University of Trieste

Dept. of Engineering and Architecture
Coupling OpenTrack with external Optimization Tools
An example in energy-efficient timetabling

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Introduction

- Professor in Transport Planning and Railway Operations, involved in research projects since 1996
- OpenTrack user since 2004
- Founder of the Railway and Traffic Laboratory (Liftlab) in 2007
  - Spin-off of the University of Trieste
  - Analysis and simulation of railway operations
  - Italy and 28 Countries in 5 Continents
  - Strategic co-operation with ESTECO S.p.A. in 2016
- API Academic license in 2017
Main network (Turin-Trieste, Brenner-Neaples)

Main junctions (Turin, Milan, Venice, Bologna, Florence, Rome, Neaples, Bari, Palermo)
References abroad

- USA
- Chile
- Argentina
- Perú
- Brasil
- Italy
- Croatia
- Serbia & Montenegro
- France
- Switzerland
- The Netherlands
- Norway
- UK
- Belgium
- Slovenia
- Spain
- Jordan
- Saudi Arabia
- Oman
- Turkey
- UAE
- Algeria
- Egypt
- South Africa
- Ethiopia
- Australia
Introduction

- Wide range of situations
  - **different levels** (from strategic planning to day by day operations)
  - **different problems** (from national networks to Metro and tram lines)
  - **different dimensions** (from 1 train to hundreds of trains)
  - Passenger, freight, mixed traffic
  - **different types of customers** (Infrastructure Managers, Train Operating Companies, Regions, Port Authorities, Consulting and Engineering companies,...)
Methodology

- OpenTrack as simulation engine
- Planning loop
- Few number of selected scenarios
  - Time consuming
  - Complex modeling
- Optimization?
ESTECO was founded as a spin-off company of the University of Trieste in the late 1990’s, by three Italian Engineers, Carlo Poloni, Luka Onesti and Enrico Nobile.

Now ESTECO is an independent technology provider of customer-focused software solutions for numerical optimization.
Over 300 international clients have relied on ESTECO software to design better and more efficient products across a wide spectrum of industrial sectors.
Research project

Research coordination

Real life railway experience
OpenTrack power user

Optimization experience and tools
Aims and outline of the presentation

- Present mainly the “architecture” of the approach
  - OpenTrack as micro-simulation engine
  - API to communicate between OpenTrack and the ESTECO Software (third party)

- Discuss a simple but interesting case study (Energy-efficient timetabling)

- Present first results and possible further developments
Problem: Introduction

- **Green** transportation is becoming more and more important from environmental perspectives.
- Optimal energy-efficient driving strategies can reduce operating costs significantly and contribute to a further increase of the sustainability of railway transportation.
- A number of models and algorithms exist to compute the optimal train trajectories.
- Still, finding the optimal sequence and switching points of the optimal driving regimes is a not trivial task.
- **Energy-Efficient Train Timetabling Problem (EETTP):** consists in energy-efficient timetable calculation considering the trade-off between energy efficiency and travel times.
- Regeneration
Problem: Literature Review

- A wide range of models and algorithms exist (see Scheepmaker, Goverde and Kroon paper on European Journal of Operational Research (2017) for a complete review of energy-efficient train control and timetabling):
  - Dynamic Programming
  - Mixed Integer Linear Programming
  - Heuristics
  - Fuzzy Logic
  - ……

- Let’s try to deal with this problem using OpenTrack
Approach based on ESTECO SOFTWARE and OPENTRACK
OpenTrack and API are used as Black Box: it generates objective and constraint values (OUTPUT VARIABLES) according to the input (INPUT VARIABLES).
## Classification of optimizers

<table>
<thead>
<tr>
<th>Gradient-based</th>
<th>Global Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single objective</td>
<td>Multi objective</td>
</tr>
<tr>
<td>B-BFGS</td>
<td>NBI-NLPQLP</td>
</tr>
<tr>
<td>NLPQLP</td>
<td>NBI-AFSQP</td>
</tr>
<tr>
<td>MIPSQP</td>
<td>SIMPLEX</td>
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<td>AFilterSQP</td>
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<td>Levenberg-Marquardt</td>
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</tr>
</tbody>
</table>
Multi-objective problems are solved using sophisticated optimization algorithms, which identify a set of Pareto designs (a set of solutions for which it is not possible to improve one goal without worsening the other).

