During the recent years there is an increasing interest in designing strategies to reduce the energy consumption in railways lines. With the existing infrastructure and the trains nowadays in service it is possible to reduce consumption optimizing the traffic operation with insignificant investment. Particularly, most trains are equipped with regenerative braking systems. The objective of this project is to reduce energy consumption in Metro de Madrid (Spain) by means of maximizing the use of regenerative braking energy. Metro de Madrid has a DC electric system, with non-invertible substations and without accumulators. Thus this regenerative braking energy can be used:
- To feed the auxiliary services of the train
- By other train demanding energy in the same electric section

Schedule re-design:

**Power determination**

- **$p$ – regenerative power**
  - Determined for each pair of possible synchronization
  - Indicates which ones are more desirable.

**Solve the DC power flow**

- Non-invertible substations
- Voltage control (1790 V)
- Quadratic mixed-integer problem
- Implemented in GAMS
- Solved using SBB

**Synchronize speed-up and slow-down processes of trains electrically connected**

**Schedule model**

- **Constraints**
  - Bounded stopping time
  - Bounded running times
  - Only 1 minute delay regarding to the advertised timetable
  - Connections assured
  - Desired target speed

**Determine the schedule**

**Implementation (2009)**

**Savings and synchronization correlation**

- Blue: Intensity show the level of synchronization of each speed-up process
- Red: Speed-up process synchronized with more than one slow-down process. More robust timetable

**Results**

Correlation between energy savings and synchronization increment of 75.2%
Measured energy savings in electrical substations 3.5% (with only one minute margin)