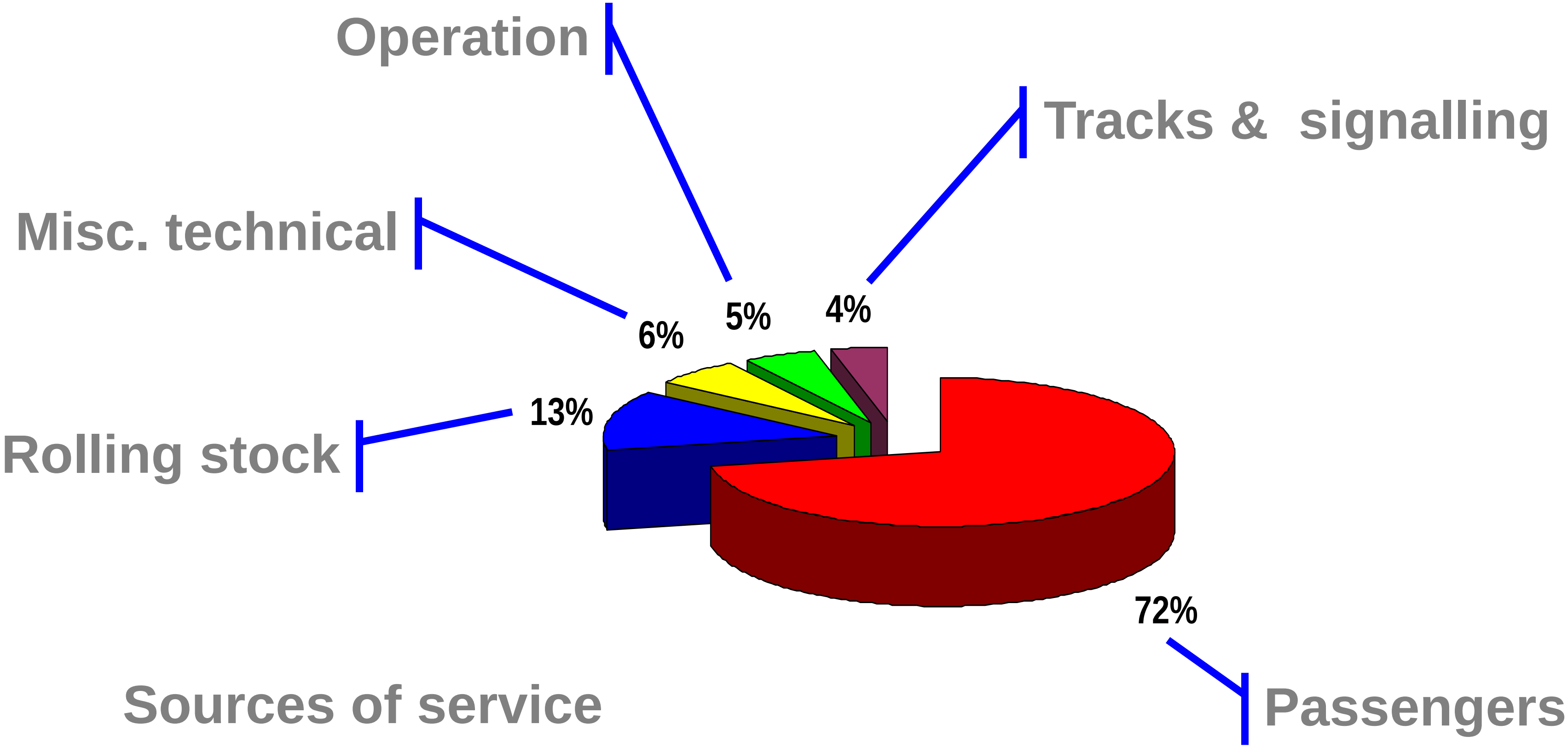
- 725 000 passengers per day

Crowdest :

- up to 24 000 pphpd



Line 1 facing recurrent regularity issues



Sources of service disruptions (2005)

