Allocating Railway Traffic with QUBO Formulated Models

FERROVIE DELLO STATO ITALIANE

REPLY DATA

#FSINNOVA

Who we are

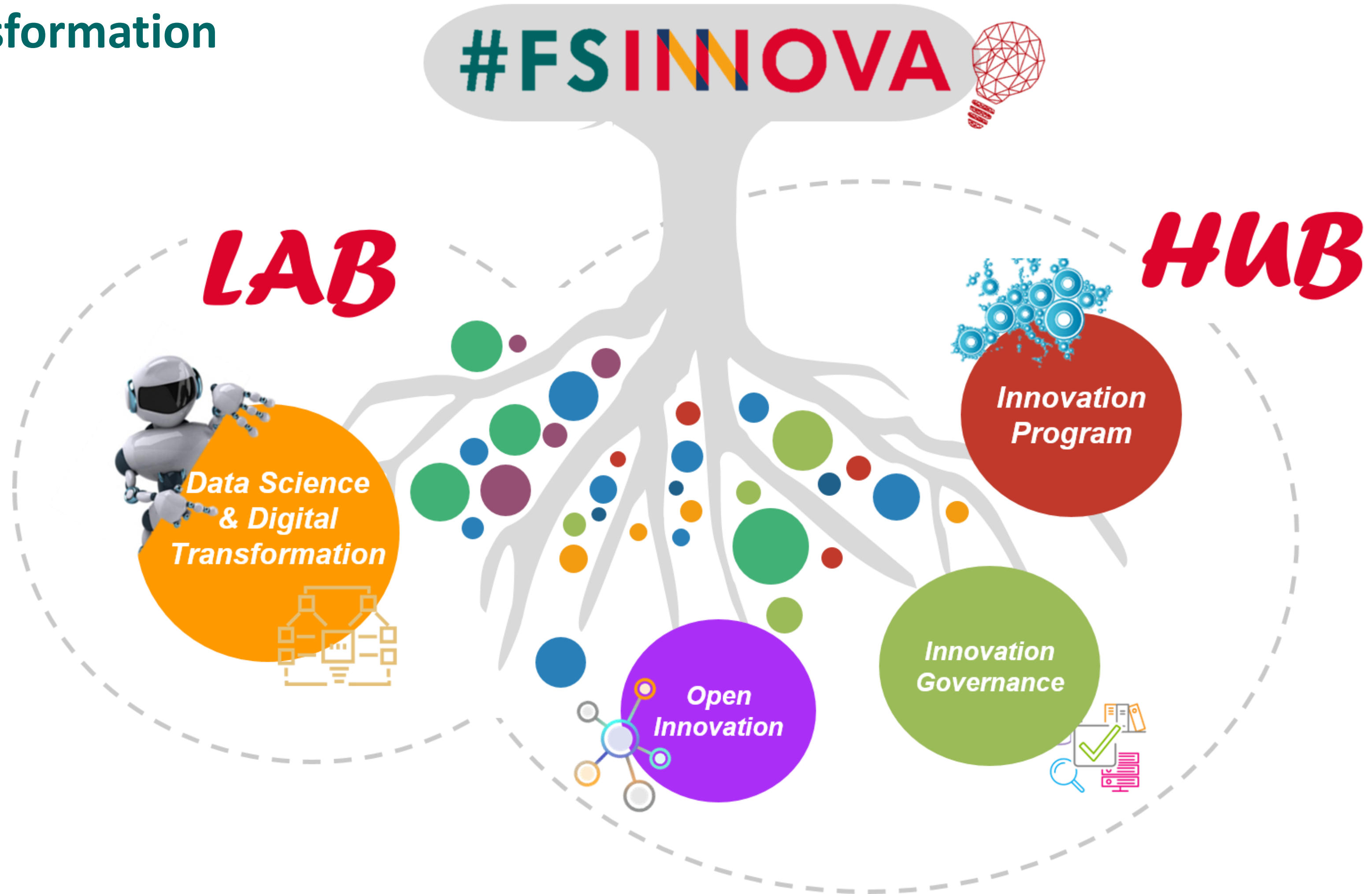
Ferrovie dello Stato Italiane S.p.A

- more than 10000 trains per day;
- 16700km long network;
- more then 2000 stations;
- 700 million passengers per year.

