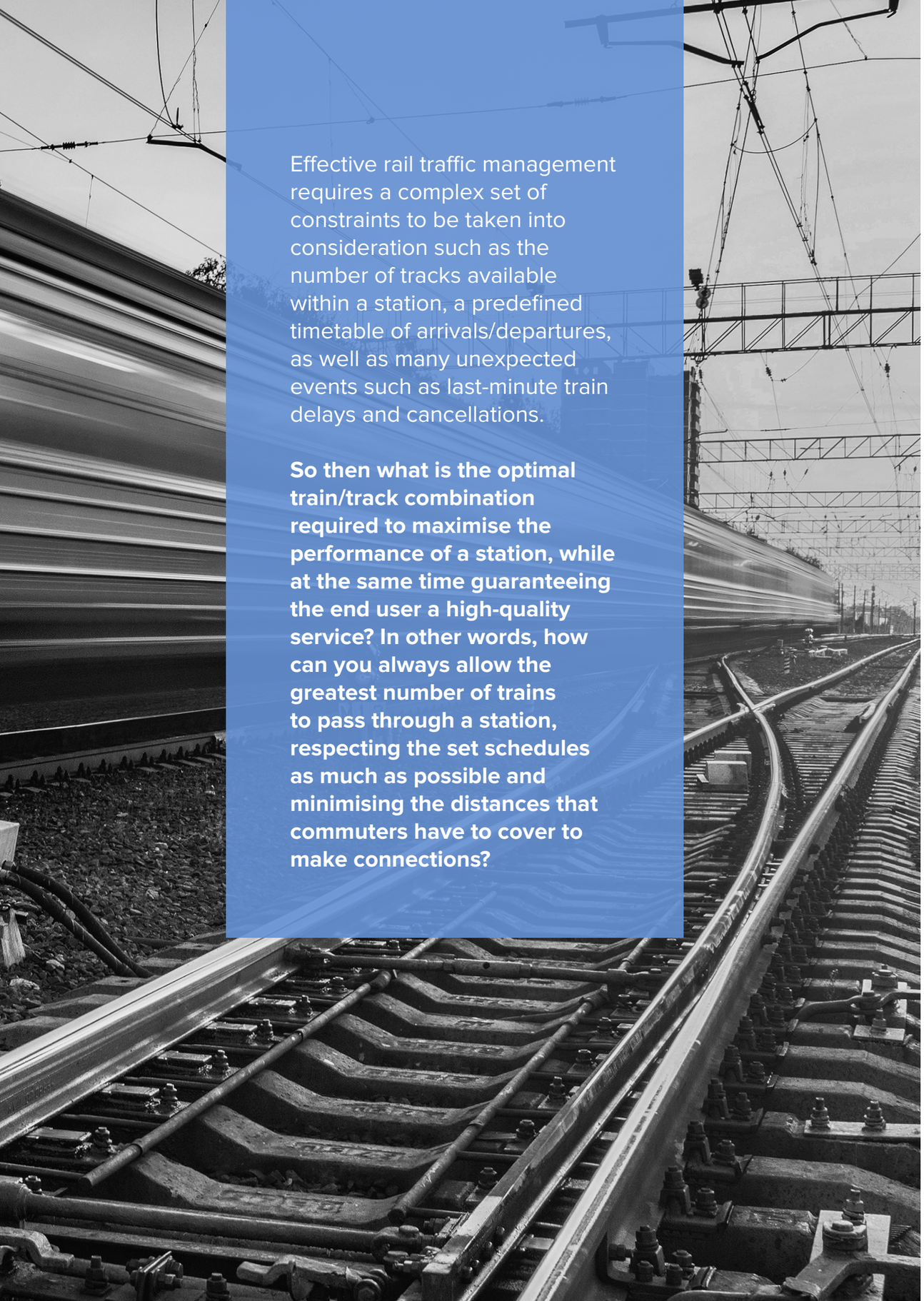
ALLOCATING RAILWAY TRAFFIC WITH QUBO

Coordinating routing trains in railway stations is a well-known and complex problem, given the many conditions to be considered and the potential for sudden unforeseen events. Using the QUBO model, Reply has demonstrated how to optimise railway traffic management with the support of Quantum Computing, while also improving the end-user experience.

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Effective rail traffic management requires a complex set of constraints to be taken into consideration such as the number of tracks available within a station, a predefined timetable of arrivals/departures, as well as many unexpected events such as last-minute train delays and cancellations.

So then what is the optimal train/track combination required to maximise the performance of a station, while at the same time guaranteeing the end user a high-quality service? In other words, how can you always allow the greatest number of trains to pass through a station, respecting the set schedules as much as possible and minimising the distances that commuters have to cover to make connections?

THE PROBLEM OF OPTIMISING THE RAIL NETWORK

The problem of **routing trains** inside a station, the so-called **TPP or Train Platforming Problem**, is widely known and, in Italy alone, is a problem faced by over 3,000 railway stations required to manage about 6 million passengers a day.

While, on the one hand, the possible combinations are potentially infinite, on the other hand, the best solution is one that can change adapt in real time as it is directly dependent on an interconnected, heterogeneous and constantly evolving scenario.

