Allocating Railway Traffic with QUBO Formulated Models
Who we are

Ferrovie dello Stato Italiane S.p.A

• more than 10000 trains per day;
• 16700km long network;
• more than 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 Constraints:**
  - 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. Distance walked by users inside the station when switching 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:

\[
\min \sum_{b \in B} c_b y_b + \sum_{i \in T} \sum_{p \in R_i} c_{i,p} x_{i,p} + \sum_{(t_1,t_2) \in T^2} \sum_{p_1 \in R_{t_1}} \sum_{p_2 \in R_{t_2}} c_{t_1,t_2,p_1,p_2} x_{t_1,t_2,p_1} x_{t_2,p_2}
\]

• 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](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:

\[ H_{\text{Ising}} = \sum_{i=0}^{N} h_i s_i + \sum_{j>i} J_{ij} s_i s_j \]

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

2. QUBO optimization:

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

A particular mapping has to be used to elaborate data through quantum annealing
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
- The penalties term modelling the optimization of the station

Operational constraints

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:

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?