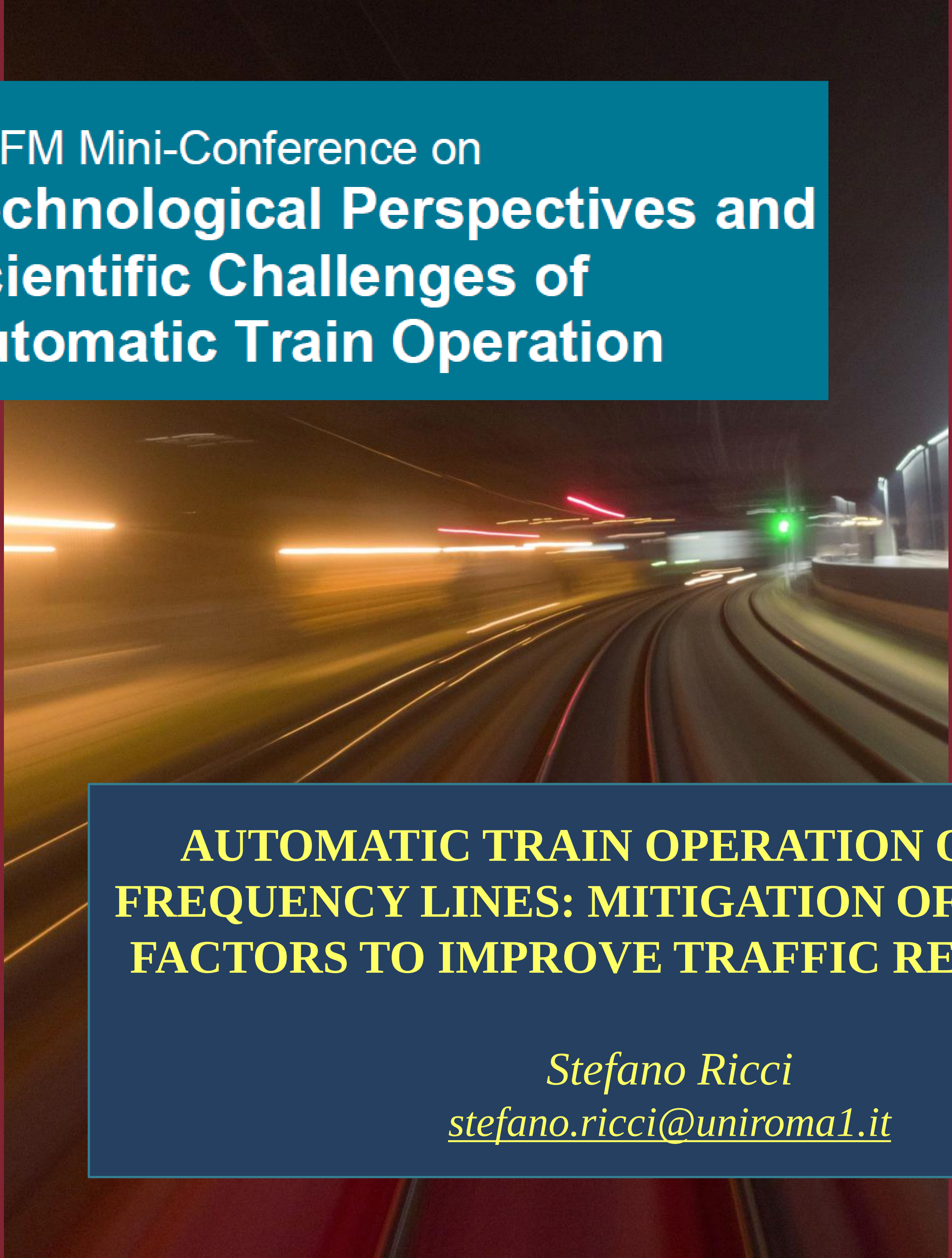

CSFM Mini-Conference on
Technological Perspectives and Scientific Challenges of Automatic Train Operation

