Train Delay Prediction System for Large-Scale Railway Networks based on Big Data Analytics

Emanuele Fumeo, D. Anguita, L. Oneto, G. Clerico, N. Mazzino, F. Papa, R. Canepa

Napoli, 24th November 2016

University of Genoa, Ansaldo STS S.p.A. and Rete Ferroviaria Italiana (RFI)

Presentation Index

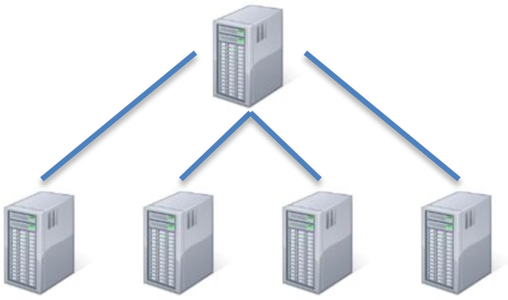
- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Big Data Analytics

Big Data refers to technologies (both HW and SW) and methodologies able **to collect, store, process, analyze and visualize large amounts of heterogeneous data**.



Big Data Analytics aims at learning from data, in order **to build generalizable data-driven models** that give accurate predictions, or **aims at finding patterns**, particularly with new and unseen similar data.

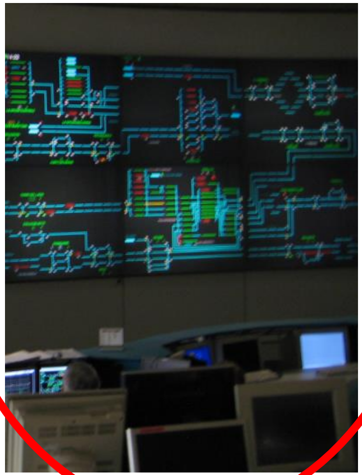
Big Data Analytics for Railways

Big Data Analytics interest in Railways is constantly growing

Companies are exploiting Big Data Analytics in any sector of railway operations

Maintenance

Traffic Management



Customer Relationship

…and many other aspects

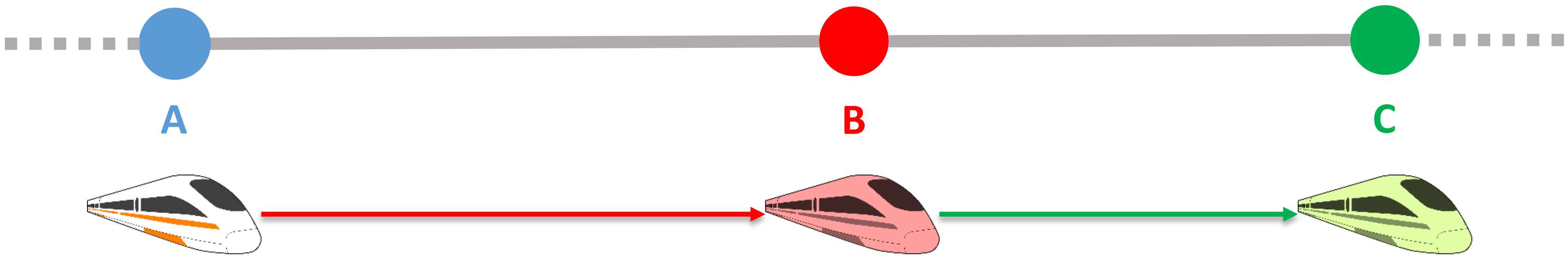
© Patrick Cashin / MTA, © Luca Mazzucco, © Maksym Kozlenko, © Kevin Hadley

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Train Delay Prediction Problem

If the train is at checkpoint A with 5 minutes of delay, what will be its delay at checkpoint B? And at checkpoint C?



