University of Trieste

Dept. of Engineering and Architecture

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University of Trieste

“Coupling OpenTrack with external Optimization Tools”

An example in energy-efficient timetabling

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Introduction

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- 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

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References in Italy

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- Main network (Turin-Trieste, Brenner-Neaples)
- Main junctions (Turin, Milan, Venice, Bologna, Florence, Rome, Neaples, Bari, Palermo)

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References abroad

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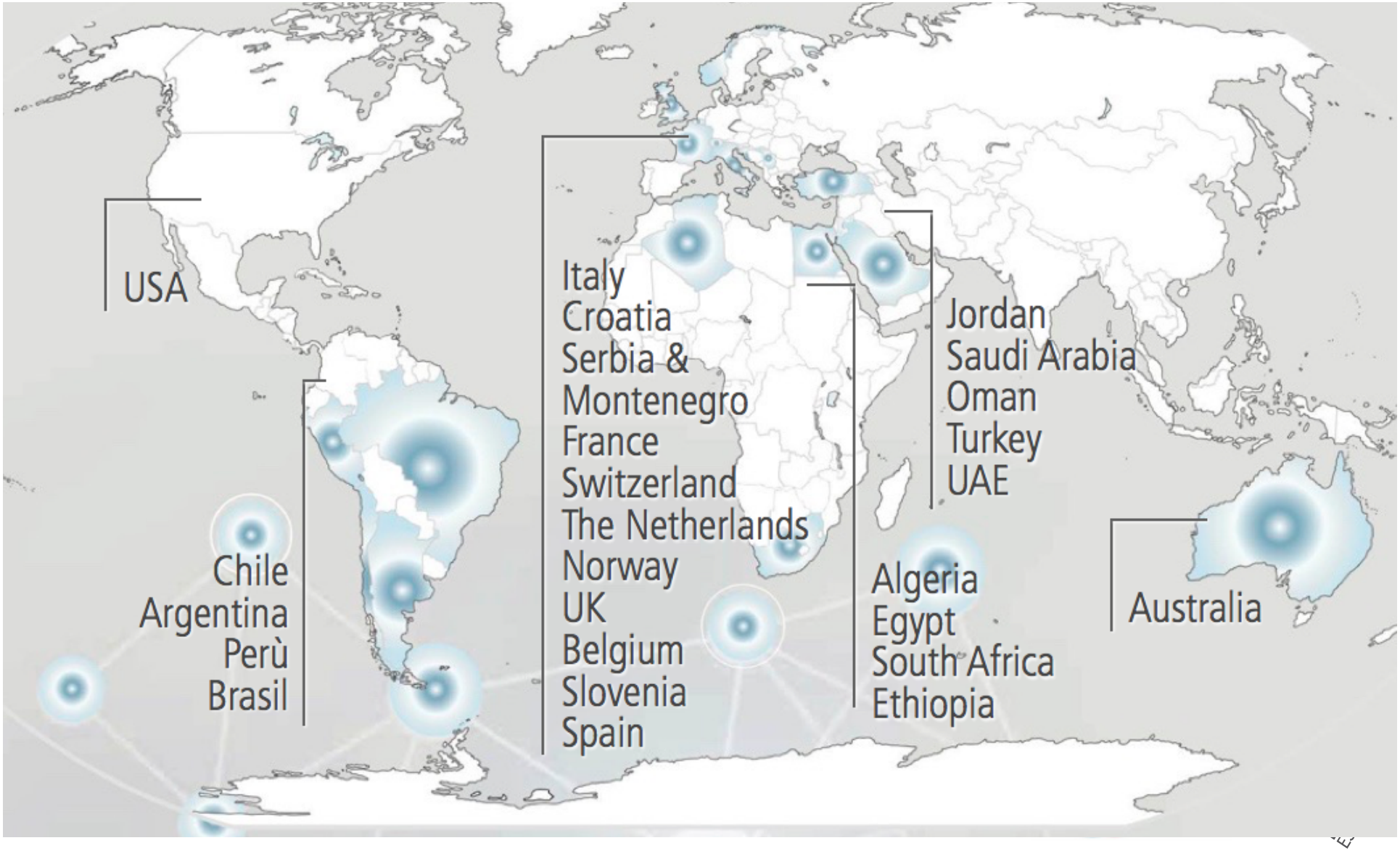

Introduction

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- 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** (from1 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,…)