With ESTECO Software you can define the most suitable optimization strategy according to:

- number, type and range of variables, objectives and constraints
- reliability and robustness required
- attainable computational resources
The specific problem

- Problem finds **train speed profile** in train's itinerary to minimize
  - ✔ Energy Consumption
  - ✔ Total Travel Time
- The train speed profile is composed by **train driving regime sequence** and possible variables are:
  - ✔ Target Speed
  - ✔ Length of Cruising regime
- Complete the itinerary
Integration with ESTECO’s Software

**SECTION 1**
- Speed limit
- Engine off

**SECTION N**
- Speed limit
- Engine off

**Black Box**

**INPUT**

**OUTPUT**
- Time
- Energy
- Time
- Energy
Open Track Api

Start OpenTrack API’s mode

Start listen server

Read file input XML

goSimulation

Start simulation

Read message from OT

Train arrived in station?

Pause simulation

Send command for next route

Last station?

Write output file

Elaboration data

Read OpenTrack’s output file
Genetic Algorithms use the analogy of natural selection and reproduction as optimization target.
An important preliminary step of an optimisation process is the **initial (population) sampling of the design space**

The initial population for Genetic Algorithm is given by Design of Experiments (DOE) Algorithms

Different algorithms (Random, Sobol, ULH,...) exit which covers the space in a different way.
Genetic algorithms: Selection

Best individuals are selected (by fitness or dominance criteria)
Genetic algorithms: Reproduction

Each individual is coded by a binary string

```
  1 0 0 1 1 1 0 0 1 0

  1 1 0 1 0 0 1 1 1 1
```

Different operators are applied to generate a new population

```
Crossover: Initial Population

  1 0 0 1 1 1 0 0 1 0

  1 1 0 1 0 0 1 1 1 1

New Individuals

  1 0 0 1 1 0 1 1 1 1

  1 1 0 1 0 1 0 0 1 0
```

Parent 1
Parent 2
Child 1
Child 2
Genetic algorithms: Reproduction

Mutation

Parent: 1 0 0 1 1 1 0 0 1 0

Child: 1 0 0 0 1 1 0 0 1 0
Test Case
Test Case

- Slope
- Altitude
## Test Case: Details

<table>
<thead>
<tr>
<th>Station</th>
<th>Speed Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>80 km/h</td>
</tr>
<tr>
<td>B</td>
<td>80 km/h</td>
</tr>
<tr>
<td>C</td>
<td>80 km/h</td>
</tr>
<tr>
<td>D</td>
<td>80 km/h</td>
</tr>
<tr>
<td>E</td>
<td>80 km/h</td>
</tr>
<tr>
<td>c_2</td>
<td>75 km/h</td>
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<tr>
<td>G</td>
<td>80 km/h</td>
</tr>
<tr>
<td>c_3</td>
<td>80 km/h</td>
</tr>
<tr>
<td>h</td>
<td>70 km/h</td>
</tr>
<tr>
<td>I</td>
<td>80 km/h</td>
</tr>
<tr>
<td>L</td>
<td>70 km/h</td>
</tr>
<tr>
<td>M</td>
<td>80 km/h</td>
</tr>
<tr>
<td>c_4</td>
<td>80 km/h</td>
</tr>
<tr>
<td>N</td>
<td>80 km/h</td>
</tr>
<tr>
<td>c_5</td>
<td></td>
</tr>
</tbody>
</table>
Test Case
Open Track Api

80 km/h 50 km/h

Speed limit range

Maximum time to engine off (before breaking)

Minimum time to engine off (to reach the following station)
Results

100% - moga-2
90% - moga-2
90% - OT User
100% - OT User

Δ Energy
Δ time
## Performance 100%

<table>
<thead>
<tr>
<th>Point</th>
<th>User OT Energy</th>
<th>User OT Time</th>
<th>moga-2 Energy</th>
<th>moga-2 Time</th>
<th>ΔTime %</th>
<th>Energy</th>
<th>Time</th>
<th>ΔEnergy %</th>
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<tbody>
<tr>
<td>A</td>
<td>762028</td>
<td>1713</td>
<td>759631</td>
<td>1700</td>
<td>0.76</td>
<td>655783</td>
<td>1713</td>
<td>13.94</td>
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<tr>
<td>B</td>
<td>626552</td>
<td>1732</td>
<td>624460</td>
<td>1719</td>
<td>0.75</td>
<td>572404</td>
<td>1731</td>
<td>8.64</td>
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<tr>
<td>C</td>
<td>570388</td>
<td>1748</td>
<td>568163</td>
<td>1734</td>
<td>0.80</td>
<td>534674</td>
<td>1749</td>
<td>6.26</td>
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</tbody>
</table>