AUTOMATIC TRAIN OPERATION ON HIGH-FREQUENCY LINES: MITIGATION OF ALEATORY FACTORS TO IMPROVE TRAFFIC REGULARITY

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The context …

Migration towards automation of high-frequency lines

Grade of Automation	Driving Operation	Starting	Braking	Door Closure	Operation in Disruptions
GoA 0	On-sight Driving	Driver	Driver	Driver	Driver
GoA 1	Manual Drive with Automated Train Protection (ATP)	Driver	Driver	Driver	Driver
GoA 2	Semi-automatic Train Operation with Driver (STO)	Automatic	Automatic	Driver	Driver
GoA 3	Attended, Driverless Train Operation (DTO)	Automatic	Automatic	Train Attendant	Train Attendant
GoA 4	Fully Automatic, Unattended Train Operation (UTO)	Automatic	Automatic	Automatic	Automatic

New lines

70-80% of new commissioned metro systems

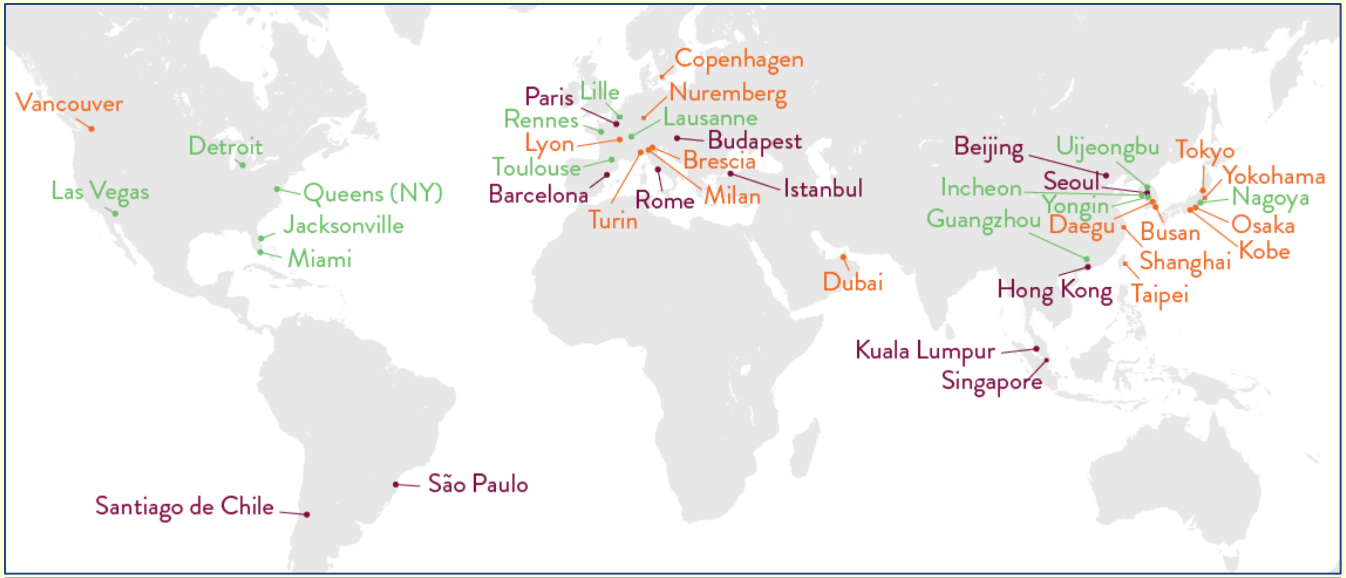
Most crowdy metro lines in operation (examples in Europe)