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Methodology

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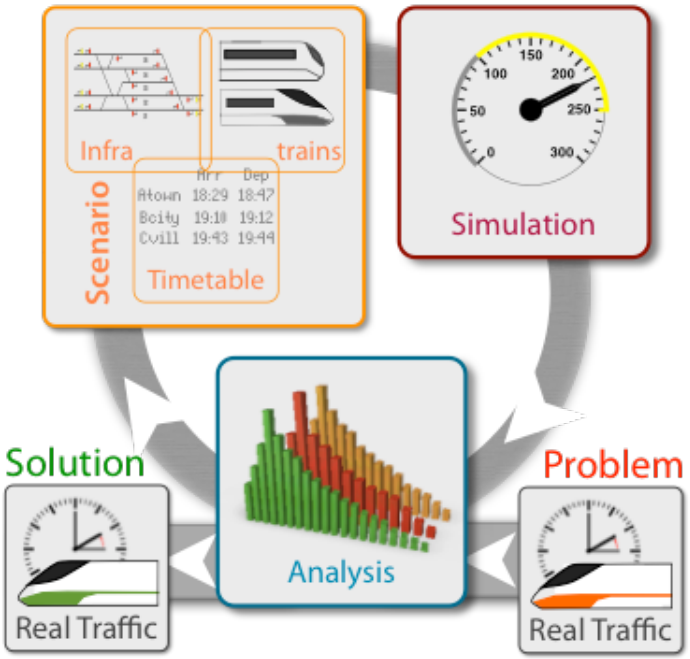
- OpenTrack as simulation engine
- Planning loop
- Few number of selected scenarios
  - ✓ Time consuming
  - ✓ Complex modeling
- Optimization?



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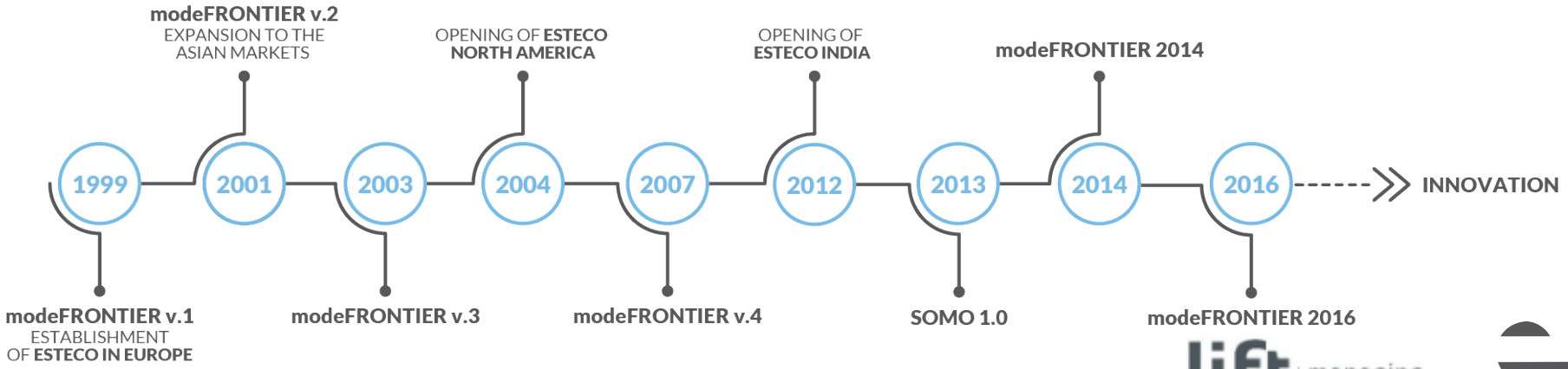
- ESTECO was founded as **spin-off company** of the University of Trieste in the **late 1990's**, by three Italian Engineers, Carlo Poloni, Luka Onesti and Enrico Nobile.

- Now ESTECO is an independent technology provider of customer-focused software solutions for numerical optimization.