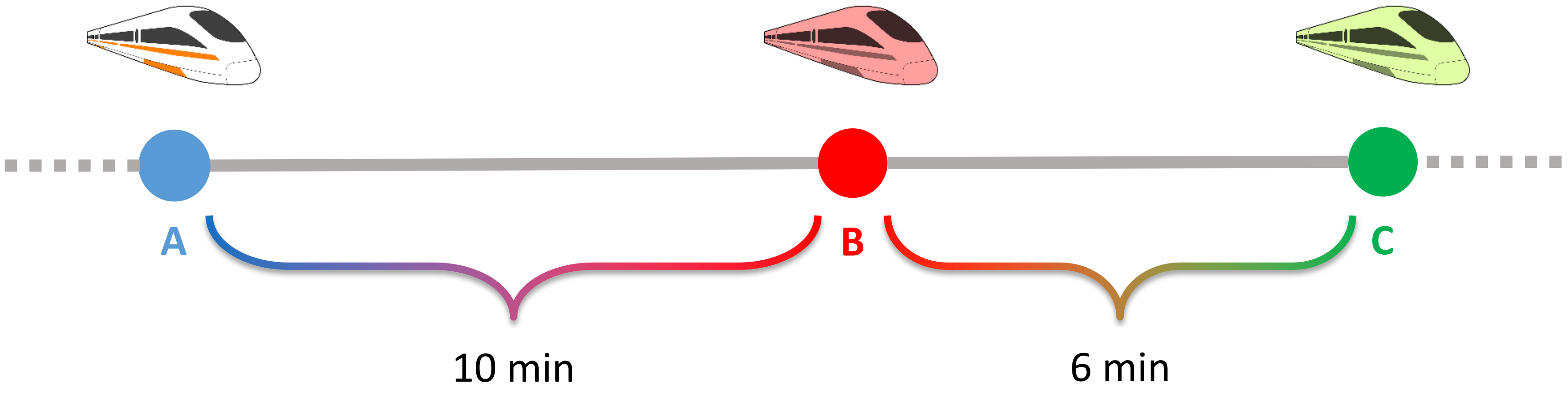
5 min Current Delay

Future Delay?

Future Delay?

Current Predictive Methodology

Current method for train delay prediction is based on line characteristics, on trains characteristics and on simple statistics, aiming at computing the amount of time needed to complete a particular section of its trip and exploiting it for predictions.



This method is not able to take into account external factors affecting railway operations!

Data-driven Train Delay Prediction

Study **train delays** depending on **train movements** and **weather conditions data**

Predict the delay of a train at each of the successive checkpoints included in its trip

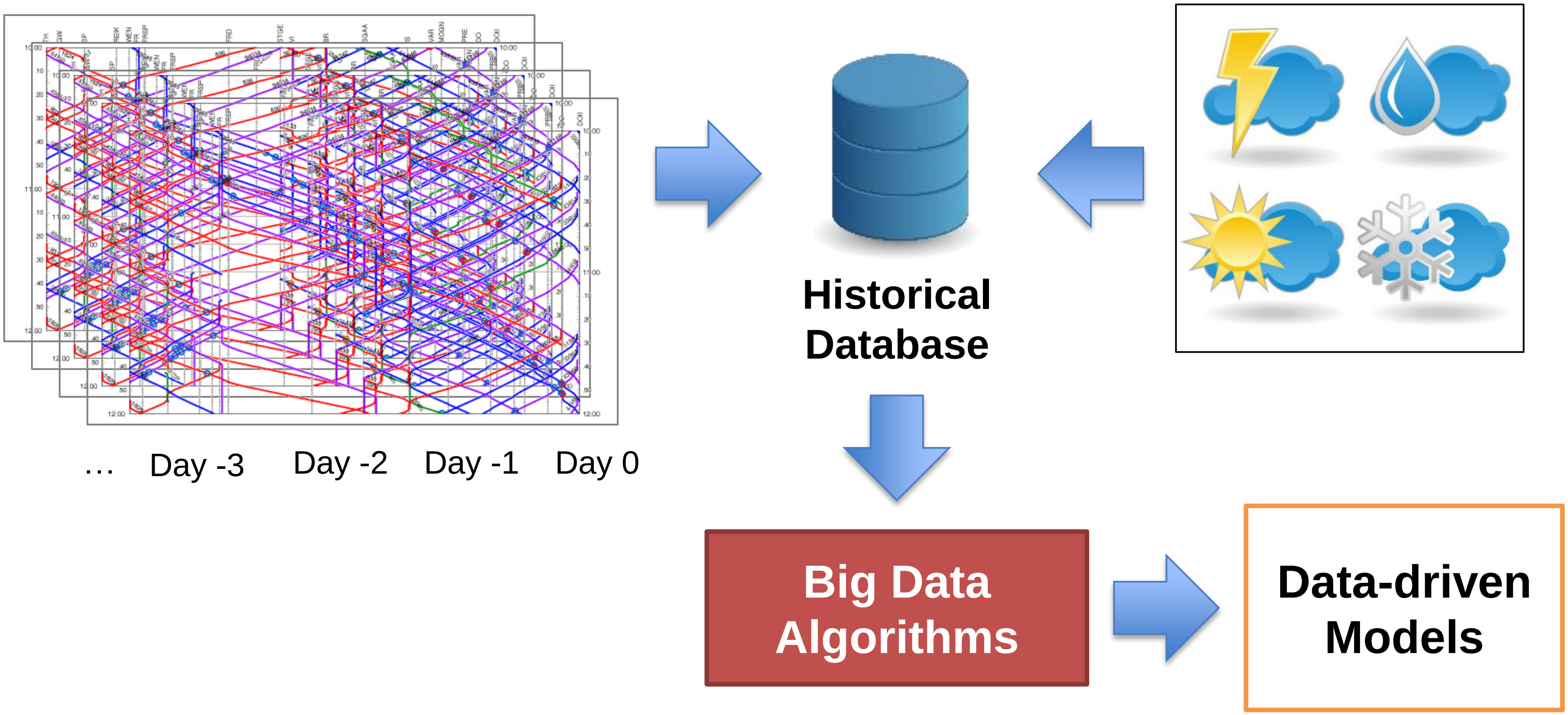
© VittGam, © maurizio messa, © Ilya Sedykh

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Data-driven Methodology – General Idea