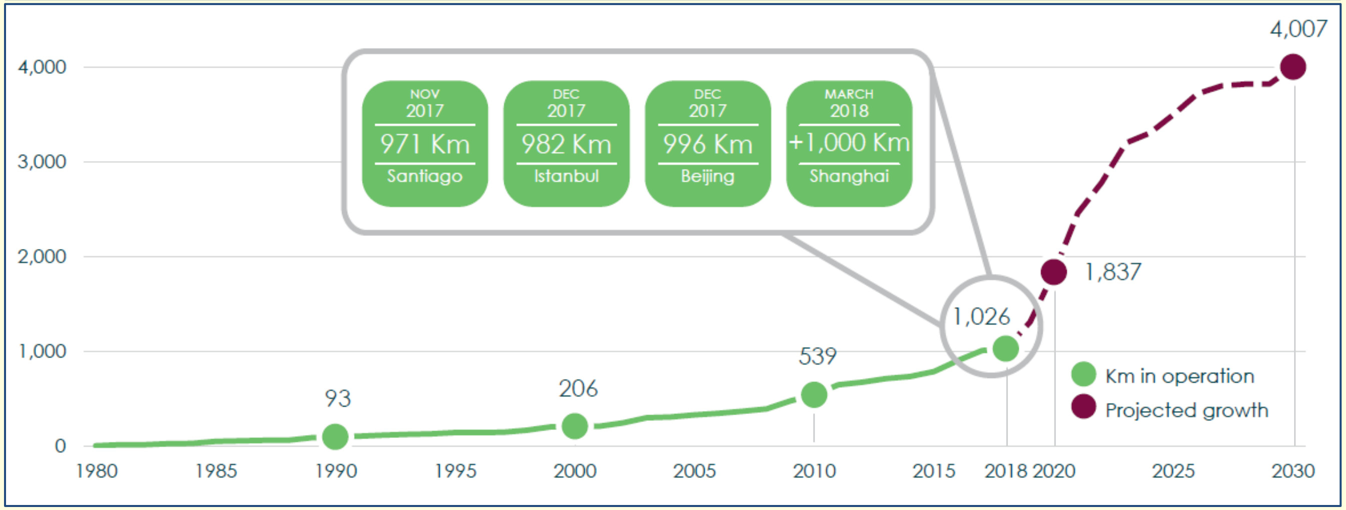
Completed: Paris Metro L1 – from GoA1 to GoA4

Ongoing: Brussels (L1, L5), Glasgow (Subway), London (Docklands)

Lyon (LA, LB), Marseille (L1, L2), Paris (L4), Vienna (U2, U5)