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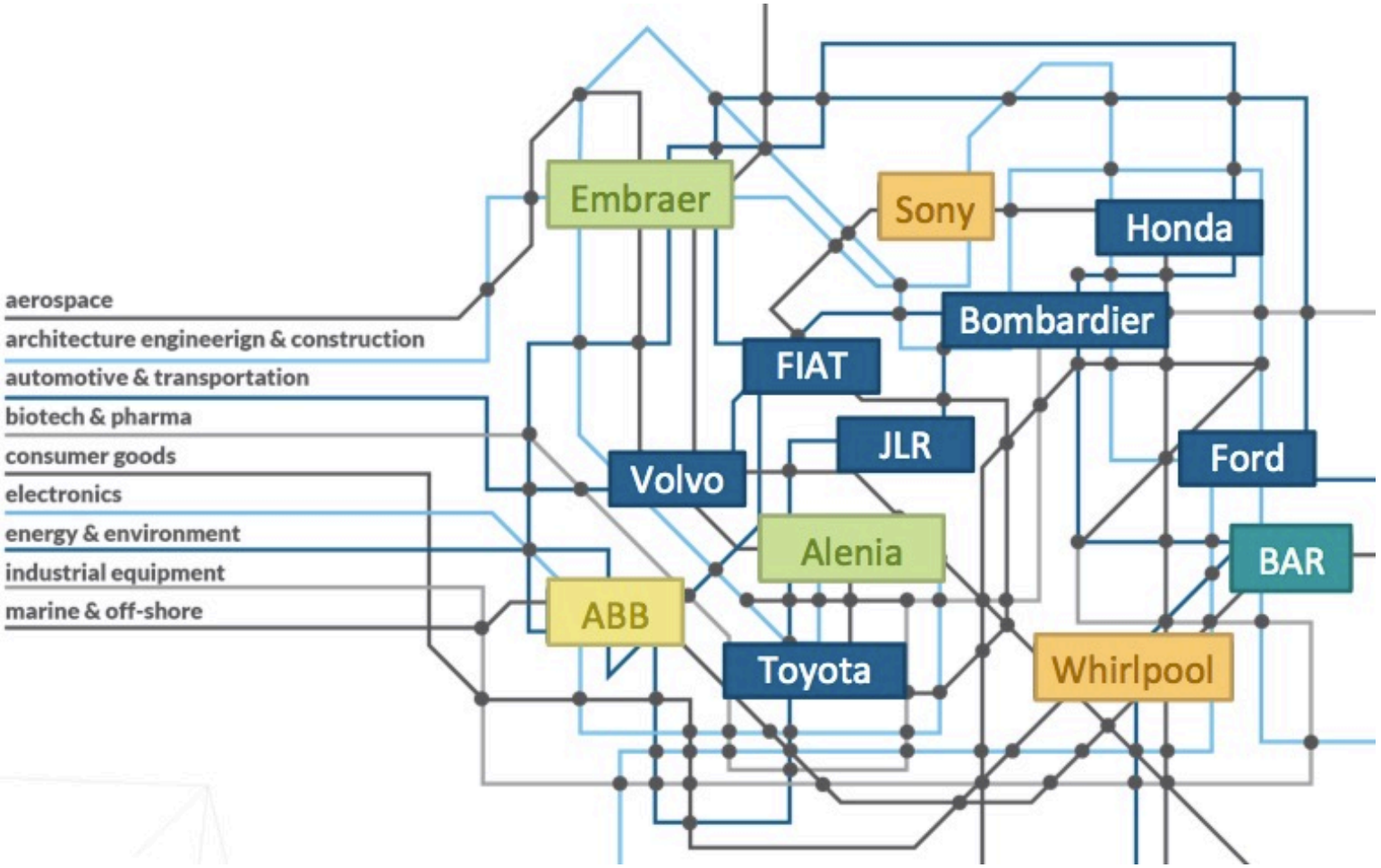

Over 300 international clients have relied on ESTECO software to design better and more efficient products across a wide spectrum of industrial sectors.

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Research project

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Research coordination

Real life railway experience
OpenTrack power user

Optimization experience and tools

Aims and outline of the presentation

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- 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

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Problem: Introduction

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- 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

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Problem: Literature Review

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- 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

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Approach based on ESTECO SOFTWARE and OPENTRACK