Use data about train movements and weather conditions to see what happened in the past and try to predict what will happen in the future



… Day -3 Day -2 Day -1 Day 0

Historical Database

Big Data Algorithms

Data-driven Models

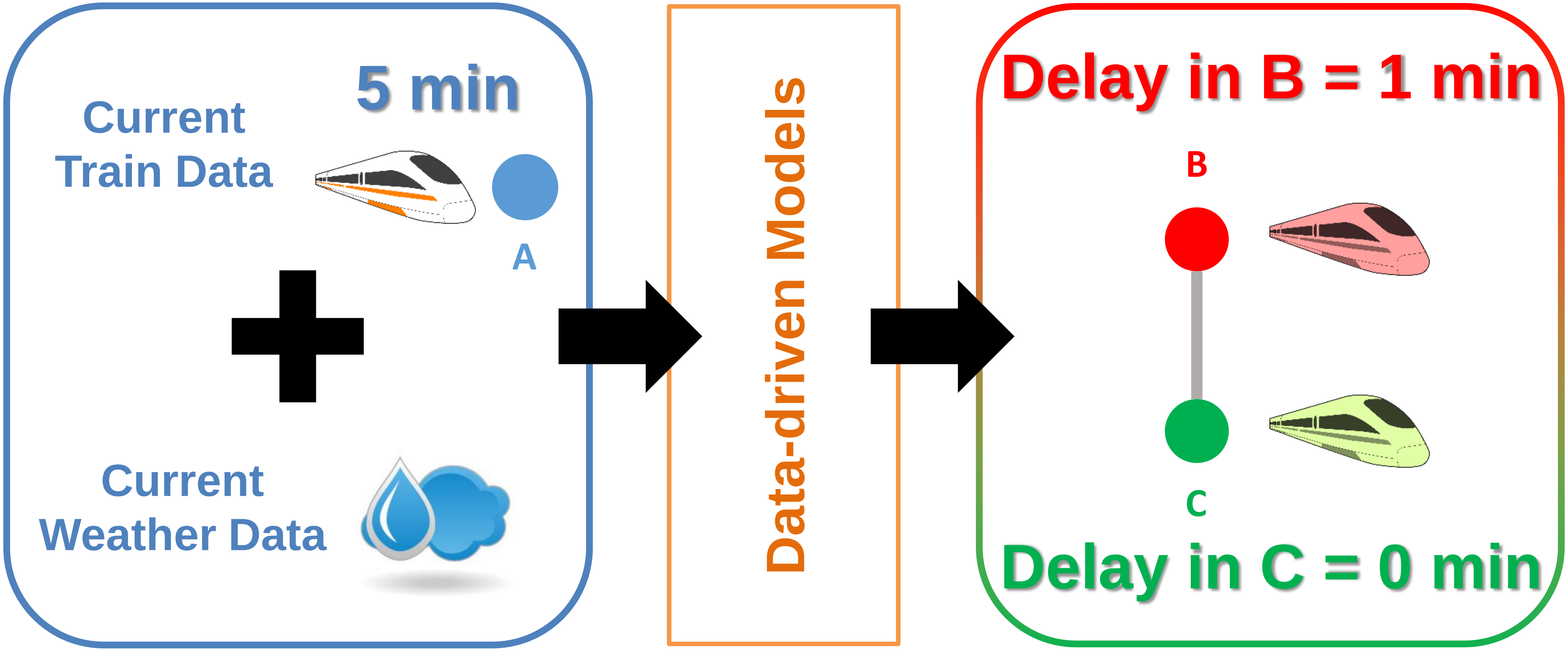
Data-driven Methodology – Implementation

Build a set of generalizable black-box data-driven models that are able to respond to new, previously unseen input data to predict train delays

Input Data (Current)

Models (black-box)

Output Data (Predictions)



Current Train Data

5 min

A

Current Weather Data

Data-driven Models

Delay in B = 1 min

B

C

Delay in C = 0 min

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Outline of the next slides

- Description of Available Data
- Problem Formalization
  - Graphical Example
  - Modelling Approach
- Tested Algorithms
- Models' Performance Assessment
- Simulation Results
- Conclusions

Description of Available Data

Train Movements (from PIC by RFI)

Records about any arrival or departure associated with a particular train at a particular checkpoint.

The data refers to **6 months** of movements in the area of **Milan**, and **1 year** in the area of **Genoa**. It includes:

- TrainID
- Checkpoint ID and name
- Scheduled departure/arrival datetime
- Actual departure/arrival delay
- Event type (origin, destination, passage, stop)

From them, we also derived **Dwell times** at checkpoints and **Running times** between subsequent ones.