Line 1 ageing infrastructure

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

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

Major choice: platform/track protection

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

Major choice: platform/track protection

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

 7272d20 - 21/03/2006

Major choice: platform/track protection

Faiveley – St Lazare dir. St Denis

Major choice: platform/track protection

CNIM – St Lazare dir. Chatillon

 7334d02 - 21/04/2006

Major choice: platform/track protection

© RATP - photo Bruno Marguerite - Portes palières métro ligne 1

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

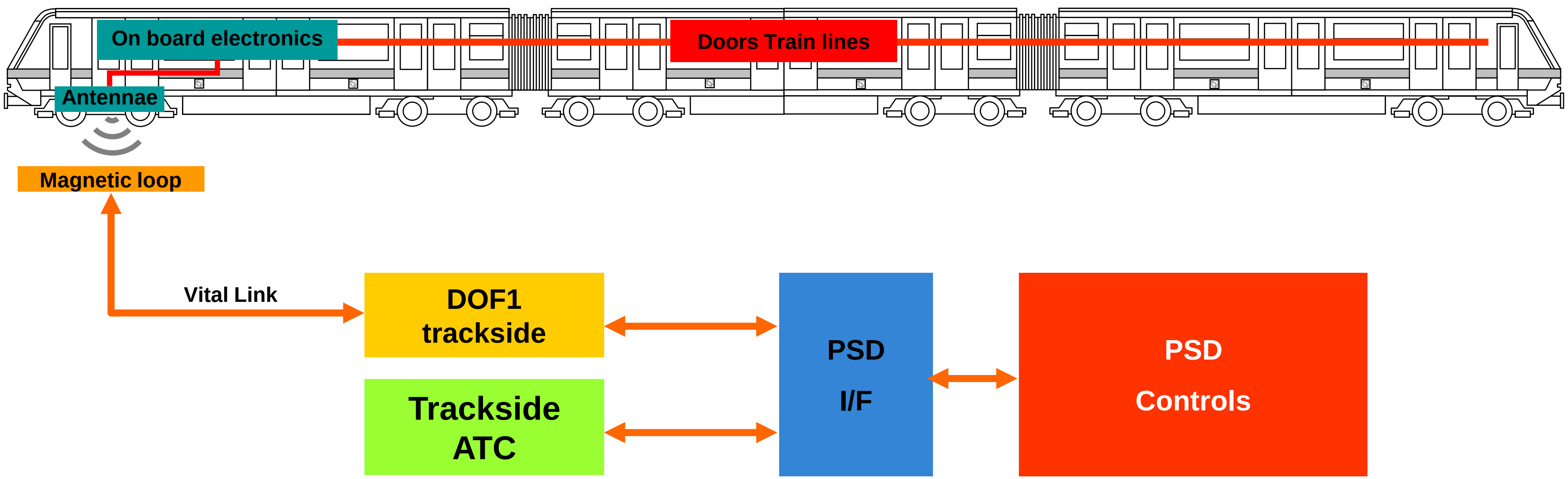
PSD : at the heart of the system

Major choice: platform/track protection

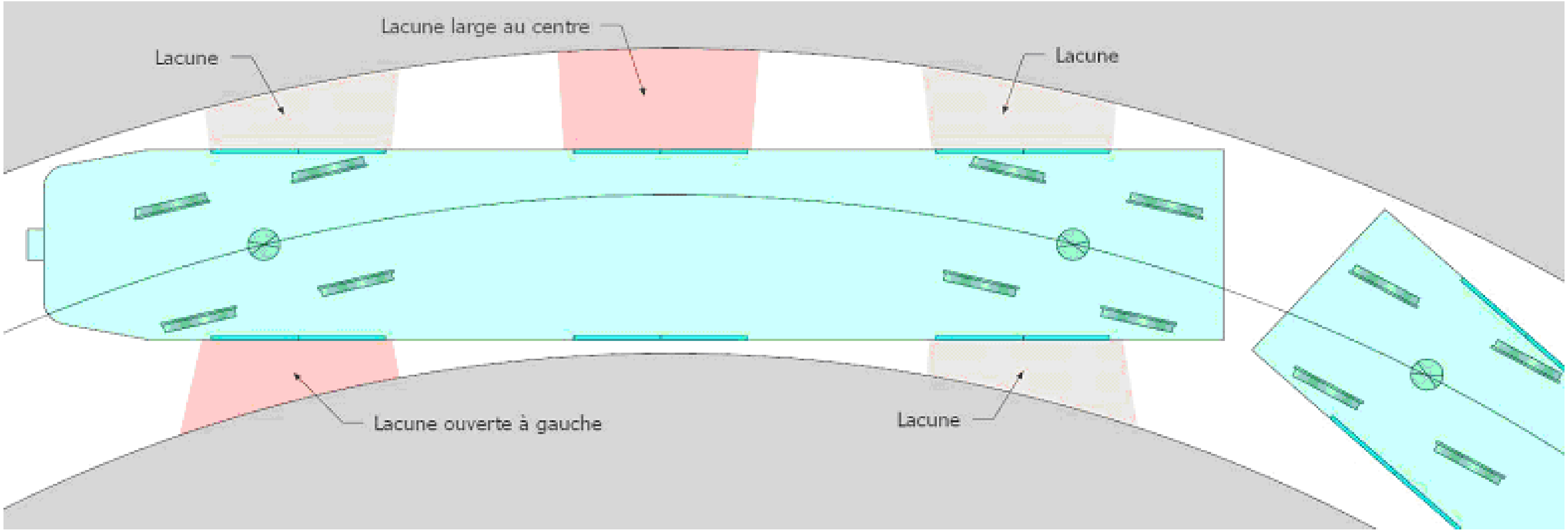
PSD need to be deployed first (before arrival of the 1st shuttle) :

- 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

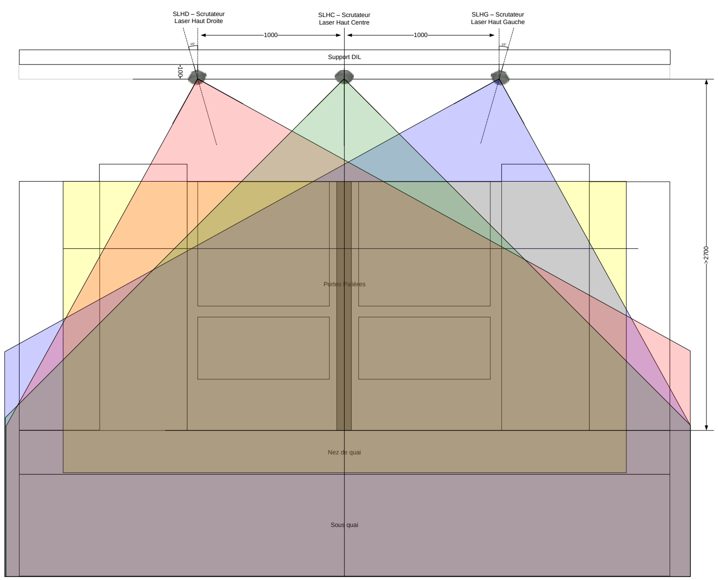
- The gap has been reduced using mechanical means:
  - For the narrower gaps : a passive horizontal aluminum bar at 1m height
  - For the medium gaps : an active horizontal aluminum bar at 1m height, interlocked
  - Flexible steps for lower gaps (under the level of platforms) entering the KE of the trains