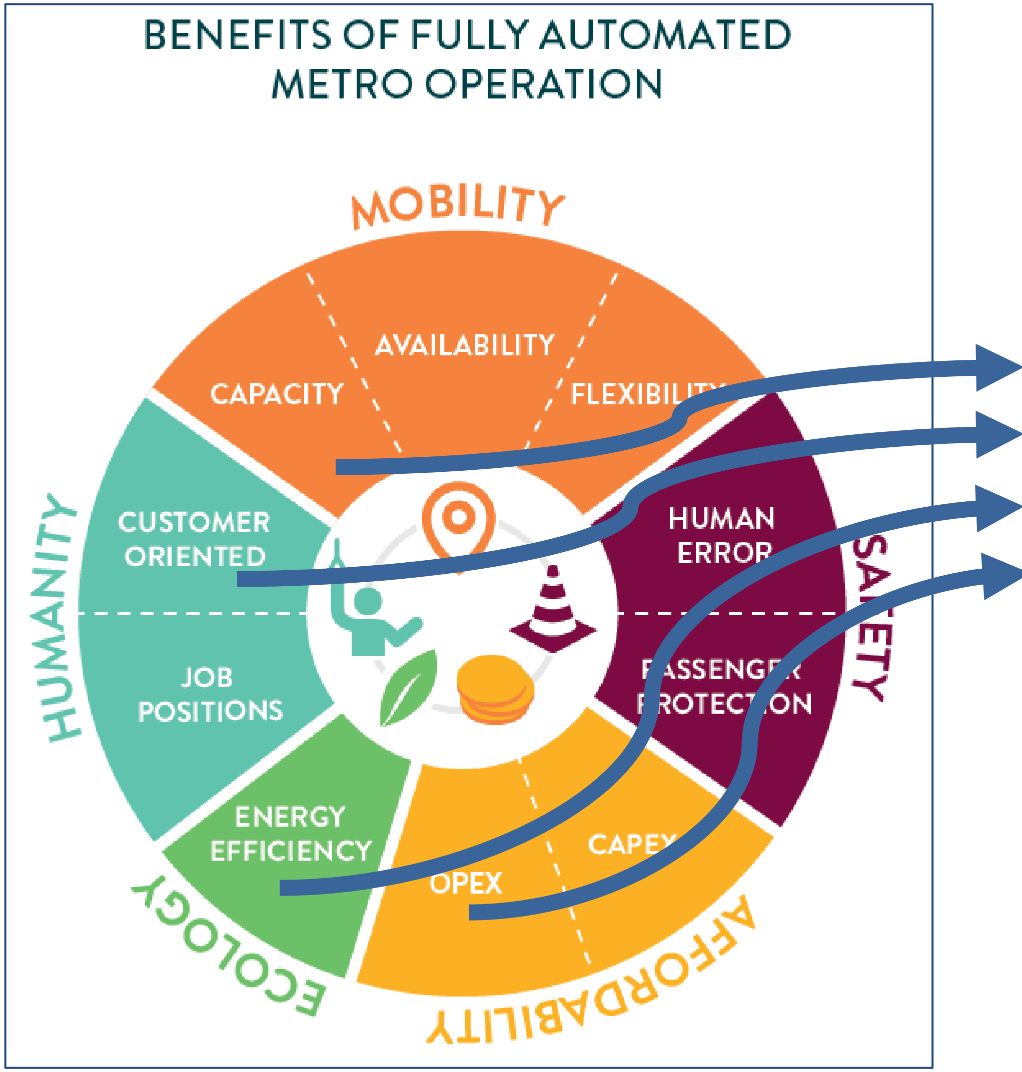
… Situation and perspectives …





Source: ***World Report on Metro Automation*** **– UITP, 2018**

… Recognized advantages of automation…



Traffic Regularity

(adherence to scheduling)

Source: *World Report on Metro Automation* – UITP, 2018

… Investigated concepts…

Objective

Measurability of advantages achievable by Automation

Method

Bottom-Up approach

1) **Operational analyses of high frequency line operated without Automatic Train Operation (ATO)**
2) **Identification of the aleatory factors affecting the operation**
3) **Derivation of suitable indices to measure the effects of detected aleatory factors**
4) **Identification of potential effects of ATO implementation in mitigating aleatory factors**
5) **Quantitative estimation of the identified mitigations**
6) **Expected improvements of *traffic regularity***

… Case study …

Roma: Metro LA

LINE A	
Opening	1980
Last extension	2000
Network operator	ATAC
Rolling stock	MA 300
Track gauge	1.435 mm
Traction	Electrical – 1.500 V
Stations	27
Length	18,425 km
Mean distance between stations	682 m
Passengers per day	450.000

Present operation

GoA1

Nominal headway: 120 s

Scheduled intervals: 165-240 s (2’45”-4’00”)