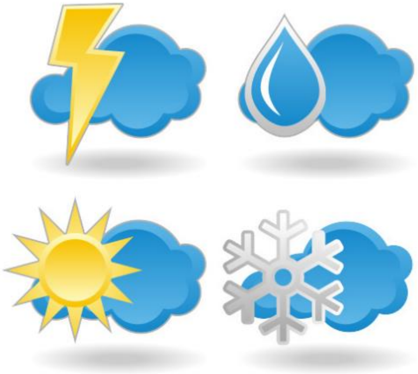
© VittGam

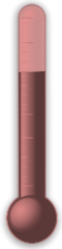
Description of Available Data

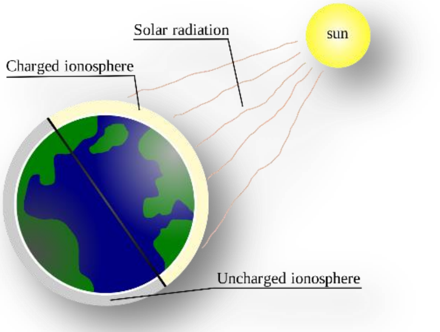
Weather Conditions (from Italian Weather Services)

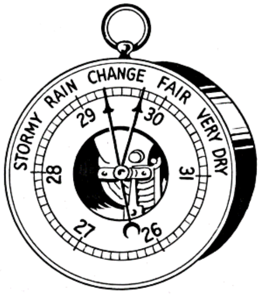
This data refers to the **same time frame** of the train movements data. Weather data contains several parameters from national weather stations:

- Temperature (min, max, average)
- Humidity (min, max, average)
- Wind (min, max, average)
- Rain Level (min, max, average)
- Pressure (min, max, average)
- Solar Radiation (min, max, average)









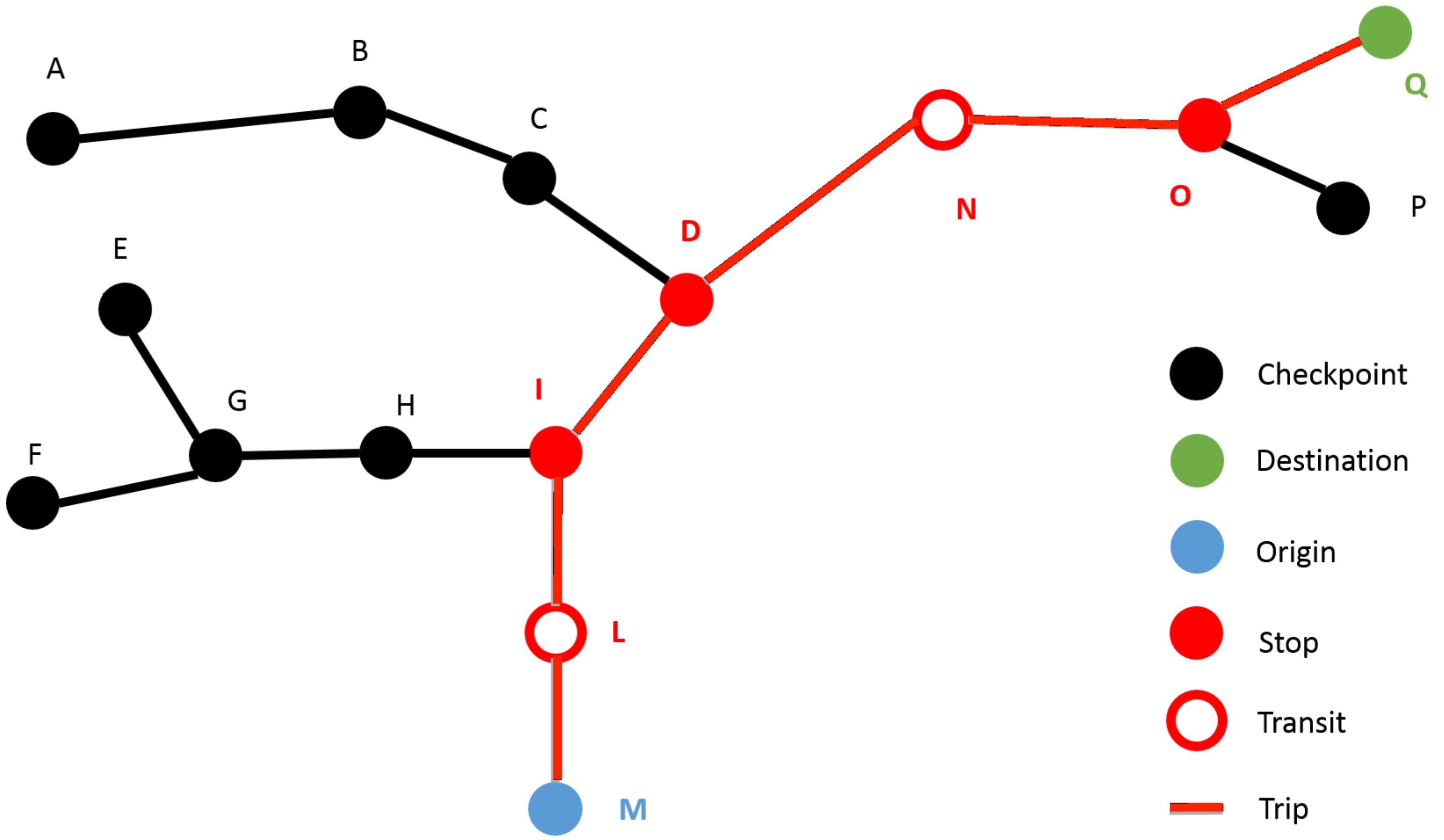
© Ilya Sedykh, © ARTunchained,
© Pearson Scott Foresman, © Editor at Large

