Energy-optimal Timetable Design for Sustainable Metro Railway Networks

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What is the problem?
- Collaboration with Thales Canada Inc, the largest provider of communication-based train control systems worldwide
- Railway timetable is a data-structure that
  - contains the arrival and departure time of every train
  - to and from all the platforms that train visits
  - over the entire service period (e.g., 18 hours)
- Goal: Want to design the energy-optimal railway timetable that will
  - minimize the energy consumption of the trains
  - maximize the transfer of regenerative energy
  - subject to the functional constraints in the railway network

Energy consumption and regeneration of a train

Our real-time optimization model
- Constraints
  - constraints are associated with trip, dwell, connection, headway (safety), and travel time
  - the constraints are linear and has a network-flow problem like structure
  - our formulation is robust with respect to box uncertainty
- Cost function to minimize
  - total effective energy consumption \( = \) total energy consumed during acceleration - total transferred regenerative energy from braking trains to accelerating trains
  - models the interplay between consumed and regenerated energy

Why should we care?
- Most modern railway networks are equipped with regenerative energy transfer mechanism
- Example: New York City Transit (NYCT) consumes more than 1,600 GWh of electricity annually
- All the new trains installed since 2018 are capable of producing regenerative braking energy, can regenerate up to 50% of the consumed energy
- If scheduled properly, a braking train can successfully transfer its regenerative energy to a nearby accelerating one
- So the energy-optimal timetable can lead to significant energy saving without any infrastructure update

Modeling effective energy consumption

Application to Shanghai Metro Network
- We apply our model to Line 8 of Shanghai Metro Network – one of the largest and busiest railway services in the world
- Compare the energy saving with existing real-world timetables
- Optimization model solved using a custom parallel interior-point algorithm
- Solution time less than 1 sec on a standard desktop computer

Reduction in effective energy consumption

Cost function
- Energy consumed during acceleration can be modeled as a linear function in trip time for metro railway networks
- Total transferred regenerative energy can be modeled as piecewise minimum of linear functions \( \Rightarrow \) can be transformed into linear constraints

Summary
- Real-time linear optimization model for designing energy-optimal timetables
- Set to be implemented globally by Thales Canada Inc