Daily trips: 617

Fleet: 33 trains

Scheduled travel time: 39 min

The second most crowdy in Europe after Paris L1, recently migrated to GoA4

Rolling stock

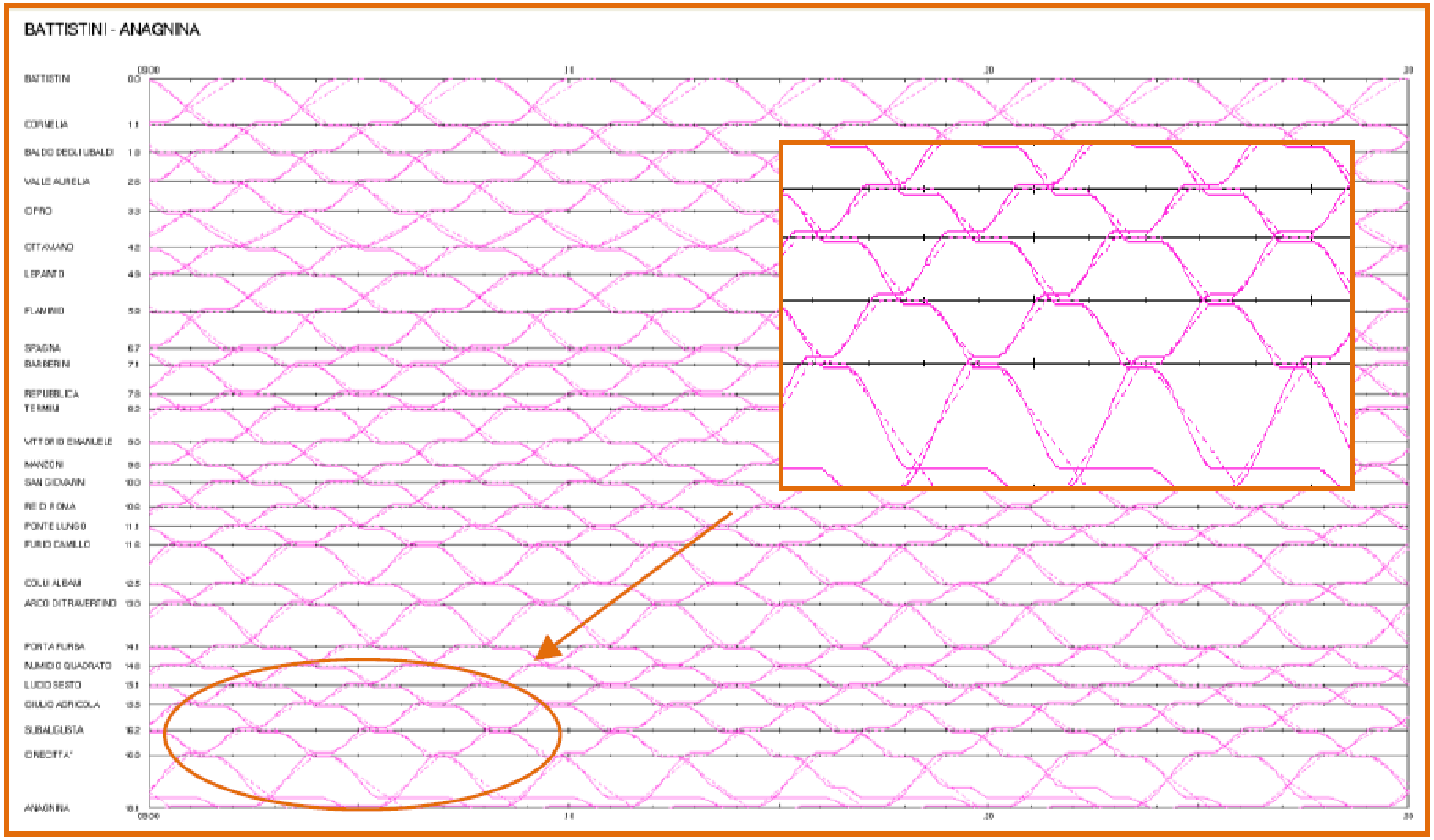
PHYSICAL CHARACTERISTICS	
Composition	>(Mc-R-M)-(M-R-Mc)<
Length of the Motor car with cab (Mc)	17.390 mm
Length of the Motor car without cab (M) and Trailer (R)	17.000 mm
Total length	102.780 mm
Doors per side	24
WEIGHTS	
Totally full loaded weight	280.216 kg
Total empty weight	190.060 kg
Conventional passenger weight	90.150 kg
Maximum load weight per axle	11.900 kg
PERFORMANCE	
Nominal line voltage	1.500 Vcc
Continuous power at wheels	2.560 kW
Speed range at maximum power	43 ÷ 90 km/h
Maximum power at wheels	3.880 kW
Peak traction effort	324,8 kN
Maximum operating speed	90 km/h
Maximum acceleration at start up to speed V = 43 km/h	1,03 m/s^2
Braking deceleration at max speed from V = 90 km/h	2,4 m/s^2

… Feedback from monitoring operation…

<u>Monitored period</u>

2 months: 7.00-9.00

Scheduled intervals: 165-180 s (2′45″-3′00″)

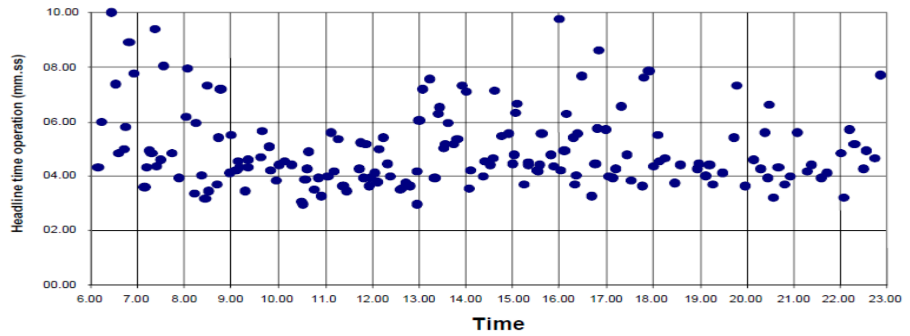


… Actual measured reversing and dwell times…

Actual reversing time at terminals

Scheduled (7.00-9.00): 240 s (4’00”)