Based on the scheduled arrival time of a given number of trains, the challenge is to determine which tracks it is optimal to place each train on. This problem may seem trivial, but in reality, it comes up against a number of inevitable complications: from the topology of the station, to the management of the simultaneous arrival of several trains, to the use of a specific optimisation logic that places additional constraints on the decisions to be made. In addition, rail networks are rigid networks in which local inefficiencies, such as delays or a malfunction, often become comprehensive, systemic and characterised by an exponential trend.

The direct effects of inadequate and/or untimely management of unexpected situations can have repercussions thousands of kilometres away, while accumulated **delays** can translate into several hours of waiting and inconvenience for thousands of passengers.

FROM MANUAL MANAGEMENT TO QUANTUM MANAGEMENT

From a mathematical point of view, the ideal allotment of tracks is configured as a non-linear problem of dynamic optimisation, which becomes increasingly more complex as the size of the station grows. In fact, this type of planning (and continuous **re-planning**) is carried out using a semi-manual approach and through the adoption of linearisation techniques that frame the problem within a linear model.

This model is often simplified in order to achieve a solution, albeit at the expense of efficiency, of optimisation and, therefore, the maximisation of the economic performance of the single railway junction, with cascading effects on the quality of the rail and tramway system as a whole.

The management of train routing in large railway stations is, in this sense, one of the most striking application cases to demonstrate the **potential of Quantum Computing**, clearly illustrating how a better and faster computing capacity can generate economic value. Indeed, being able to optimise dynamically means being able to accommodate more trains, without having to support investments for new tracks; it also means guaranteeing arrival and departure schedules and therefore increasing the station's accommodation capacity.



RECEPTION OF SEVERAL TRAINS



GUARANTEED HOURS



INCREASED ACCOMMODATION CAPACITY

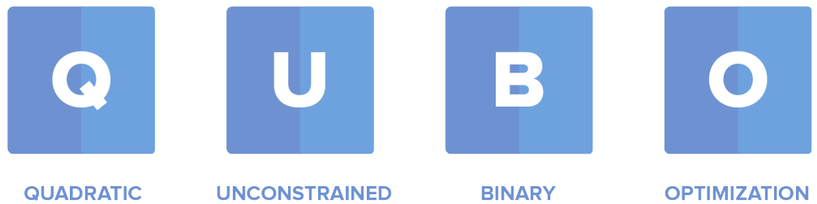
QUANTUM-INSPIRED ALGORITHMS AT THE SERVICE OF THE RAIL ECOSYSTEM

In this new technological framework, Reply has launched a multi-disciplinary research group dedicated exclusively to Quantum Computing, focused on developing concrete solutions for companies and businesses. More specifically, the work conducted by the Reply team is centred on quantum optimisation algorithms, including thorough concrete case studies and collaboration with international players.

In the rail mobility sector in particular, the practice developed by Reply demonstrates that it is possible to tackle the **Train Platforming Problem** successfully, through the adoption of an automated and quantum-based approach, which is also capable of improving passenger flows inside the station.

REPLY EXPERIMENTATION WITHIN AN ITALIAN RAILWAY STATION

Taking full advantage of the potential of Quantum Computing, Reply has developed a **QUBO** model, which stands for **Quadratic Unconstrained Binary Optimisation**. A mathematical formalism designed to describe quadratic and binary variable combinatorial optimisation problems.



Starting from the timetable of a medium-large Italian station with about twenty tracks, which sees about 400 trains passing through per day, with an average of over two thousand time overlaps, the Reply team modelled the actual state using the **QUBO algorithm**, introducing the following terms:

1. Associating each train to a single track: so not two and not zero.

2. Avoiding time overlaps, in order to avoid collisions.

3. Bringing trains with long connection times per hour as close as possible, in order to help passengers with connections (to perform this calculation, the Reply team simulated people walking inside the station).

The experiment was carried out twice, first excluding and then including the term relating to the optimisation of the **distance travelled** (point 3), making it possible to compare the two scenarios (non-optimised/optimised configuration).

The results were quite impressive: in the first case, non-optimised configuration, the model placed trains on the tracks in a feasible manner, almost randomly.

In the second case, optimised configuration, there was an average reduction of about 30% of the walking distance required for passengers to make a connection; moreover, as a result of the new, optimised management, the station showed a **higher capacity** than with the non-optimised management. In fact, some of the tracks remained unused for long periods of time.

THE RESULTS: OPTIMISED MANAGEMENT AND IMPROVED USER EXPERIENCE

Reply's experience has demonstrated, in a clear and concrete way, precisely how the QUBO algorithm is able to improve the passenger experience inside a station (point 3), to optimise the use of tracks and to increase, for the same size/infrastructure, the capacity of railway lines: in other words, the number of trains that can pass through a station in the unit of time or within a predetermined time frame, thus freeing up space for adding new journeys to the timetable.



The result obtained takes on even greater importance if we consider that the number of commuters who take the train every day in Italy is growing and is expected to reach 10 million passengers within the decade, both when it comes to regional trains and underground lines, including high-speed trains, and that currently train travel is the most environmentally friendly means of transport. In this scenario, Quantum Computing can therefore also serve as a valid and effective ally to promoting **sustainable mobility**.