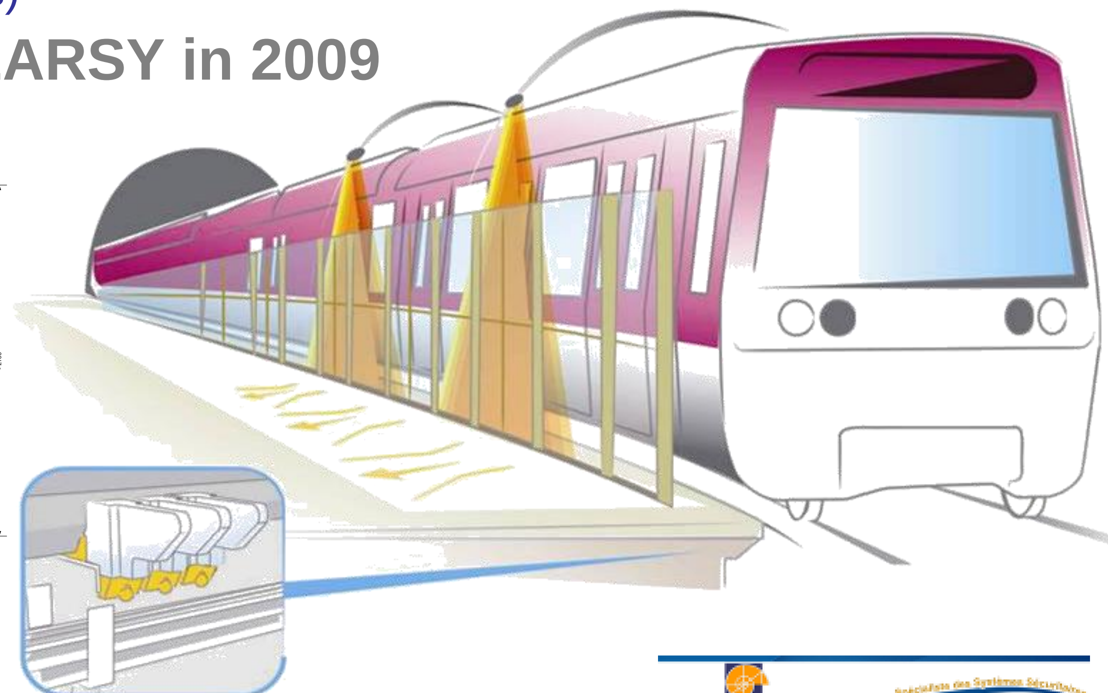
Major choice: track protection

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





Major choice: Automatic Train Control

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

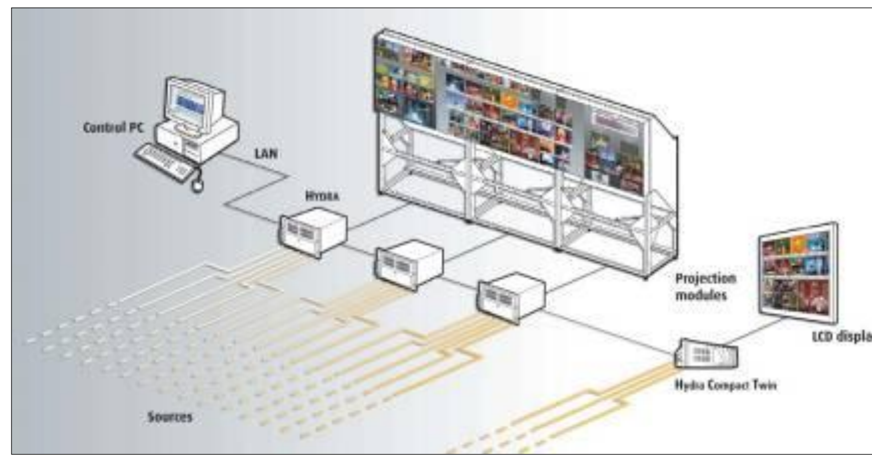
- Radio train to track transmission @5.9 GHz
- Video projected overhead control panel
- System test bench for validation tests

Contract awarded in 2006 to SIEMENS

Major choice: passengers communication system

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

Major choice: safety case

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

49x6 cars trains 98 On-bord Safety Computers 6 Safety Zone Controllers 9 Remote Safety I/O Modules 27 Non-Vital PLC 176 Optical Barriers 700 Beacons on track 68 Radio Bases 92 Trackside Radio Antennas 98 Trainborne Radios 16 Video Projectors in OCC 5 Operating Positions in OCC 15 ATS Servers 32 Technical Rooms 4 Closing Grids 637 Onboard Com. Controllers 280 PSD Video Cameras 75 WIFI Access Points 1176 Trainborne Video Displays 686 Trainborne Video Cameras 22 Comm. Servers (12 Operating Positions) 2268 Platform Screen Doors 25 PSD Servers 18 Entrapment Detection Systems 152 Interlocked Routes 300 Signal Boxes 270 Track Circuits 53 Motorized Points