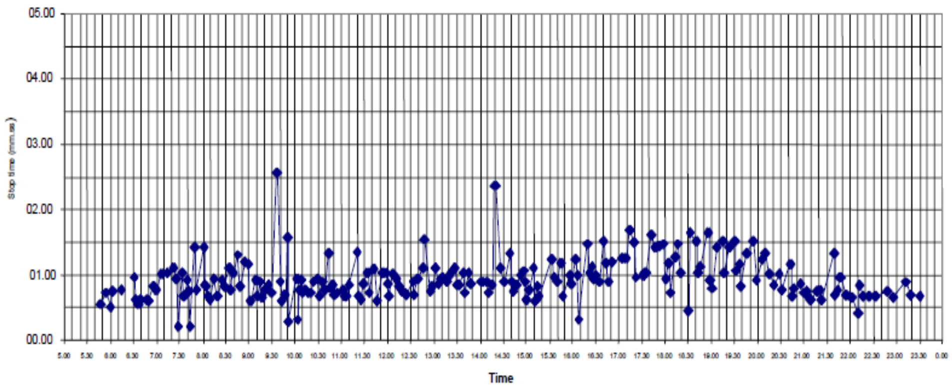
Average (7.00-9.00): 464 s (7’44”) +93%



Actual dwell time at intermediate stations

Scheduled (7.00-9.00): 20-30 s (0’20”-0’30”)

Average (7.00-9.00): 33 s (0’33”) +10-65%

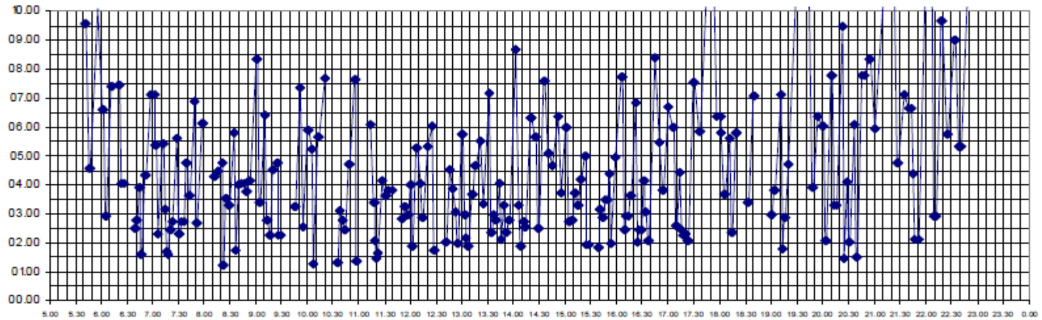


… Actual measured headways …

<u>Headways at terminals</u>

Scheduled (7.00-9.00): 165-180 s (2’45”-3’00”)

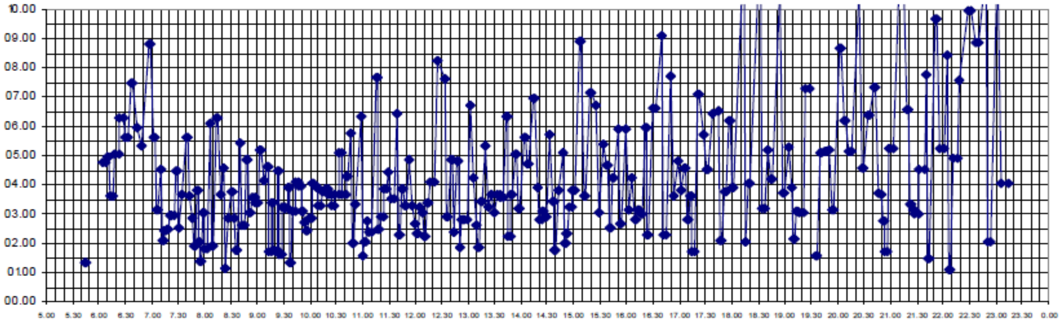
Average (7.00-9.00): 316 s (5’16”) +76-91%



<u>Headways at intermediate stations</u>

Scheduled (7.00-9.00): 165-180 s (2’45”-3’00”)