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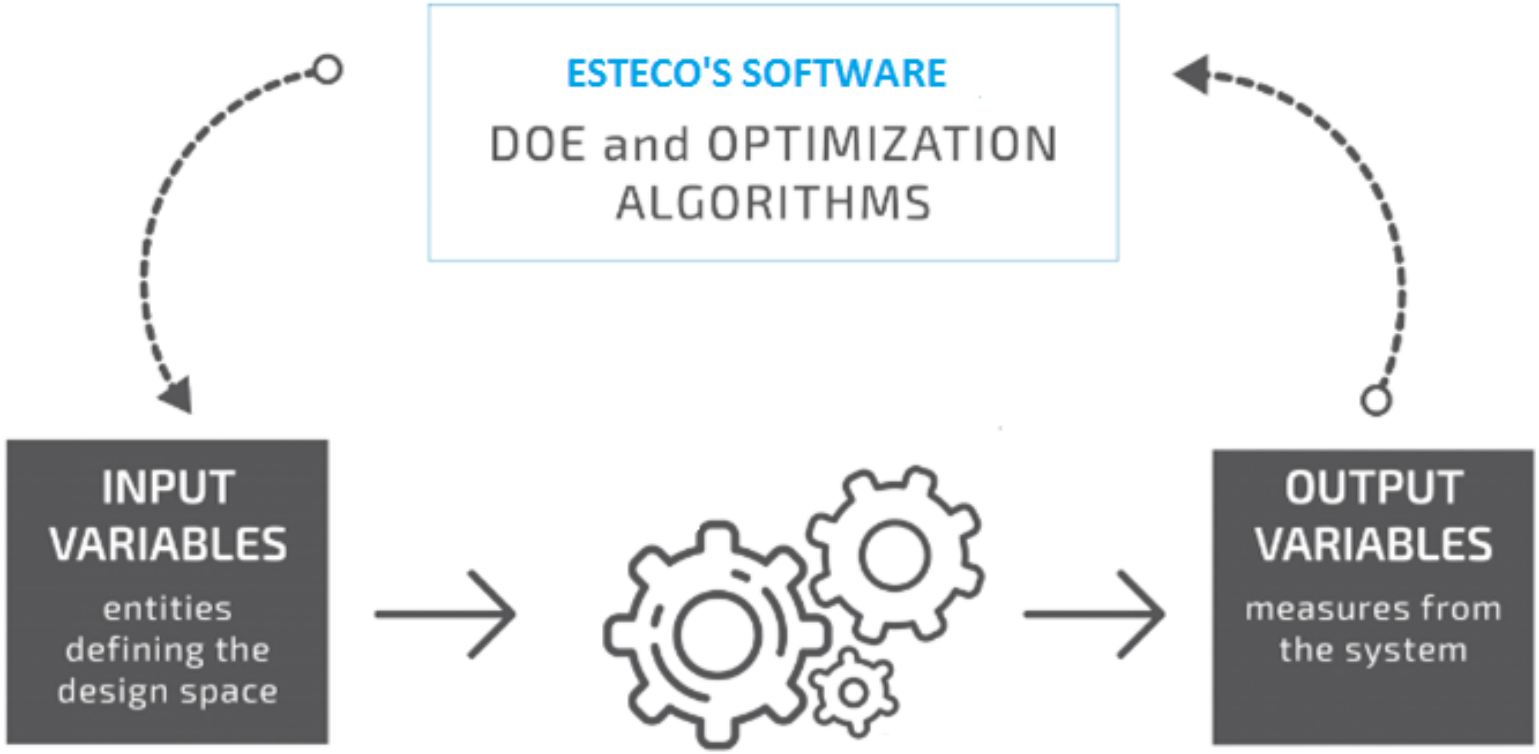

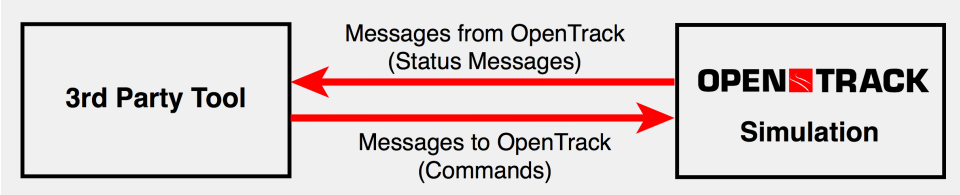

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Integration with ESTECO's Software

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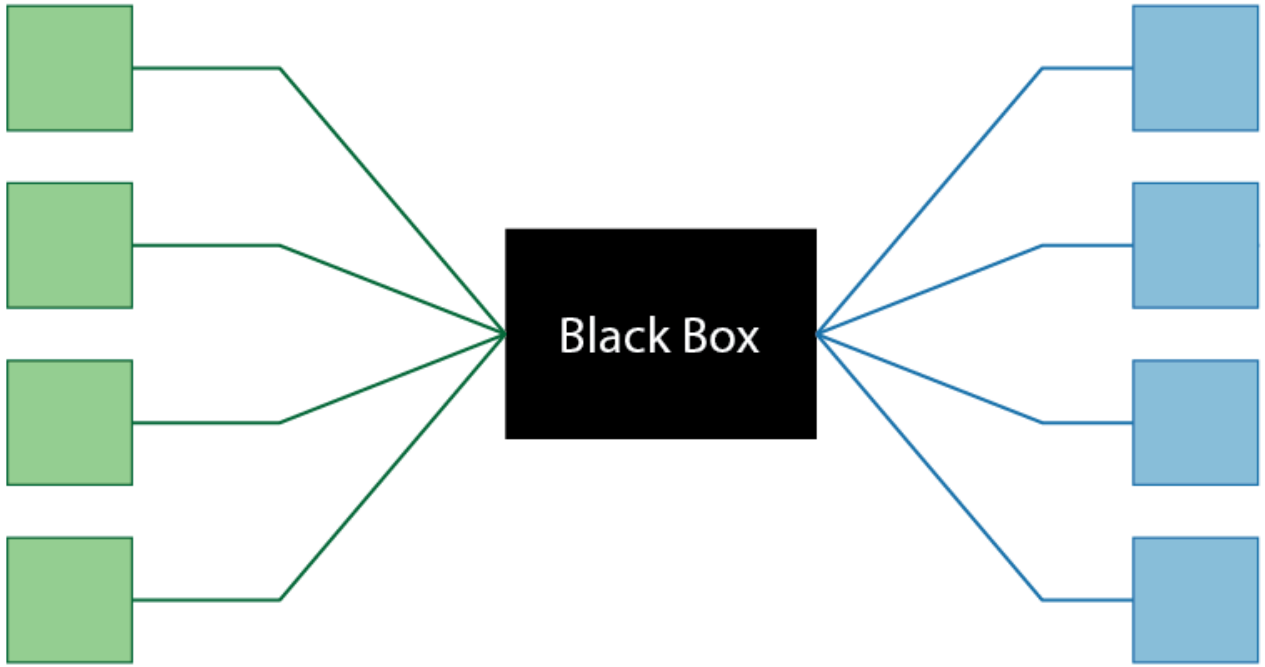