Problem Formalization

How we approached the train delay prediction problem from a data-driven point of view

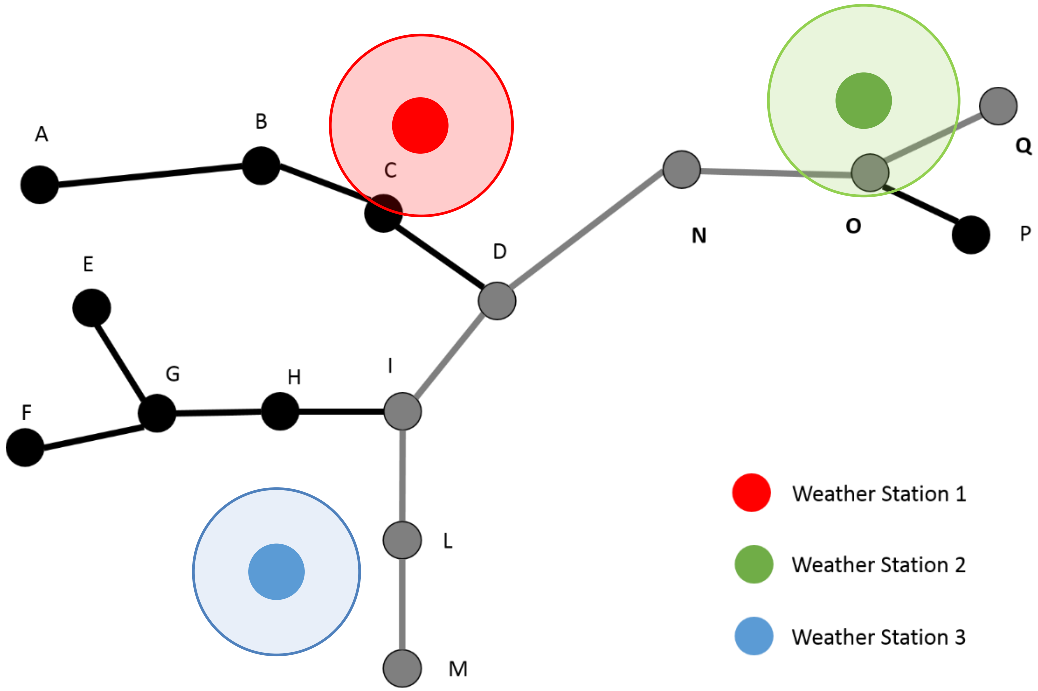
Example – Generic Train trip

A train trip starts from station “M” and ends at station “Q”



Example – Selection of weather stations

For each checkpoint in the trip, consider data from the **closest weather station**



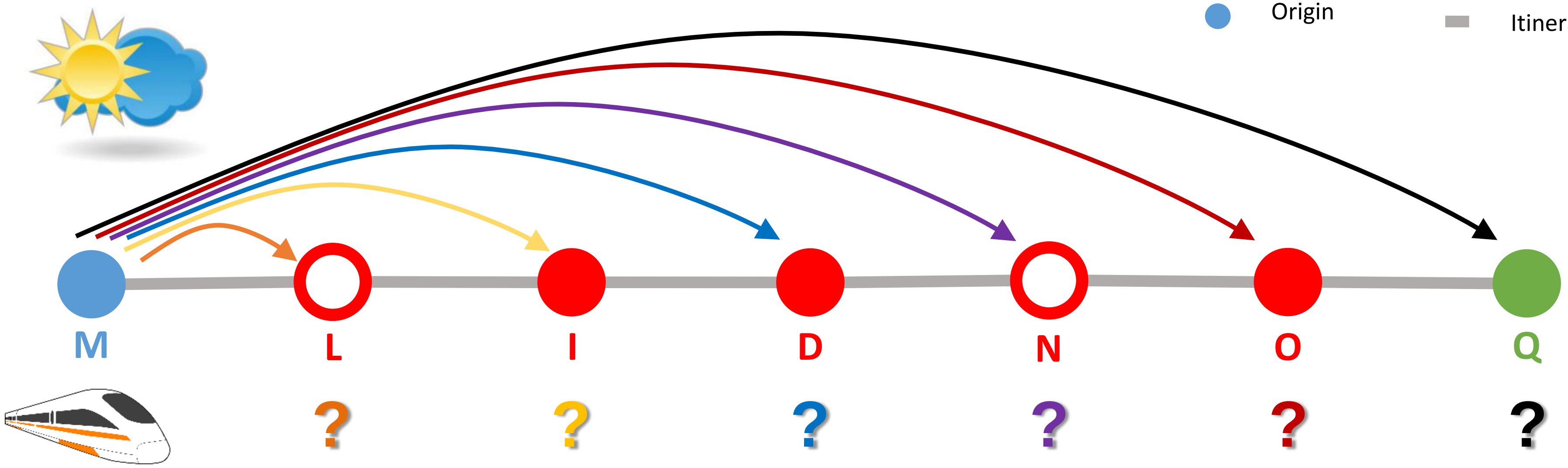
We consider data from weather station 3 for checkpoints M, L and I.