Who we are

Data Science and Digital Transformation

- Experiments in Innovation:
  - AI and Machine Learning
  - IoT
  - Blockchain
  - **Quantum Technologies**
  - …



Optimization problems at FS

Many hard optimization problems:

- Workforce deployment;
- deployment of trains for maintenance;
- multimodal optimization of time table schedule;
- load optimization for freight trains;
- ...

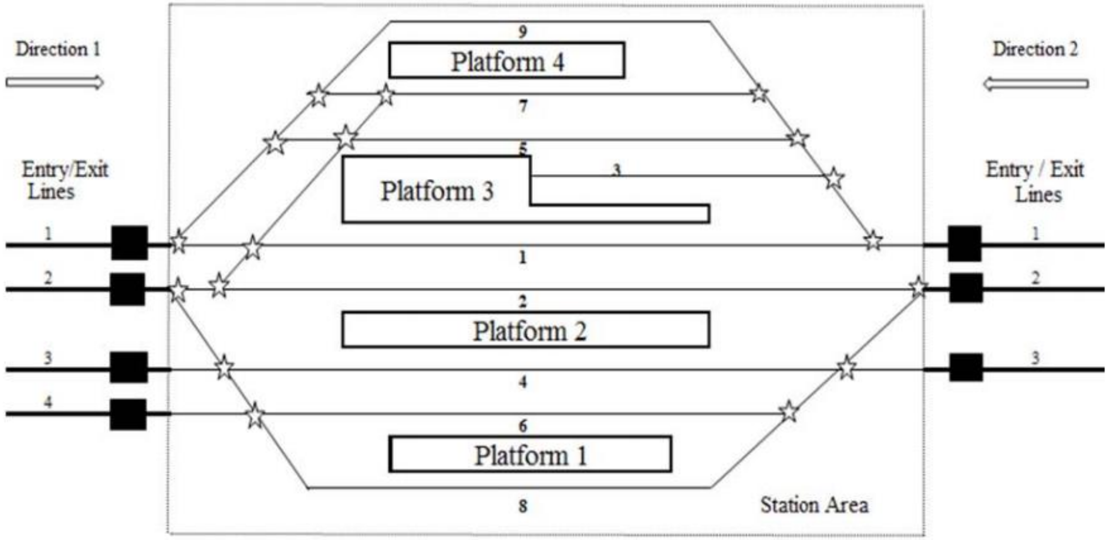
Some of these are currently optimized by automatic or semi-automatic engines while other are manually solved.

Can we use Quantum Technologies to solve some of these?

Train Platforming Problem (TPP)

The problem of assigning a platform to each train approaching a station given a predefined timetable.

- *Operational* Contraints:
  - 1-to-1 assignment of train to platform (no overlapping, no double assignment)
  - Station topology (not every track leads to every direction)



- *Commercial* Optimization
  - Eg. Distanze walked by users inside the station when switchin trains

Solving the TPP in every day planning

Currently the TPP in FS is solved:

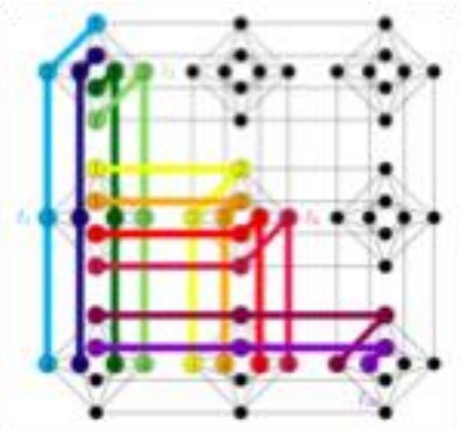
- semi manually
- according to a small set of heuristics
- with **no commercial optimization**

- In order to introduce an objective function the problem must be transformed into a **quadratic constrained optimization**

- The formulation of the Train Platforming Problem (TPP) is:

Quadratic model!

$$\min \sum_{b\in B} c_b y_b + \sum_{t\in T}\sum_{p\in P_t} c_{t,p}\, x_{t,p} + \sum_{(t_1,t_2)\in T^2}\sum_{p_1\in P_{t_1}}\sum_{p_2\in P_{t_2}} c_{t_1,p_1,t_2,p_2}\, x_{t_1,p_1}\, x_{t_2,p_2} \quad (*)$$



- Next approach: **QUBO**

→ faster to solve and suitable to be run on a quantum computer.