OpenTrack and API are used as Black Box: it generates objective and constraint values (OUTPUT VARIABLES) according to the input (INPUT VARIABLES)

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Classification of optimizers

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Gradient-based		Global Search		
Single objective	Multi objective	Single objective	Multi objective	
			Rapid	Robust
B-BFGS NLPQLP MIPSQP AFilterSQP Levenberg-Marquardt	NBI-NLPQLP NBI-AFSQP	SIMPLEX	MOGT FAST	MOGA-II NSGA-II ARMOGA MOPSO ES MOSA HYBRID SAnGeA

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Multi Objective Optimization with ESTECO Software

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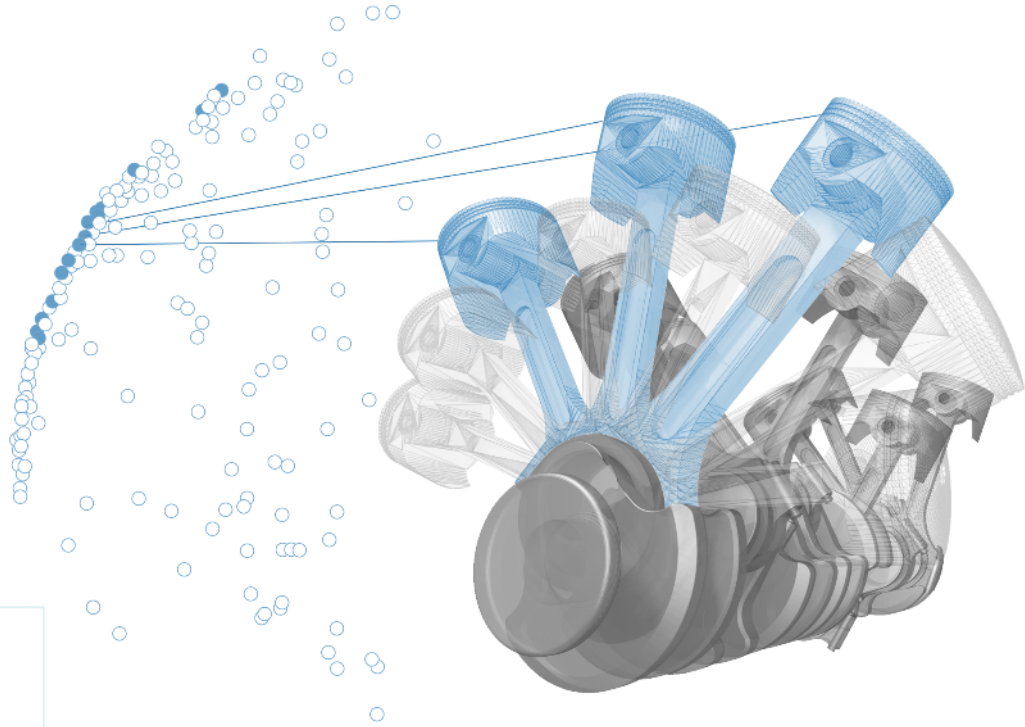
Multi-objective problems are solved using **sophisticated optimization algorithms**, which identify a set of **Pareto designs** (a set of solutions for which it is not possible to improve one goal without worsening the other).