We consider data from weather station 1 for checkpoint D.

We consider data from weather station 2 for checkpoints N, O and Q.

Example – Modelling

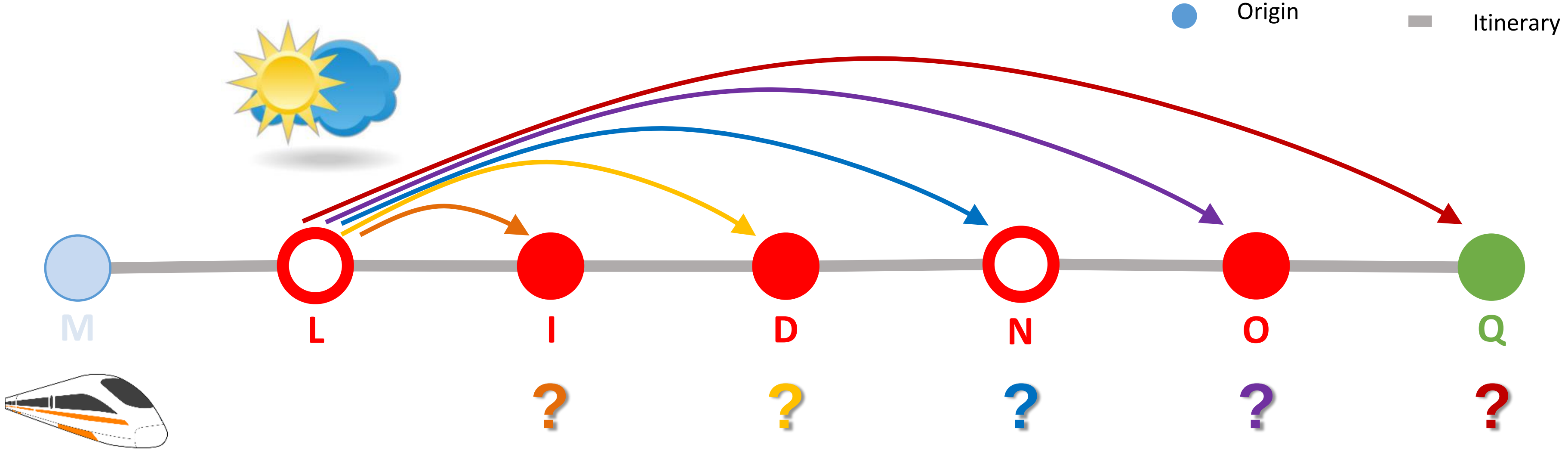
● Checkpoint
● Destination
● Origin
● Stop
◉ Transit
▬ Itinerary



For each train and for each of the successive checkpoints composing its trip, a **data-driven multivariate regression model** is built, which will output delay predictions for arrival and departures for the corresponding checkpoint.

Each arrow represents a data-driven model.
In this example, 6 different models for this train at checkpoint “M” have to be built.

Example – Modelling



The same approach is applied each time the train moves to a subsequent station, so **to exploit the new information as soon as it is available.**

For this train at checkpoint "L", 5 data-driven models have to be built. **For the entire train trip, 6 + 5 + … + 2 + 1 = 21 different models have to built.**

Train Delay Prediction as a Big Data problem

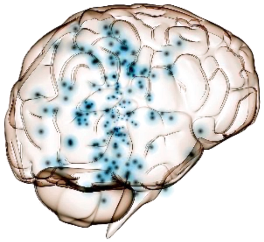
Every day, in the entire Italy:

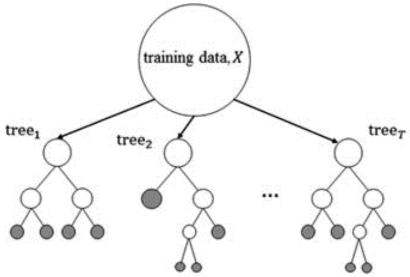
- **≈10 000 trains** from the service perspective (i.e. unique train IDs)
- Average of **≈12 checkpoints for every train**
- **≈120 000 movements**
- **≈10 GB of messages**

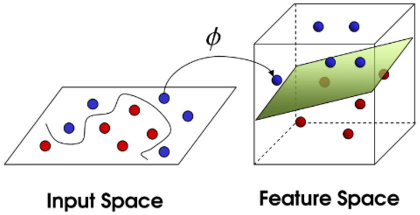
Therefore, exploiting the proposed approach results in **more than 600 000 delay prediction models**

Tested Big Data Regression Algorithms

- Extreme Learning Machines (ELM)
- Random Forest (ensemble of Decision Trees)
- Kernel Regularized Least Squares (KRLS)