(*) Ref: Solution of the train platforming problem. https://doi.org/10.1287/trsc.1100.0366

Business interest

The model:

- it facilitates the flow of passengers within the station
- allows a better planning of the station workforce deployment as well as resources logistic
- Increases station capacity
- Could also be applied to multimodal passenger connectivity optimizing the mobility through multiple transportation systems (train, bus, tram, etc).

Know how:

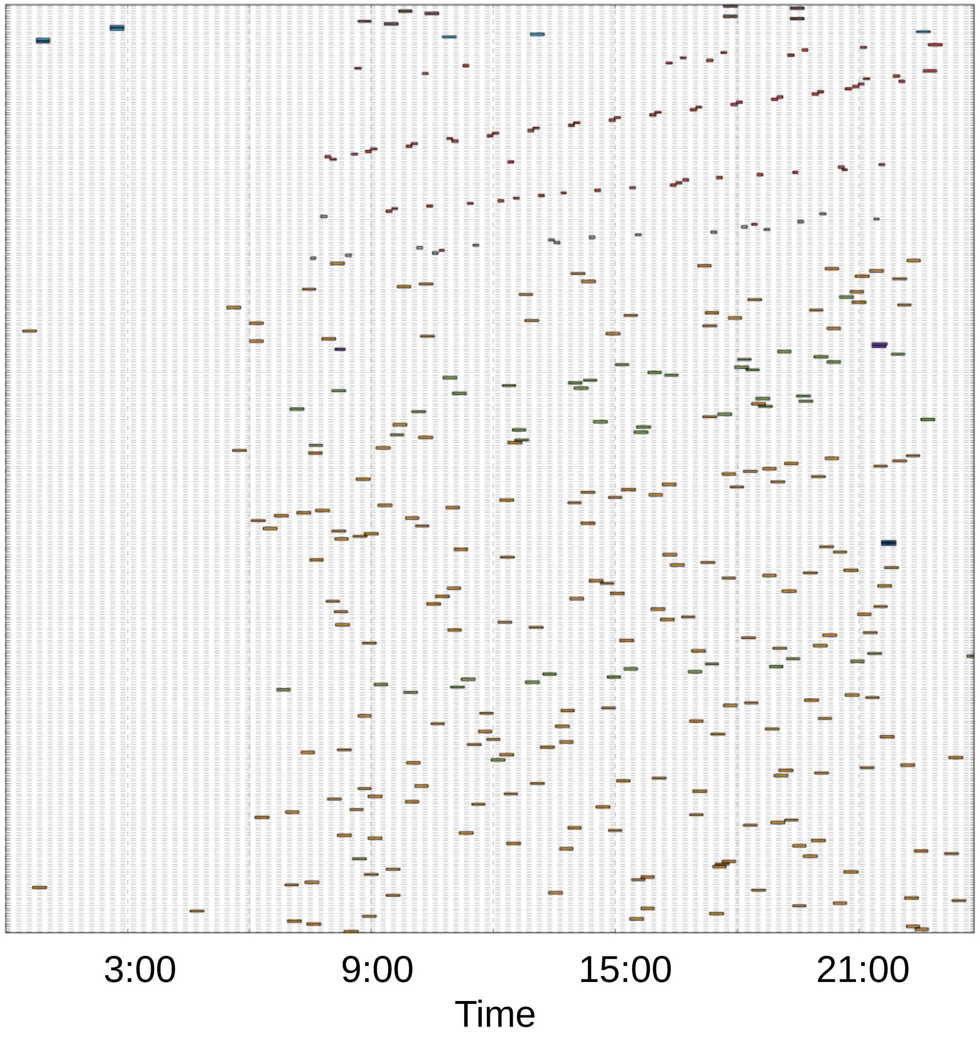
- Apply the know-how to other optimizations problem

The dataset

- Firenze Santa Maria Novella
- Platforms: 19
- Trains per day: ~400
    Regional and long haul (also busses...)
- Simple topology: all the platforms are on the same level