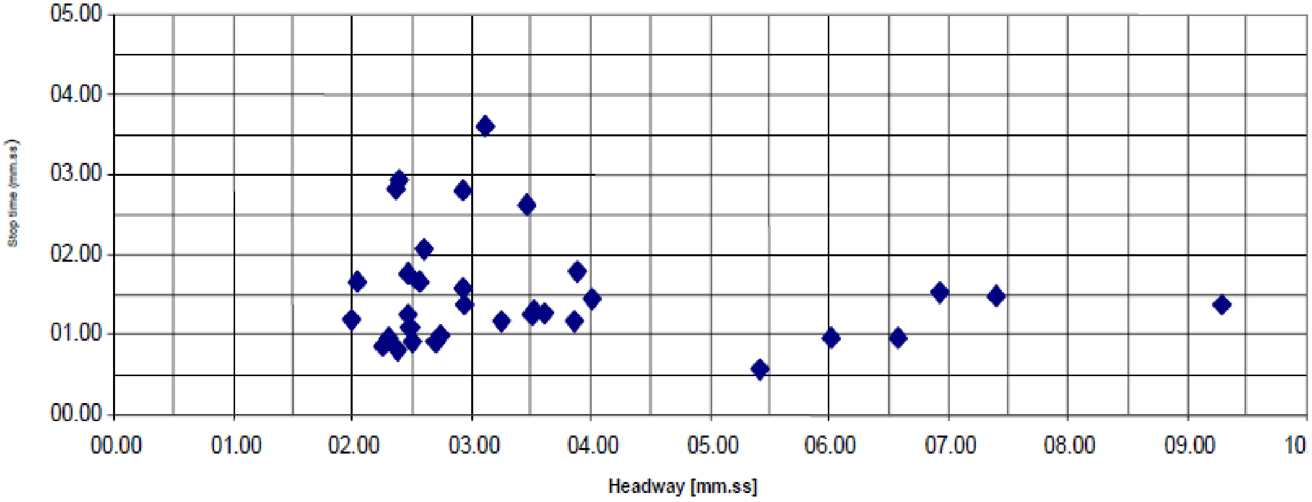
Average (7.00-9.00): 208 s (3’28”) +16-26%



***Regularly perturbed* operation**

… Reversing times vs. headways …

Reversing time at terminals vs. headways



Lack of correlation among key parameters

Disordered perturbed **operation**

Relevant influence of aleatory factors

Need of synthetic quantitative indicators

… Proposed synthetic quantitative indicators …

<u>Regularity index at a station</u>

$$f_i = \left| h_{real_i} - h_{sch_i} \right|$$

h_{real_i} = actual headway between the arrival of i and i+1
h_{sch_i} = timetable headway between the arrival of i and i+1

<u>Average regularity index at a station</u>

$$\overline{f} = \frac{1}{n} \sum_{i=1}^{n} \left| h_{real_i} - h_{sch_i} \right|$$

n = number of trips

<u>Standard deviation of reliability index</u>

$$\sigma_f = \sqrt{\frac{1}{n-1} \left(\sum_{i=1}^{n} f_i^2 - n\overline{f^2} \right)}$$

<u>Irregularity coefficient</u>

Actual/Timetable headway (independent from the timetable)

$$B = \frac{\overline{f}}{\overline{h}_{sch}} * 100 \qquad \overline{h}_{sch} = \frac{1}{n} \sum_{i=1}^{n} h_{sch_i}$$

… Potential effects of Automation …

Main functions subject to Automation

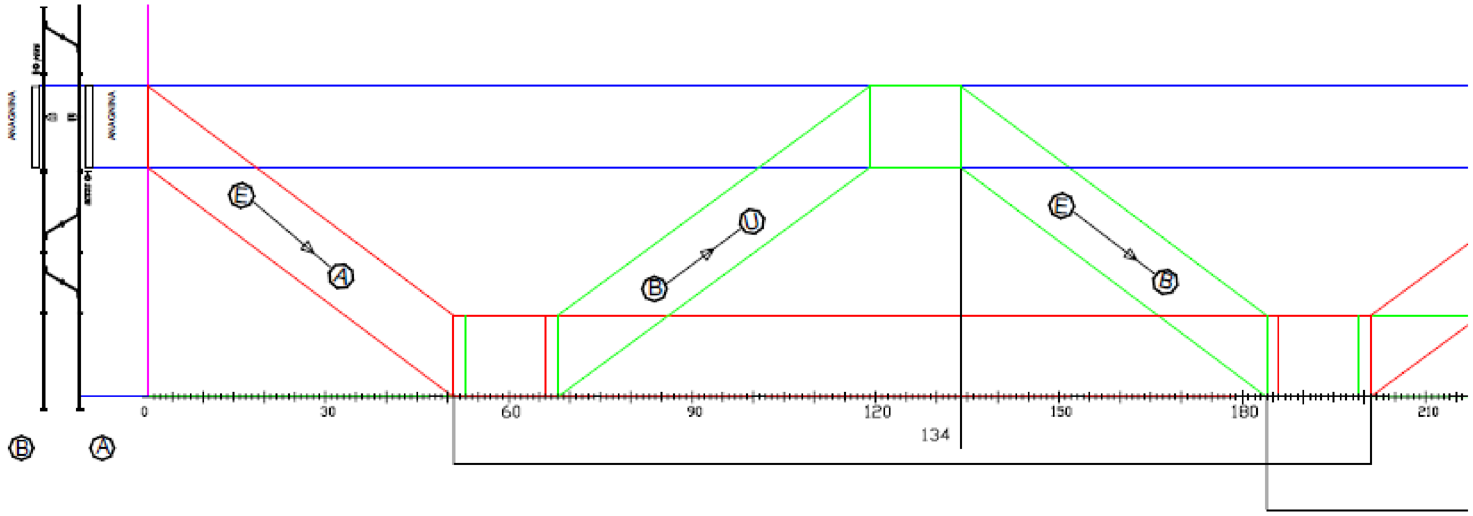
- **Control of acceleration up to the maximum speed**
- **Control of cruise speed**
- **Control of braking and precise stop at platforms**
- **Control of dwell time duration**
- **Reversing maneuvers at the terminals**