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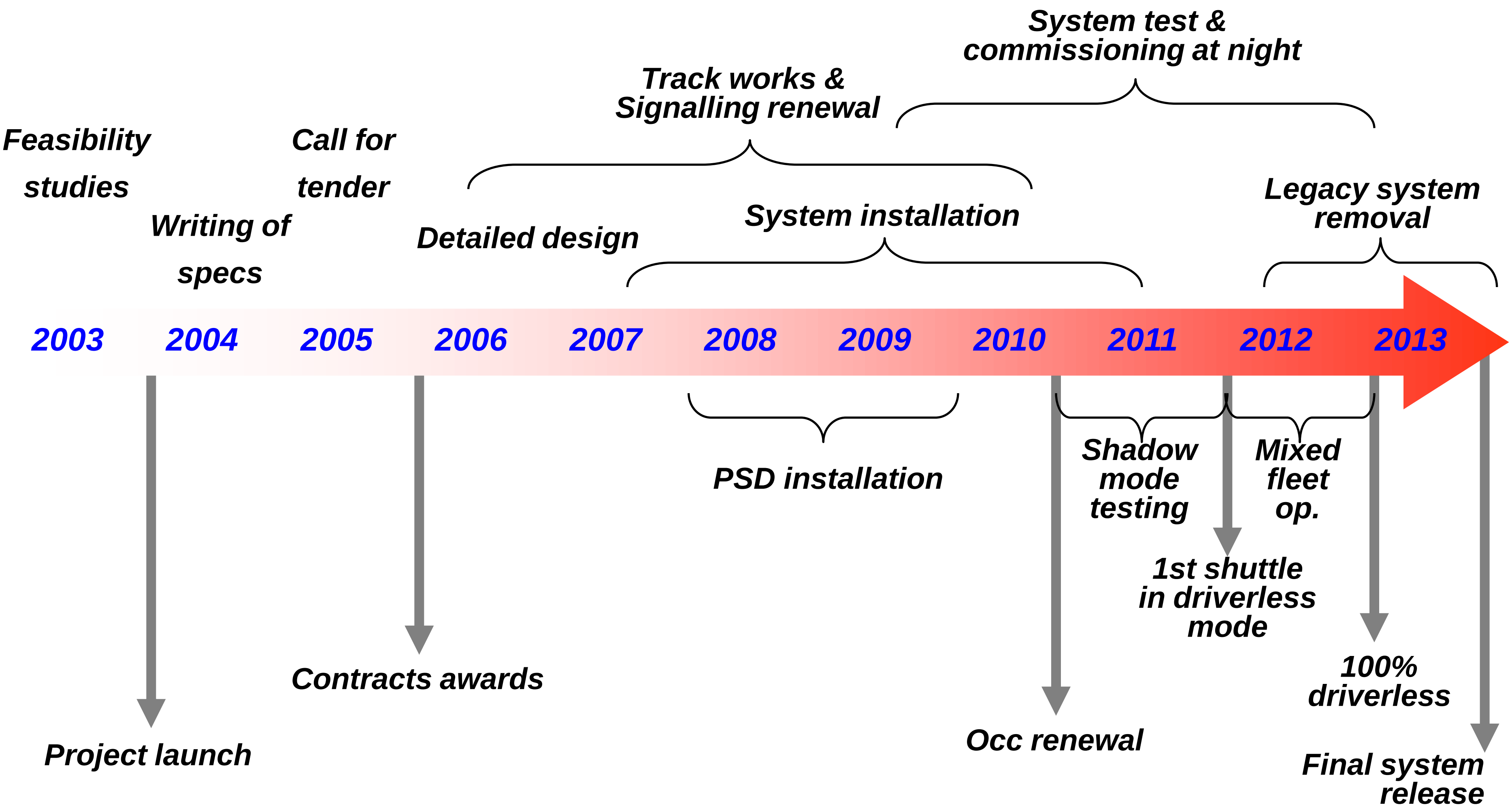
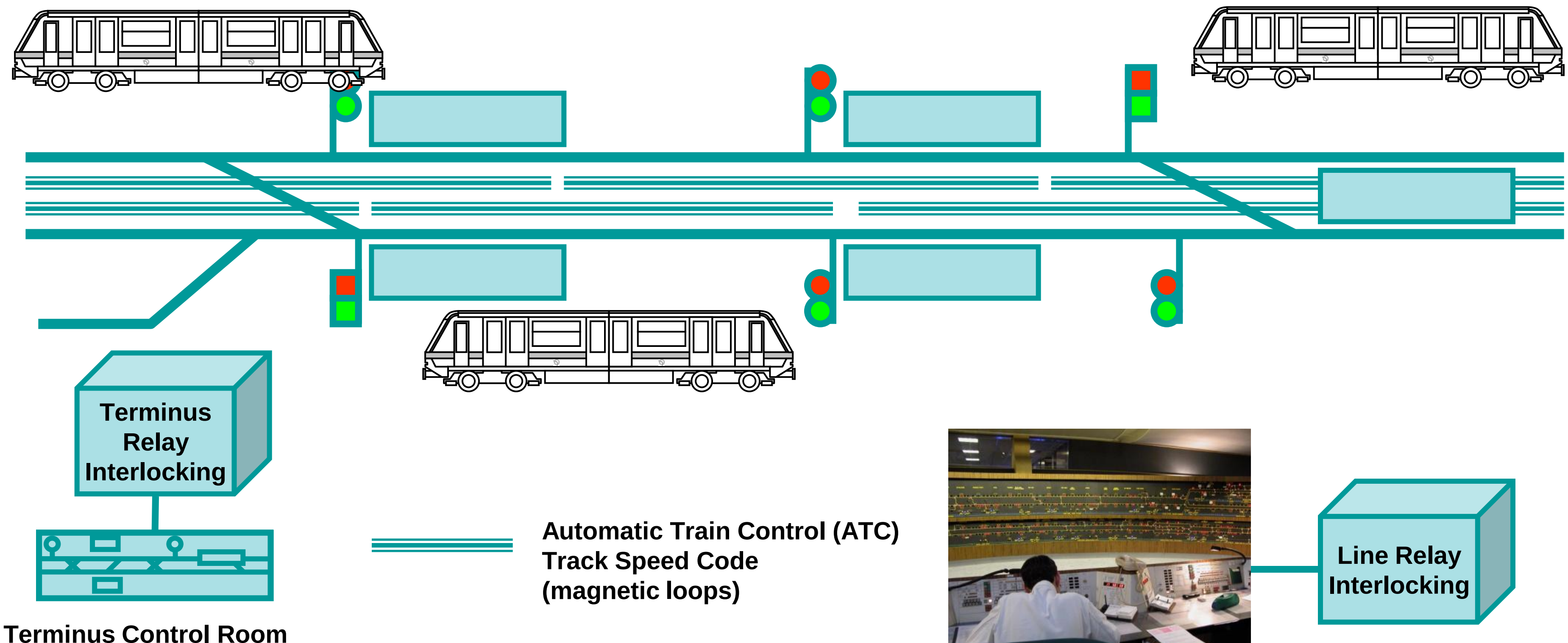
Paris metro line 1, Overall schedule & project milestones