Train Traffic Analysis

- More than 2000 temporal overlapping to avoid
- Total number of variables is about 7000
- Rescheduling in near real time requires huge computational power
- Considering the effects of a delay on the planning is challenging
- Optimizing the station as part of the network (propagation of delays and maximization of the network effect)



Dwave computational model

Problems can be formulated as:

1. Ising models:

$$H_{ising} = \sum_{i=0}^{N} h_i s_i + \sum_{j>i} J_{ij} s_i \, s_j$$

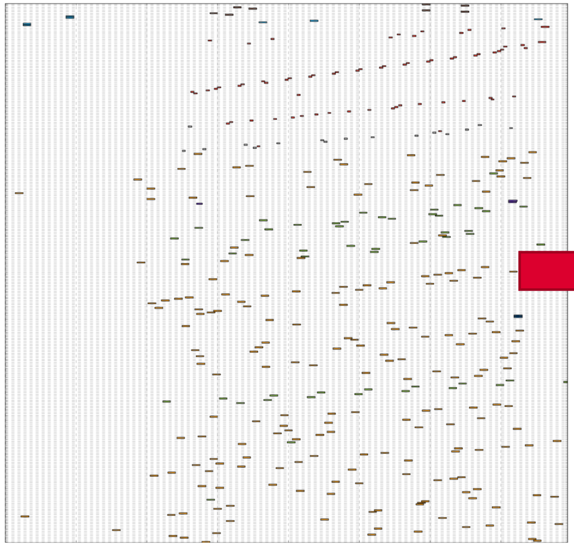
2. QUBO optimization:

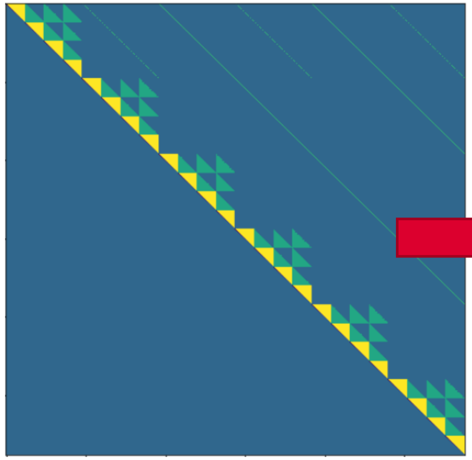
$$\min_{x} \left(\sum_{j \geq i} x_i \, Q_{ij} x_j \right)$$

- Q is the matrix that encodes our problem
- x_i are binary variables representing pairs (train, platform)
- $x_i = 1$ if corresponding train t is placed on platform p

A particular mapping has to be used to elaborate data through quantum annealing

Processing data with Quantum Annealing





QUBO objective function

1. Data analysis and preparation

2. QUBO formulation of the problem

3. Solution through classical Qbsolv or Dwave quantum annealing

QUBO objective function

The Hamiltonian to be minimized can be divided into:

$E(x)$

- The term related to the single assignment of a train
- The part responsible for the temporal overlapping of different trains on the same platform