Achievable effects on the operation

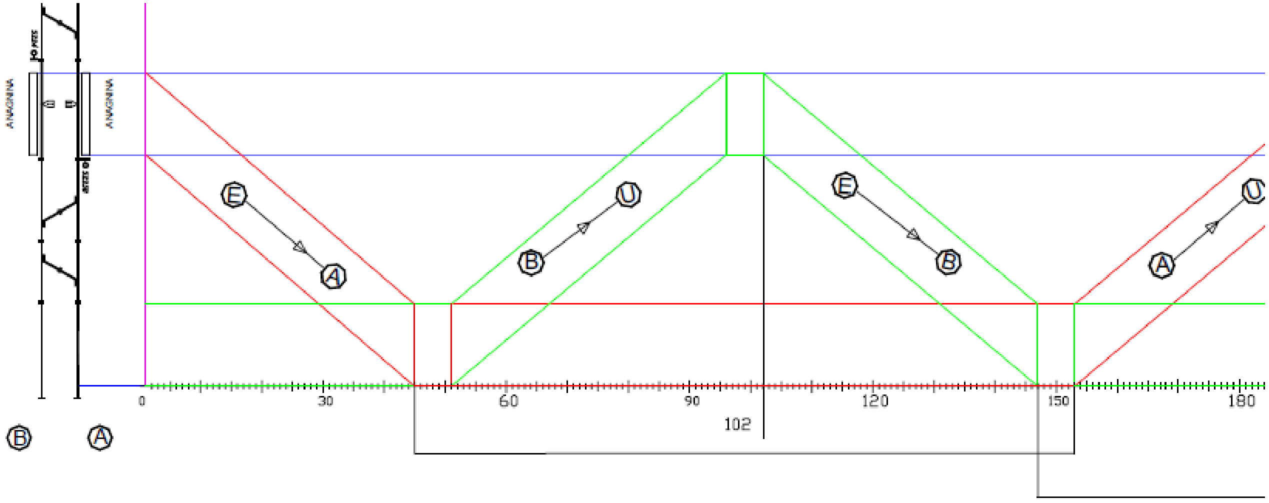
- **Regular departures and uniform shorter headways**
- **Uniform shorter running times**
- **Uniform shorter dwell time**
- **Uniform shorter reversing time at terminals**

… Reversing maneuvers at terminals …

Manual



Automated



… Conclusions …

Key achievements

- The operation of the high-frequency lines is extremely sensible to disturbances and disruptions that penalize the traffic regularity
- The penalization of traffic regularity is normally due to a combination of systematic and aleatory factors
- The aleatory factors are frequently depending on human behaviours both of drivers and passengers
- The effects of the human behaviours can be strongly mitigated by the progressive migration towards the Automation
- The Automation can play an important role to increase the traffic regularity
- The increase of traffic regularity can bring relevant advantages in terms of capacity, customer satisfaction, operational costs, energy consumptions and CO_2 emissions

Research perspectives

- Various approaches for the quantification of these advantages populate the literature
- Further research developments should focus on the consolidation of methods combining robust formalization with extensive validation based on data from lines operated with various levels of automation

… and thank you for your kind attention !

Questions are welcome !

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