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

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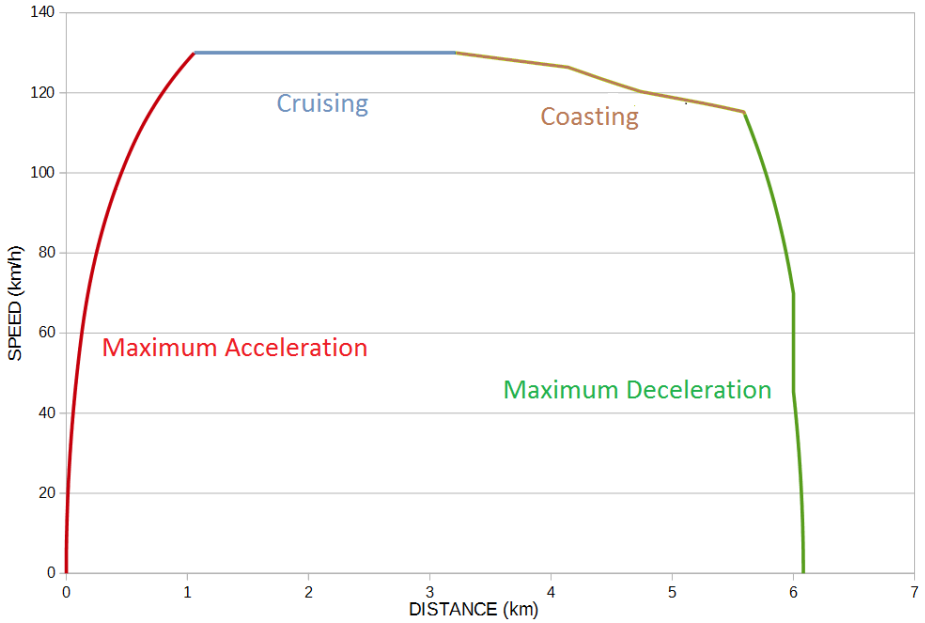
- Problem finds train speed profile in train's itinerary to minimize
  - ✓ Energy Consumption
  - ✓ Total Travel Time
- The train speed profile is composed by *train driving regime* sequence and possible variables are:
  - ✓ Target Speed
  - ✓ Length of Cruising regime
- Complete the itinerary



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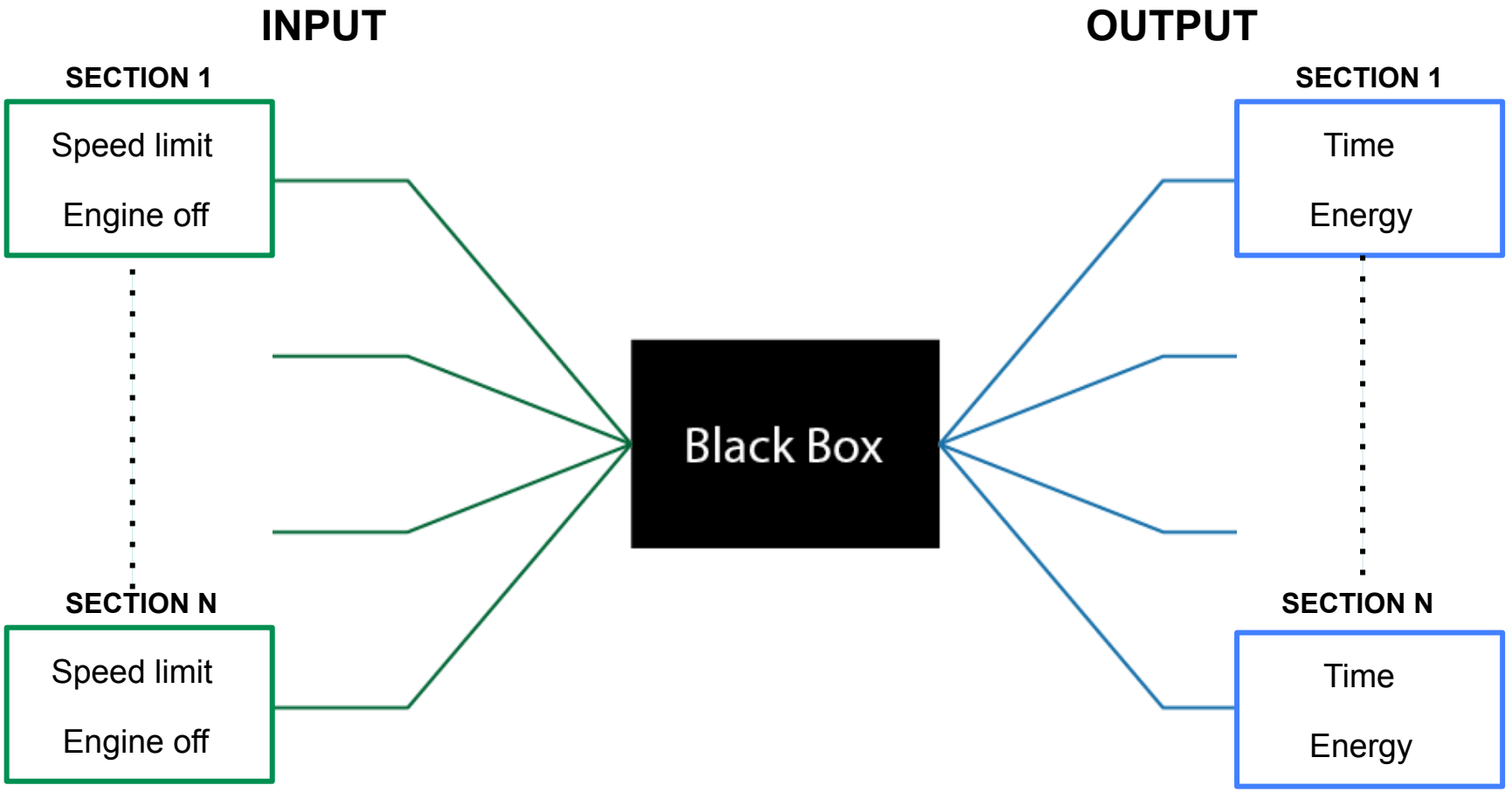