Operational constraints

- The penalties term modelling the optimization of the station

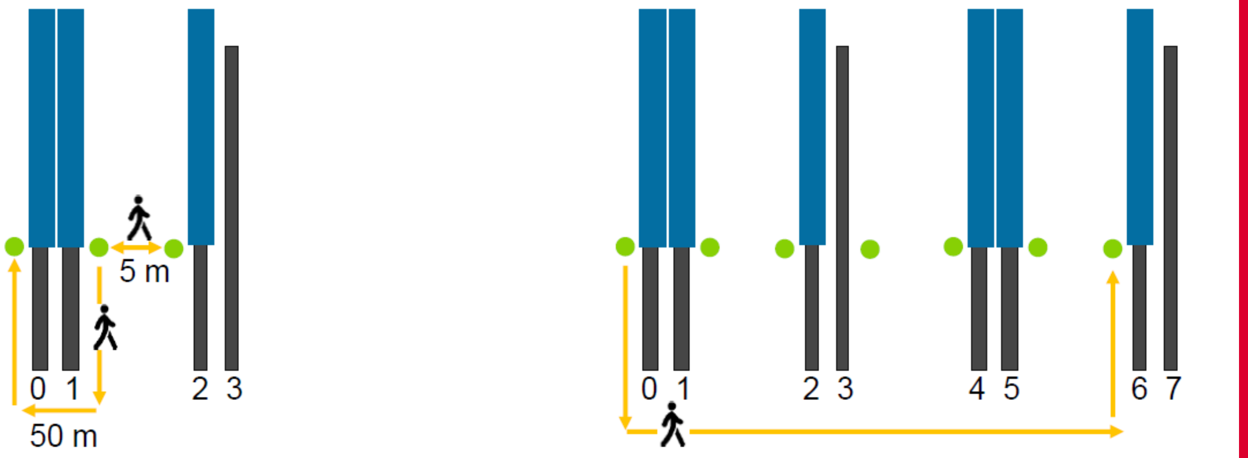
Optimization part

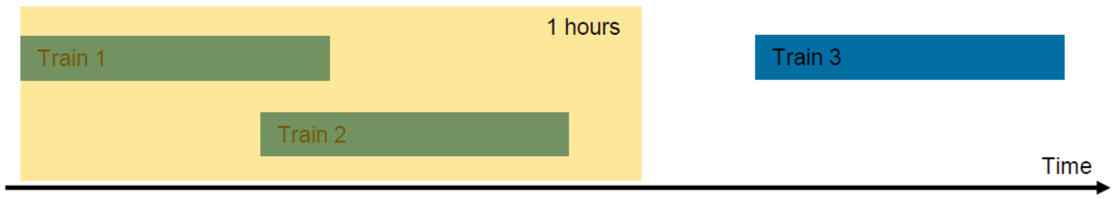
The optimization

- **Optimization measure**: Walking distance to switch trains

- We consider trains to be in coincidence only within 1 hour of temporal window.

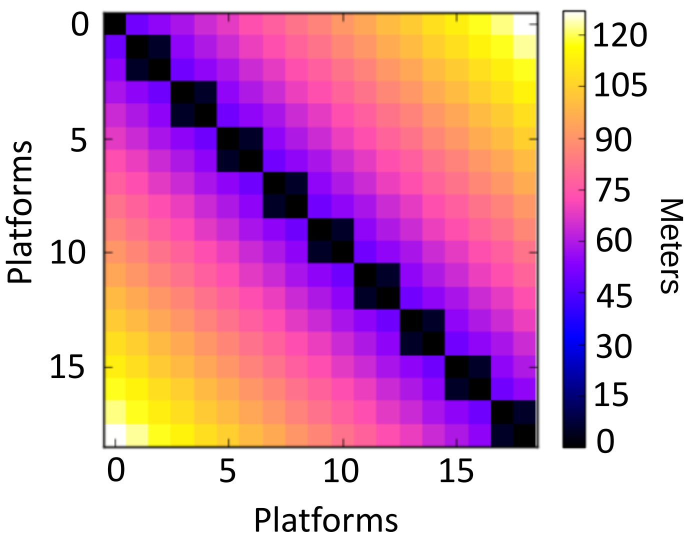
- Allow train with longer coincidence time to be placed further apart



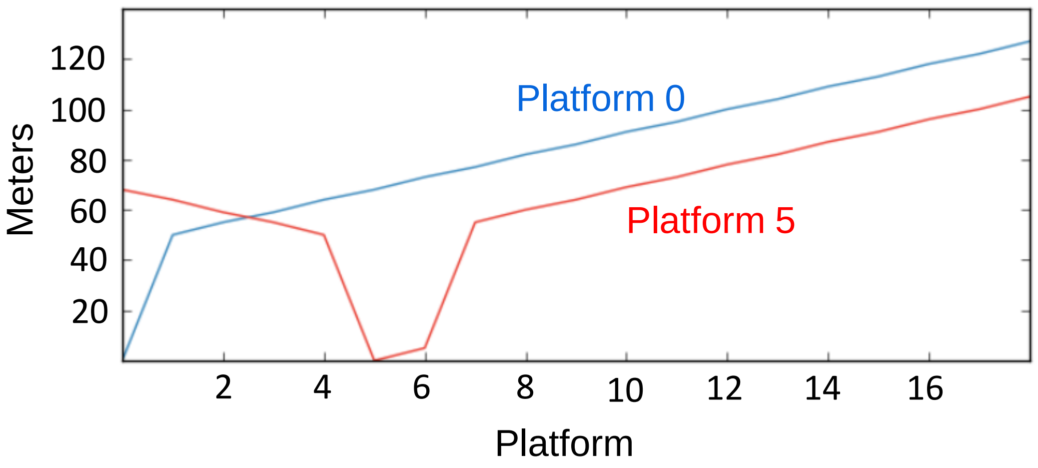


The distance matrix

Modelling the walking distance between different set of platforms:



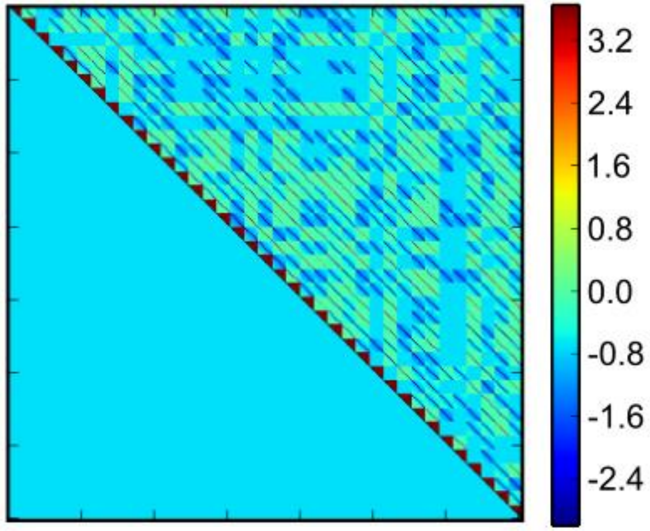
Evaluating the distances of platforms
from the first and 5th platform:



By using this calibration it is possible to calculate the QUBO configuration of the problem

The QUBO matrix

- The QUBO matrix encapsulates all the data and constraints
- All the platforms are initially considered as equally important: this is a simplification
- Additional constraints consider the connectivity between platforms
- Huge dataset: this QUBO contains about 7000 variables