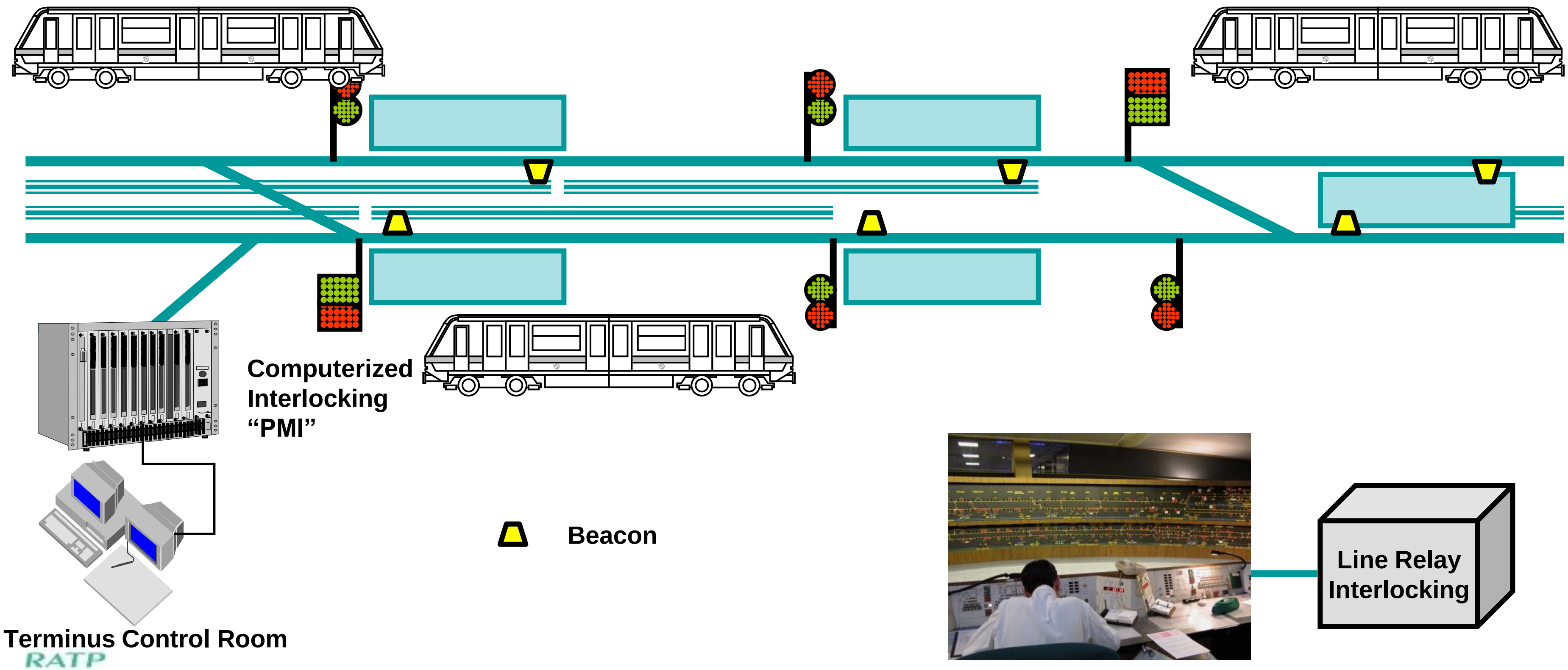
Migration Principles in 6 steps
Initial situation

- 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)



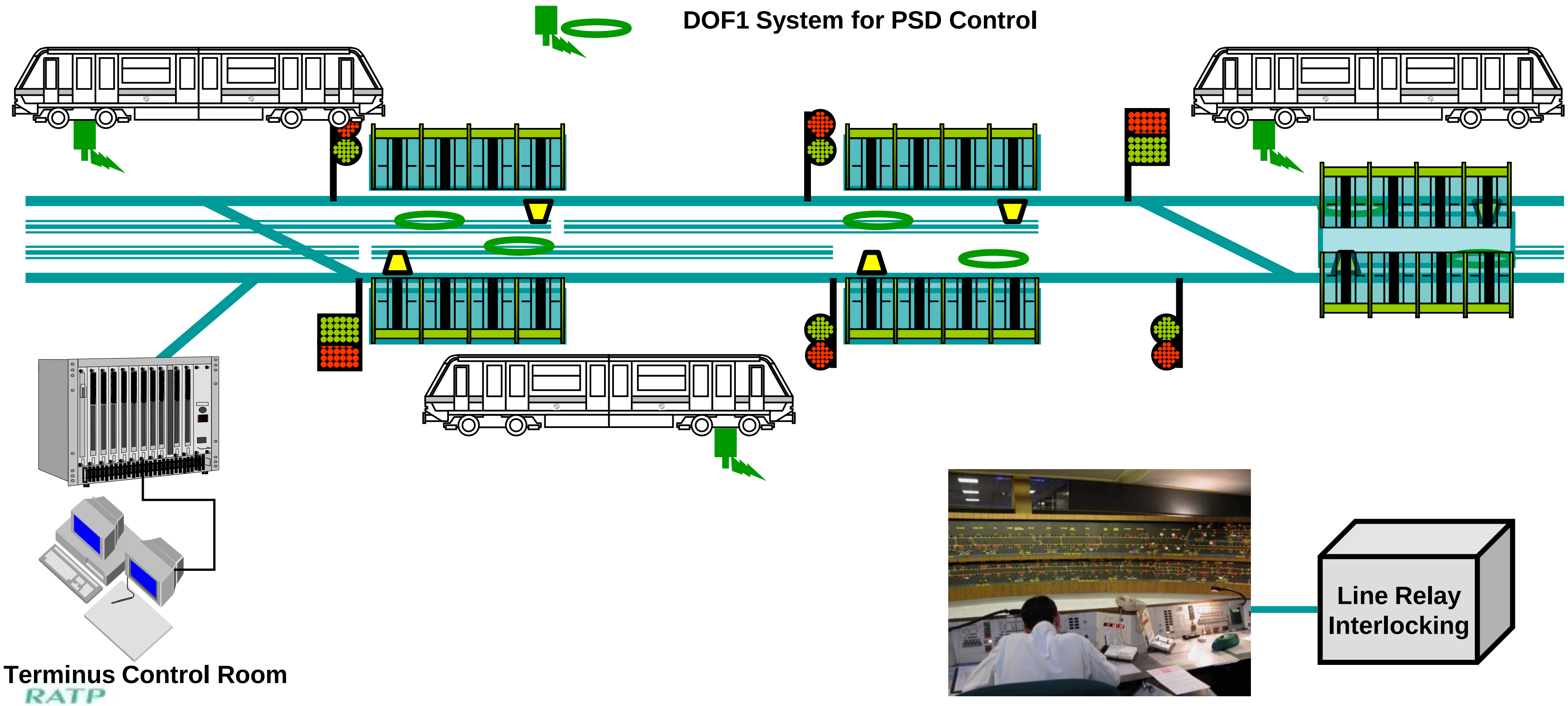
Migration Principles in 6 steps
Step 1: Signalling and trackside enabling works