## Performance 90%

<table>
<thead>
<tr>
<th>Point</th>
<th>User OT Energy</th>
<th>User OT Time</th>
<th>moga-2 Energy</th>
<th>moga-2 Time</th>
<th>ΔTime %</th>
<th>Energy</th>
<th>Time</th>
<th>ΔEnergy %</th>
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<tbody>
<tr>
<td>D</td>
<td>715276</td>
<td>1746</td>
<td>714079</td>
<td>1740</td>
<td>0.34</td>
<td>648951</td>
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<td>E</td>
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<td>1769</td>
<td>605612</td>
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<td>566103</td>
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<td>552414</td>
<td>1773</td>
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<td>537253</td>
<td>1783</td>
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<tr>
<td>STATION</td>
<td>Performances 100%</td>
<td>Example Solution Moga-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>---------</td>
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</tr>
<tr>
<td></td>
<td>Time</td>
<td>Time</td>
<td>Margins</td>
<td>ΔTime %</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>A</td>
<td>01:00:00</td>
<td>01:00:00</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>B</td>
<td>01:01:22</td>
<td>01:01:27</td>
<td>00:00:05</td>
<td>5.81%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C</td>
<td>01:02:54</td>
<td>01:03:00</td>
<td>00:00:01</td>
<td>1.16%</td>
<td></td>
<td></td>
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<tr>
<td>D</td>
<td>01:05:09</td>
<td>01:05:28</td>
<td>00:00:13</td>
<td>15.12%</td>
<td></td>
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<tr>
<td>E</td>
<td>01:07:08</td>
<td>01:07:43</td>
<td>00:00:16</td>
<td>18.60%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C2</td>
<td>01:09:00</td>
<td>01:09:40</td>
<td>00:00:05</td>
<td>5.81%</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>F</td>
<td>01:10:44</td>
<td>01:11:26</td>
<td>00:00:02</td>
<td>2.33%</td>
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</tr>
<tr>
<td>G</td>
<td>01:13:03</td>
<td>01:13:55</td>
<td>00:00:10</td>
<td>11.63%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>C3</td>
<td>01:15:00</td>
<td>01:15:54</td>
<td>00:00:02</td>
<td>2.33%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>01:17:04</td>
<td>01:18:00</td>
<td>00:00:02</td>
<td>2.33%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>01:19:05</td>
<td>01:20:08</td>
<td>00:00:07</td>
<td>8.14%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>01:20:58</td>
<td>01:22:09</td>
<td>00:00:08</td>
<td>9.30%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>01:23:12</td>
<td>01:24:29</td>
<td>00:00:06</td>
<td>6.98%</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>C4</td>
<td>01:25:00</td>
<td>01:26:24</td>
<td>00:00:07</td>
<td>8.14%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>01:26:38</td>
<td>01:28:04</td>
<td>00:00:02</td>
<td>2.33%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C5</td>
<td>01:27:54</td>
<td>01:29:20</td>
<td>00:00:00</td>
<td>0.00%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td>00:27:54</td>
<td>00:29:20</td>
<td>00:01:26</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
MOGA-II Results
NSGA-II Results
MOGA-2 and NSGA-2 Comparison
File *.tsvP

```java
public void mecPower() throws IOException {
    for (int a = 0; a < 25; a++)
        if (this.tsvp.readLine() == null)
            System.out.println("File bad format!!!");
    String lastline = null;
    while ((line=tsvp.readLine())!= null) {
        String[] dati = line.split("\t", 8);
        calcMacPower(valueOf(dati[6]));
    }
}

public void calcMacPower(double value) {
    consumi = consumi + value;
}
```
Results

Rigenerazione pura
Results
Conclusions

- API makes it possible to create a connection to a third party optimization tool
- This may allow to use OpenTrack as micro-simulation engine and increase its potentials
  - OpenTrack model with API license
  - Identify exactly Input and Output variables and what is fixed
  - Optimization tool license
- Increase the number of simulated scenarios (thousands instead of few)
- Increase the quality of results
- First tests are promising
Further developments

- Extend the application to real life problems by using existing API commands
- Suggest the development of specific new commands within API
- Analyze the performances of existing optimization algorithms for railway specific applications
- Development of possible improved algorithms
Thank you for your attention

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