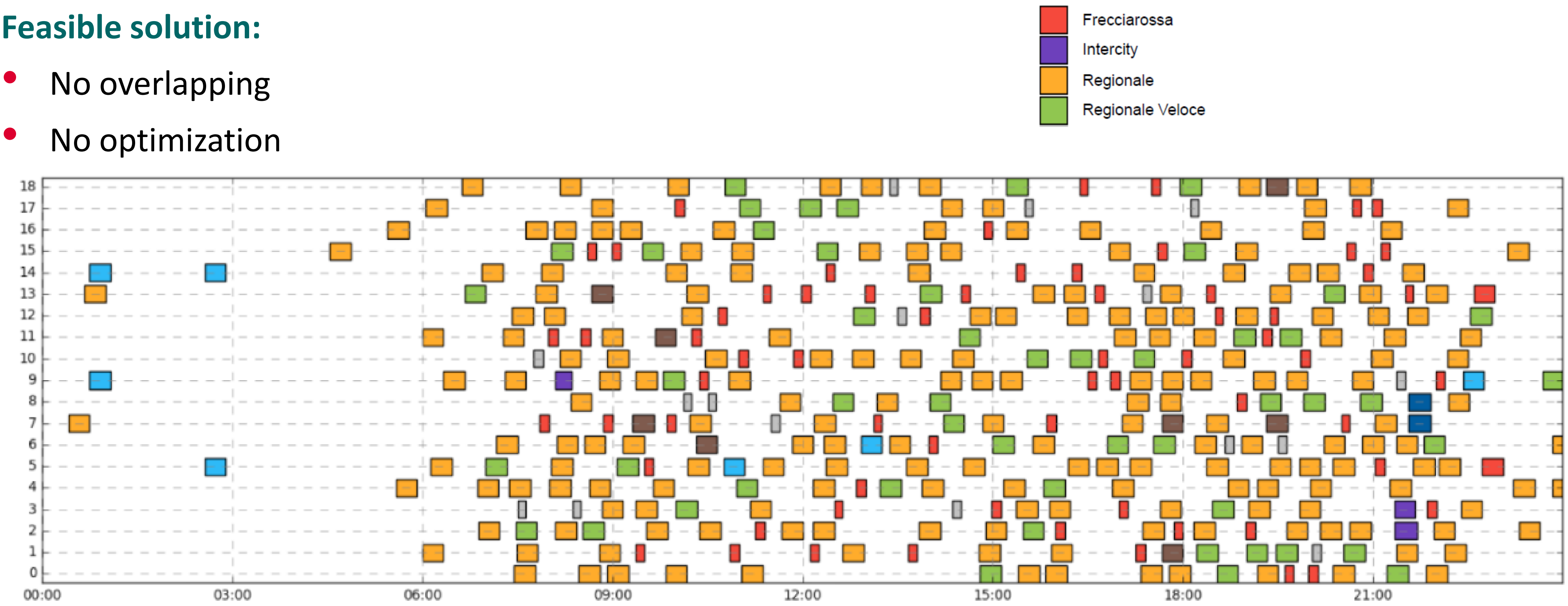


We solved this matrix by using the Dwave Qbsolv running a classical tabu-search on a HPC cluster

Solution

Feasible solution:

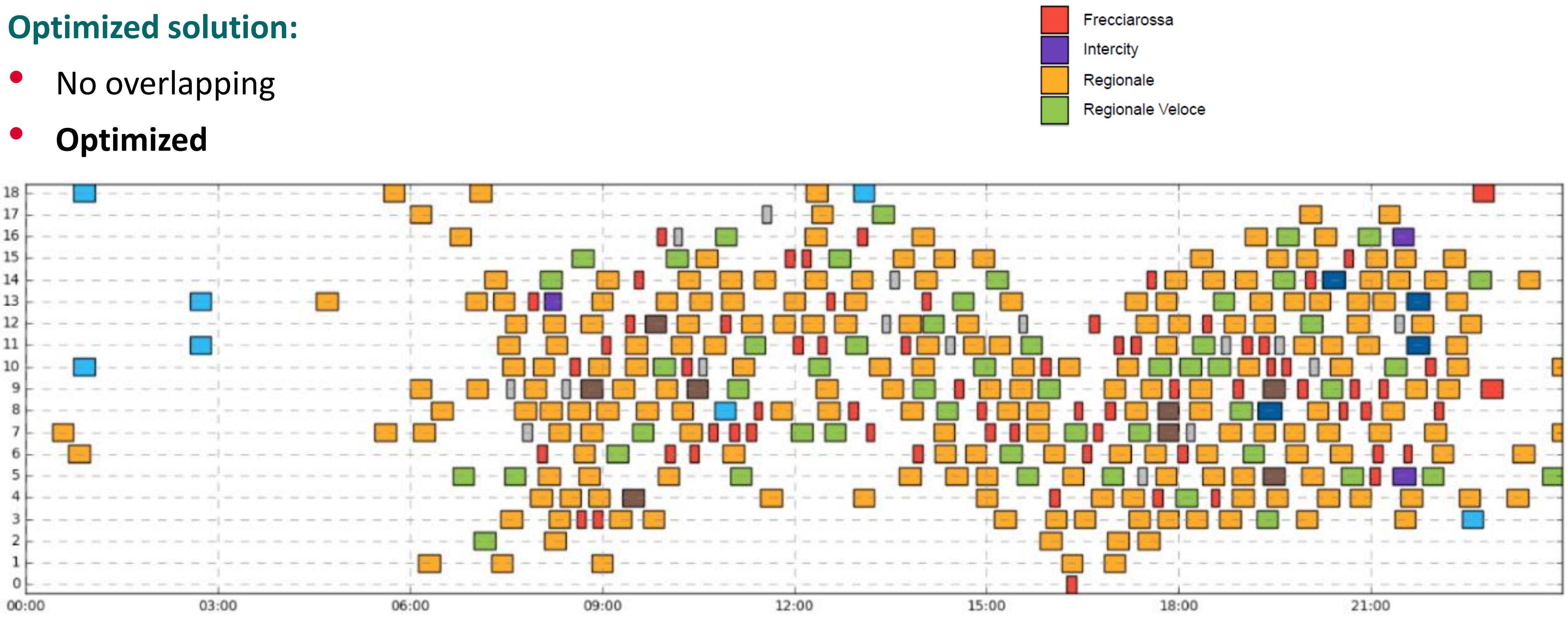
- No overlapping
- No optimization



Solution

Optimized solution:

- No overlapping
- **Optimized**



Quality: 30% better placement (measured by average distance walked)