- Modernization with computerized interlocking in terminus
- Signals with LEDs bulbs, Beacons & Optical barriers inst.
- Additional signalling functions
- Modernization of HV controls



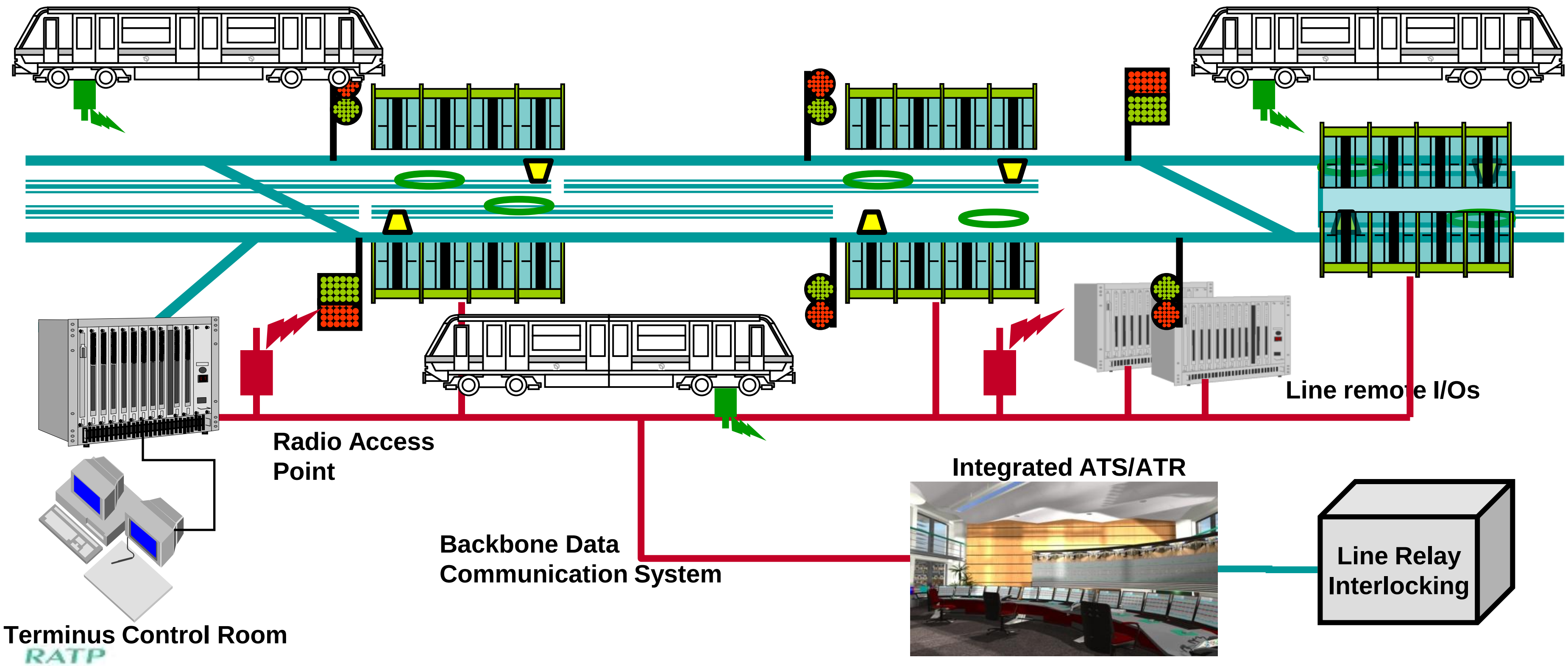
Migration Principles in 6 steps
Step 2: PSD deployment

- Installation of a remote PSD control on board trains and reception loops in stations (DOF1 system)
- Then, installation of PSD