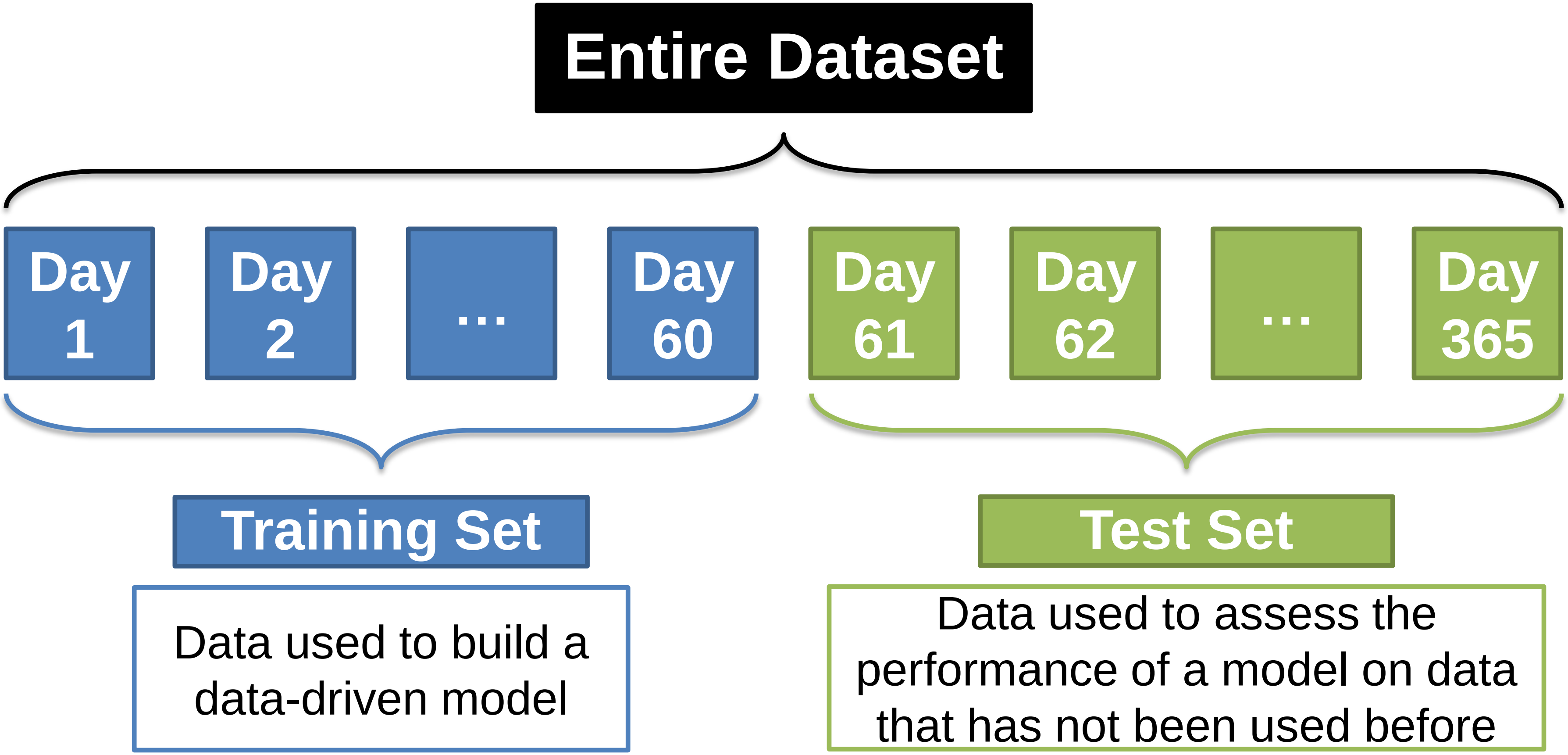






Implementation for the Big Data framework on Apache Spark (Apache Hadoop)