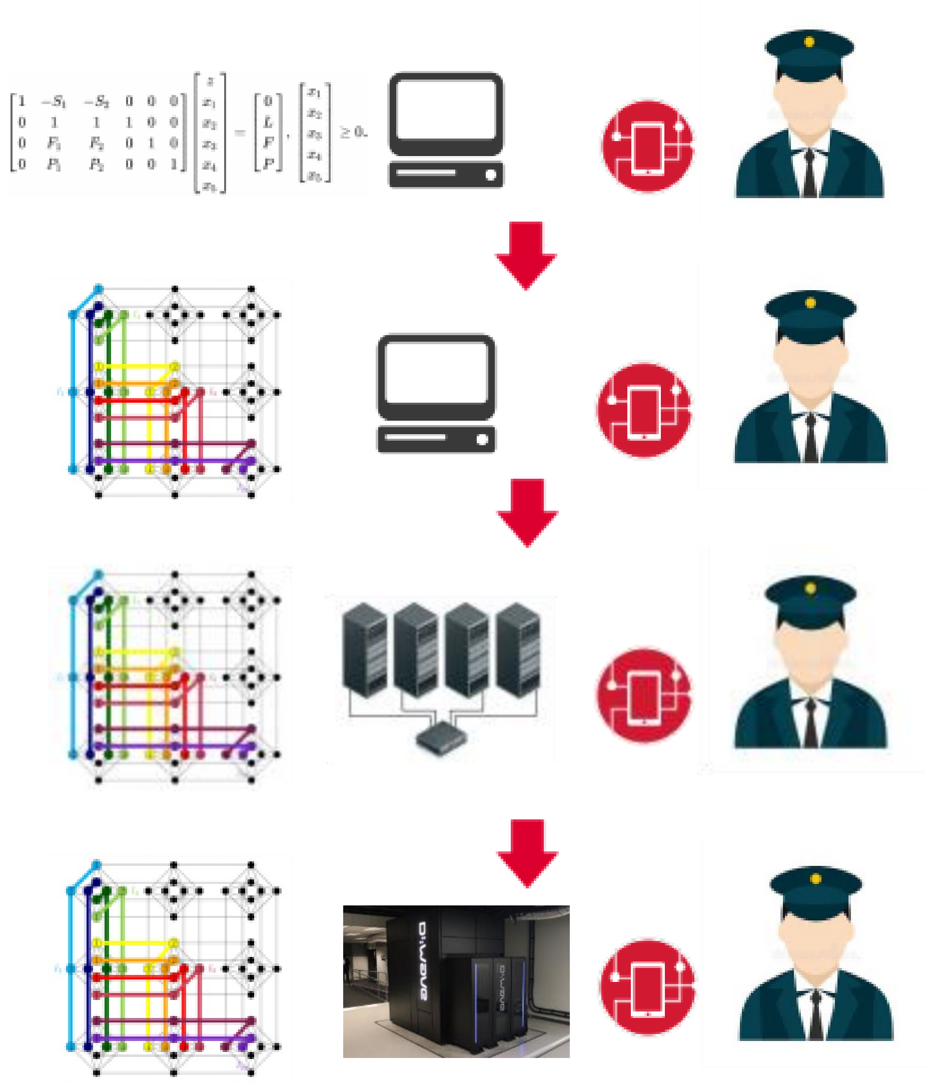
Computational time

All our experimentations on real datasets so far have been performed on classical hardware

On a single node laptop, the problem was solved in about 15 minutes

On a HPC cluster this QUBO formulation was solved in about 2 minutes; considerably fast, but still not enough to be usable in real time

The next step would be to test the solver on a real QPU



Conclusion and Future Perspectives

Further Improvements.

- Generalize to different station layouts
  - Distance matrix changes, but overall algorithm is exactly the same
- Consider platforms connectivity:
  - Not all the platforms are connected with specific directions
- Consider multimodality:
  - Bus terminal near the station, parking lot for car sharing services...
- Take into account real time changes:
  - How to reschedule the platforming in case of delays and/or disruptive changes (e.g.: unusable platforms, maintenance, …)?

Future perspectives.

- Test the algorithm on a quantum device
- Develop further know-how on Quantum approaches to optimization

Publication and Collaboration.

- Work accepted at ***World Railway Research Conference*** (Tokyo, Oct 2019)

Questions?