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Open Track Api

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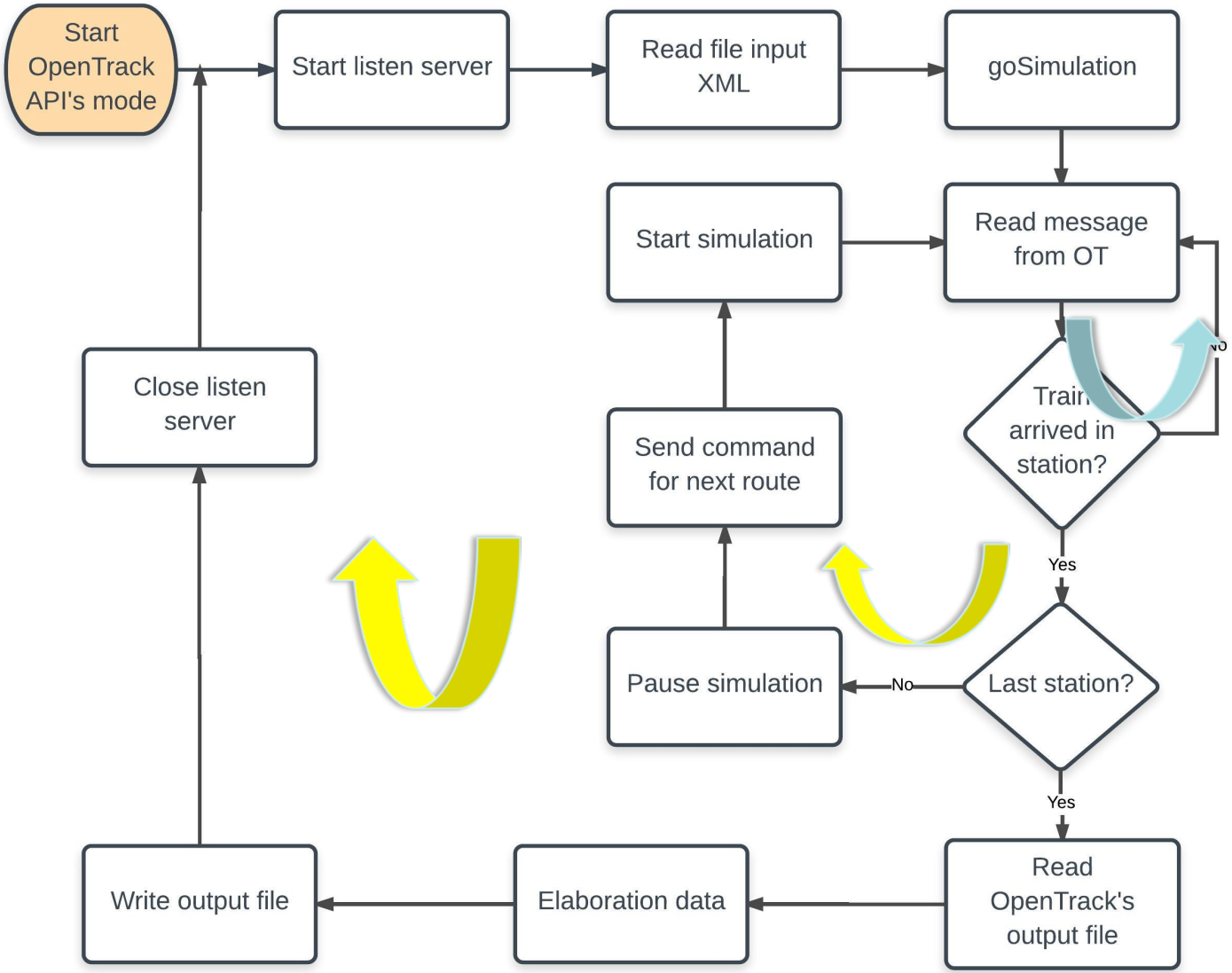