Performance Assessment Methodology



Entire Dataset

Day 1 | Day 2 | … | Day 60 | Day 61 | Day 62 | … | Day 365

Training Set

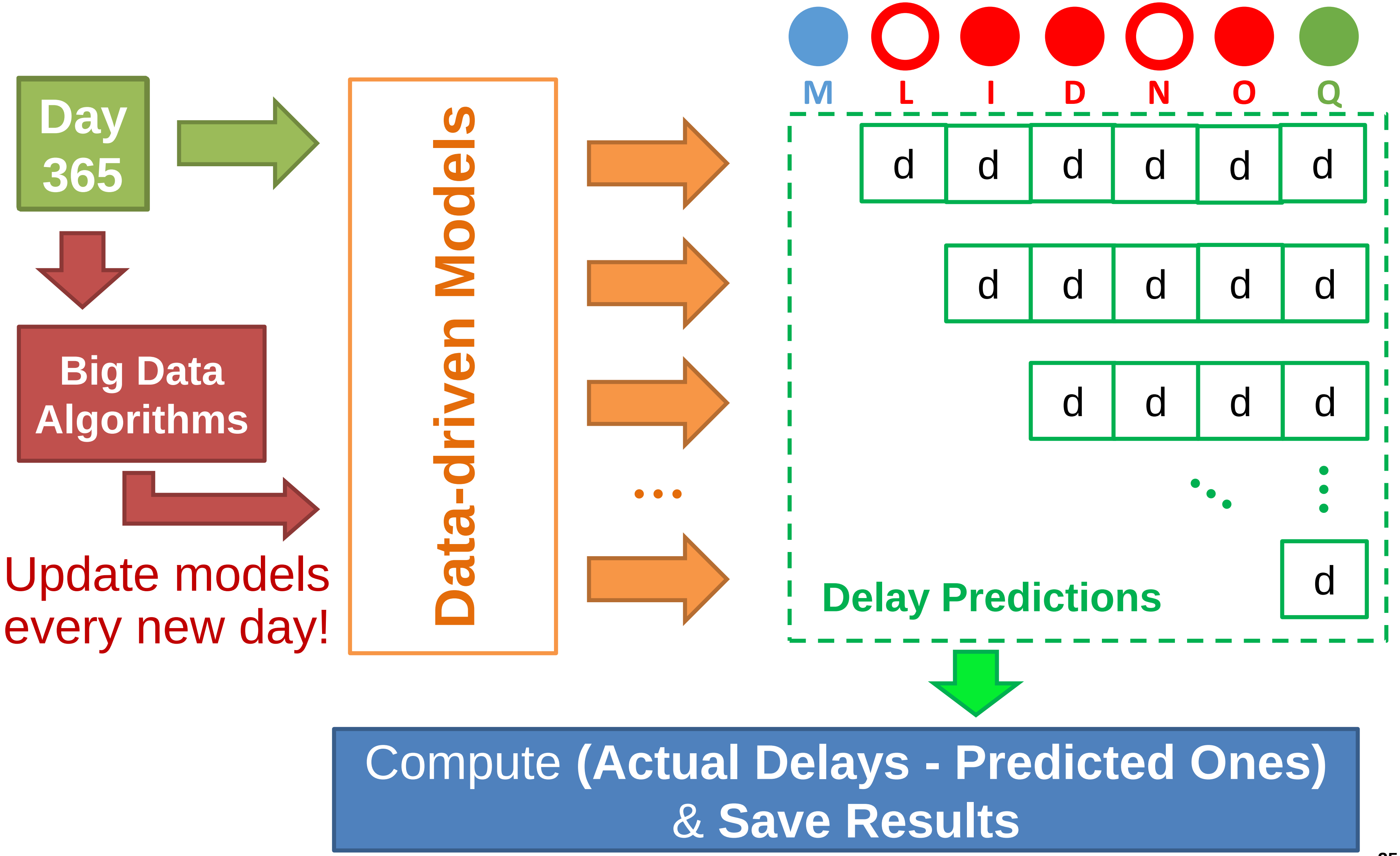
Data used to build a data-driven model

Test Set

Data used to assess the performance of a model on data that has not been used before

Test set is exploited **for simulations**, so to compare predictions with what really happened in the past

Simulations for Performance Assessment



Day 365

Big Data Algorithms

Update models every new day!

Data-driven Models

Delay Predictions

Compute (Actual Delays - Predicted Ones) & Save Results

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Summary of Simulation Results

Model	Current technique	Best data-driven model (without weather)	Best data-driven model (with weather)

AVG & VAR (Actual Delay – Predicted Delay)	mean = 3.3 min
	variance = ±1.6 min
		mean = 2.0 min
		variance = ±0.3 min
			mean = 1.9 min
			variance = ±0.3 min

- **Improvement factor ≈ ×1.7** (on total average)
- The **accuracy of the data-driven methods is quite homogeneous** (see variance) with respect to different trains and stations, while the current technique suffers from high fluctuations
- The inclusion of **weather data further improves the model,** although slightly

Presentation Index

- Big Data Analytics for Railways
- The Problem of Train Delay Prediction
- Data-driven Methodology
- Description of the Work Done
- Results
- Conclusions

Conclusions

- The new delay prediction system **outperforms the current one**
- The new technique is **designed to cope with large scale railway networks** generating large amounts of data
- It could be **integrated in a TMS solution** to provide advanced and accurate forecasting of train delays

Next Research Steps:

- Find **new railway data to be integrated in data-driven models** (e.g. state of infrastructure assets, train compositions, etc.)
- Consider the integration of **other external data** (e.g. passenger flows for passenger services) in order to analyze whether a further performance improvement is possible

Acknowledgements

In2Rail

C4R
Capacity for Rail

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION
HORIZON 2020

SEVENTH FRAMEWORK
PROGRAMME

THANK YOU FOR YOUR ATTENTION

Train Delay Prediction System for Large-Scale Railway Networks based on Big Data Analytics

Emanuele Fumeo, D. Anguita, L. Oneto, G. Clerico, N. Mazzino, F. Papa, R. Canepa

Napoli, 24th November 2016

Ansaldo STS S.p.A., University of Genoa and Rete Ferroviaria Italiana (RFI)