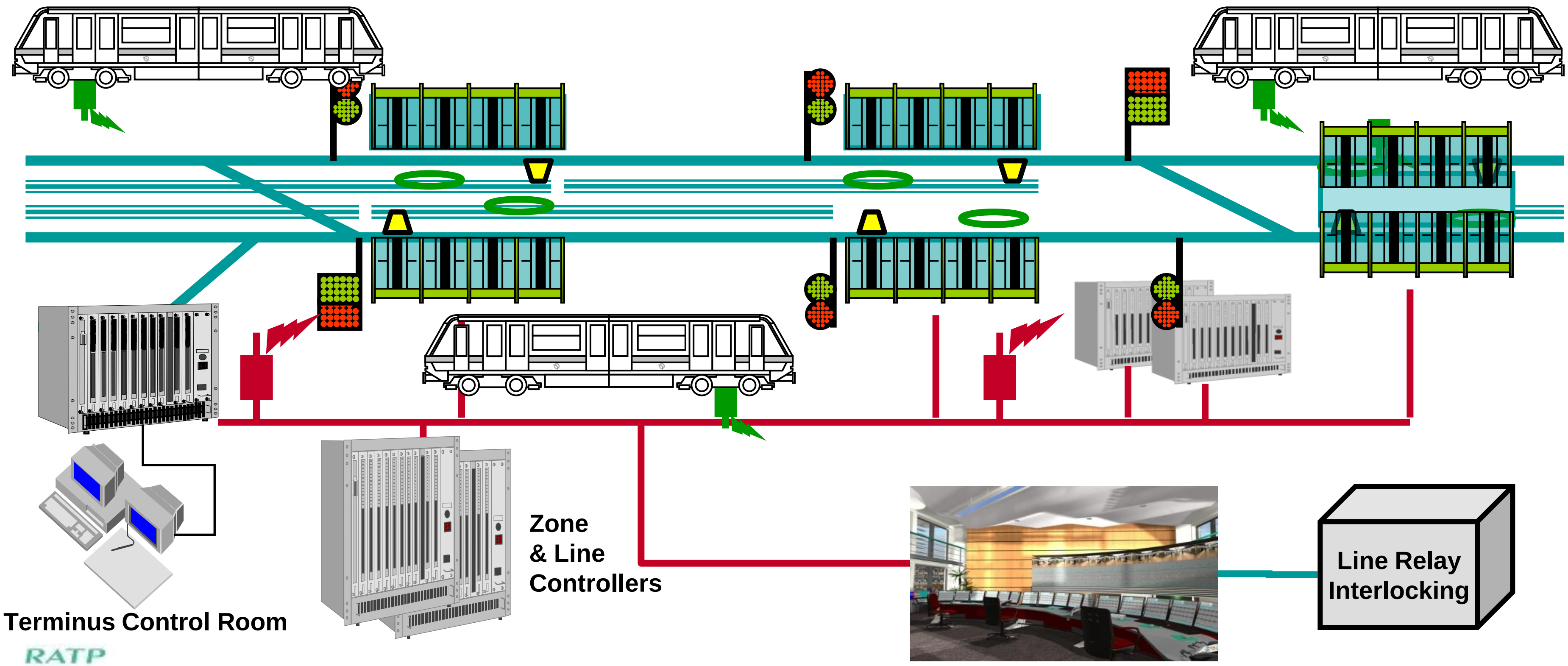
Migration Principles in 6 steps
Step 3: Operation under supervision of new OCC

- DCS Installation (Backbone Network + Radio Access Points
- Installation of Trackside Remote I/Os
- Replacement of OCC with integrated ATS/ATR



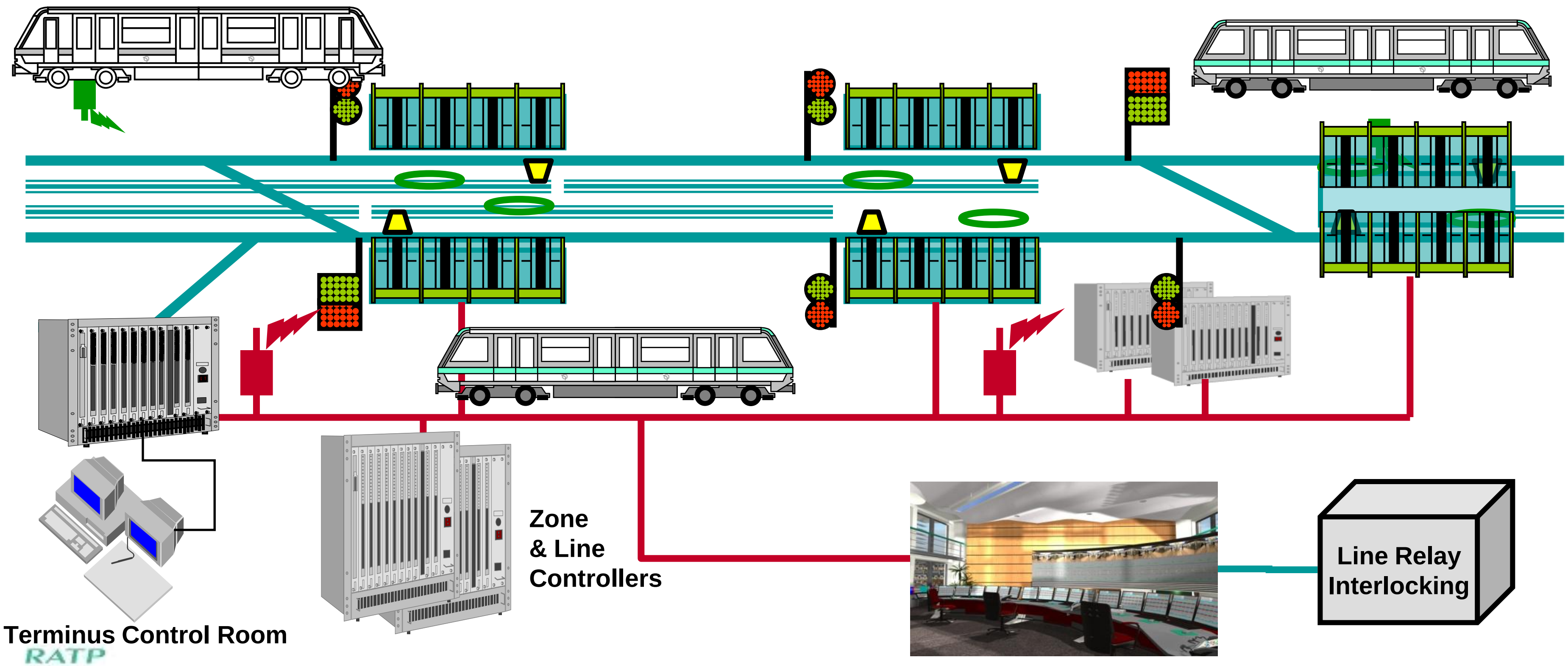
Migration Principles in 6 steps
Step 4: System Deployment

- Installation of System Trackside Zone & Line Controllers
- System Test and Commissioning at Nights
  (with first Driverless Train)



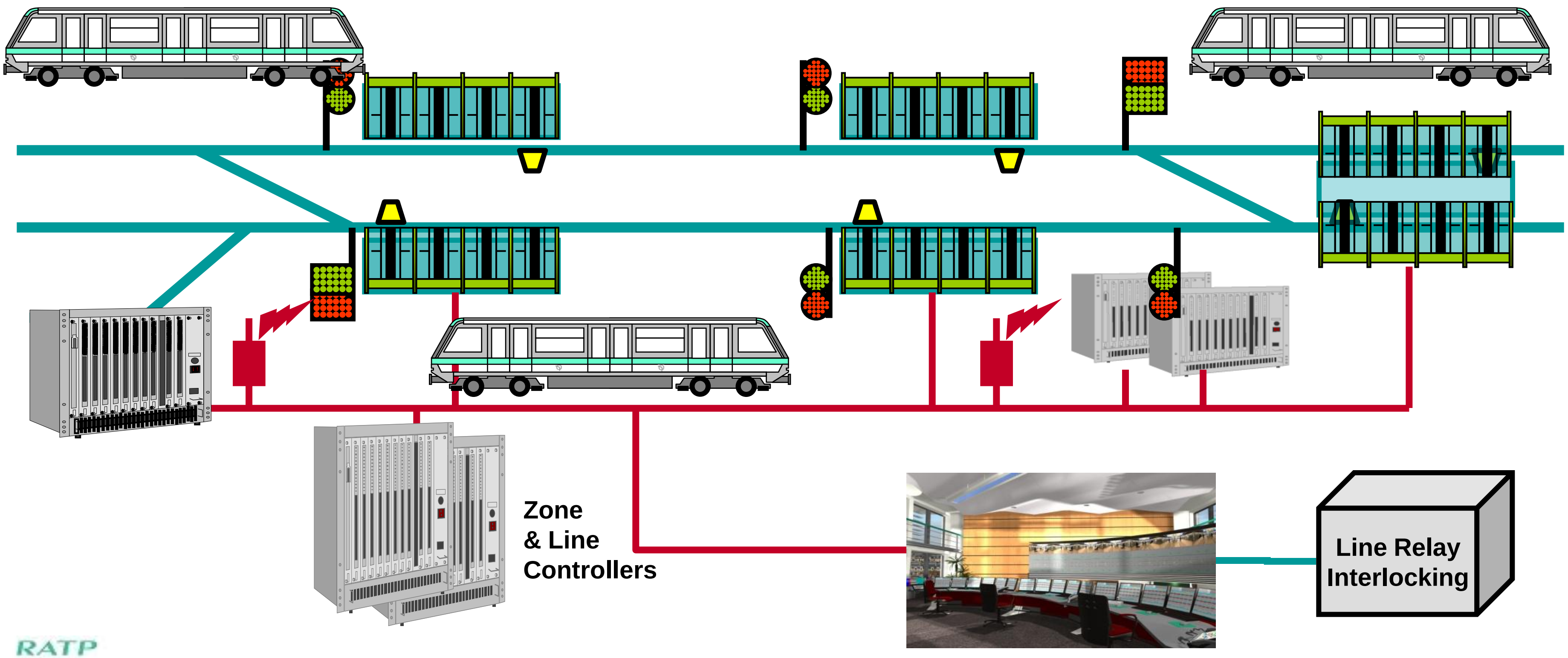
Migration Principles in 6 steps
Step 5: Mixed fleet operation

- 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



Paris metro line 1, a story of migration to driverless operation

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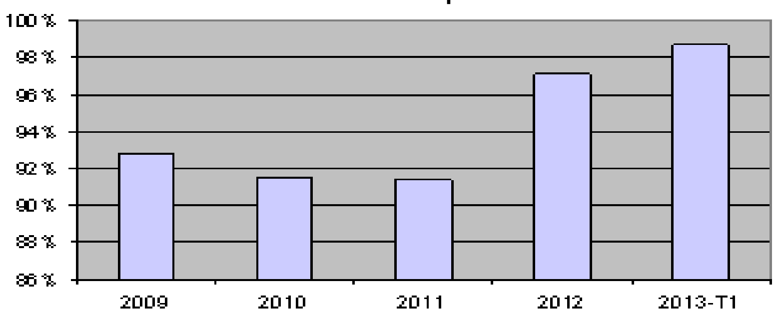
Paris metro line 1,
Main outcomes

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 »

Peak hour output rate



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

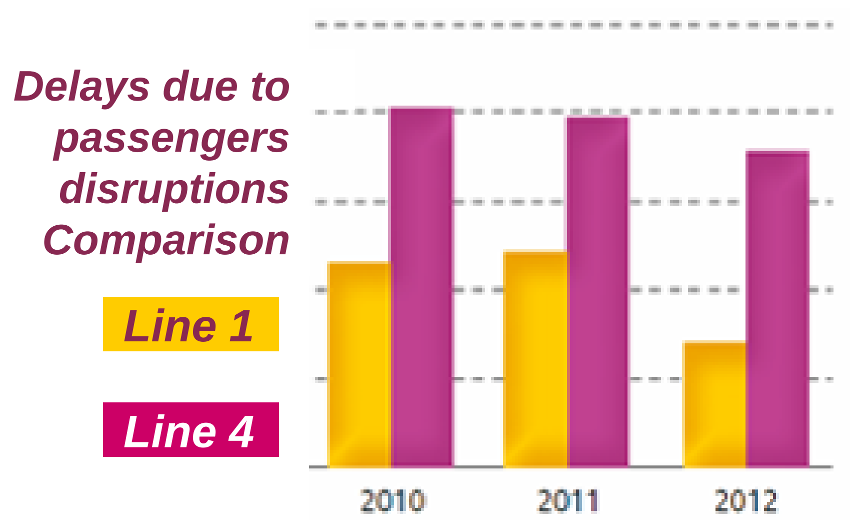
- Connected to all metro lines (13) and suburban lines (5)
- Complementary line to RER B and D in Paris (high density of passengers)
- South extension (3 stations) and future connection to Greater Paris network

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

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

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