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Solution Strategy: Genetic algorithms

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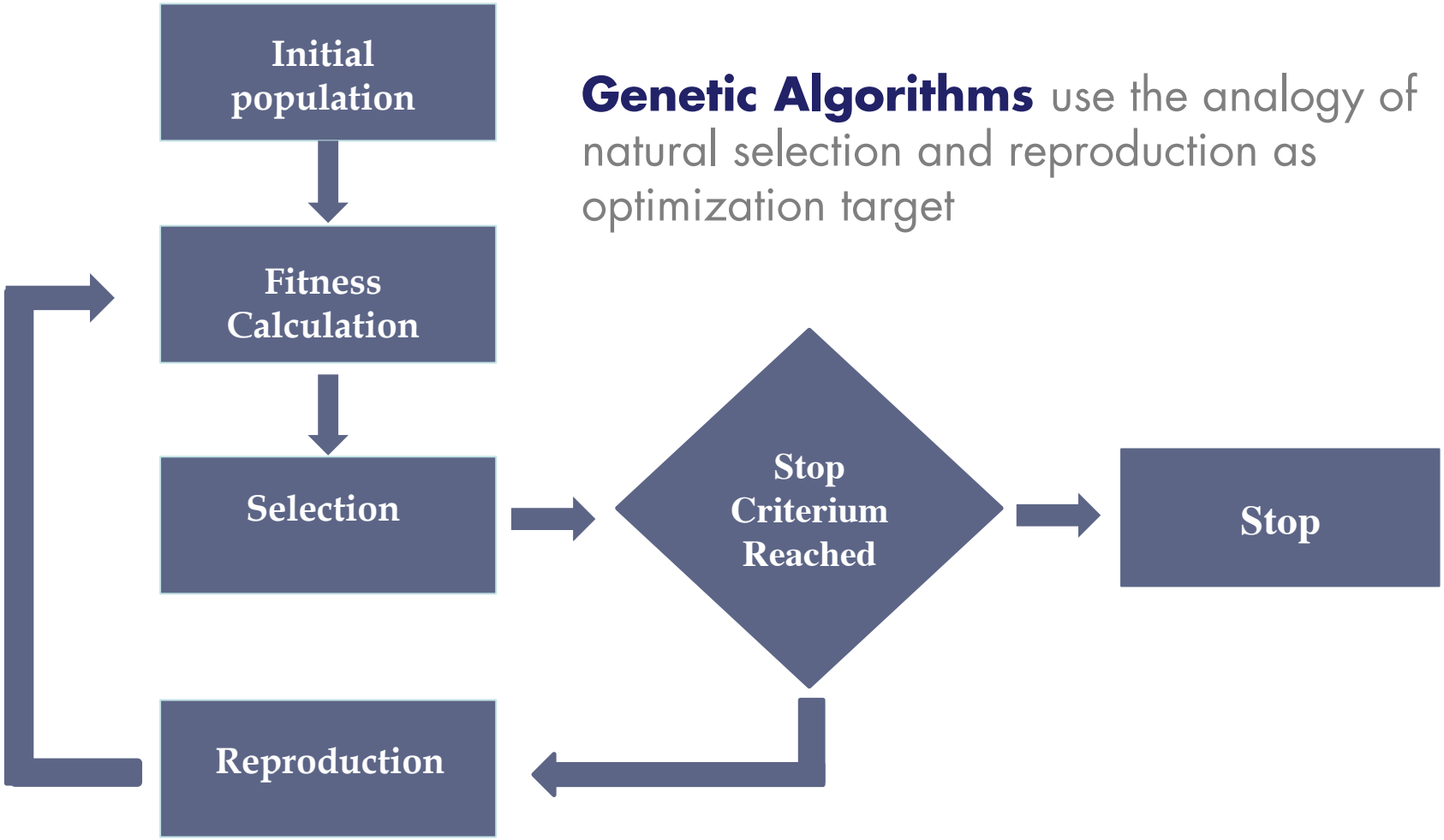

Genetic Algorithms use the analogy of natural selection and reproduction as optimization target

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Design of Experiments (DOE)

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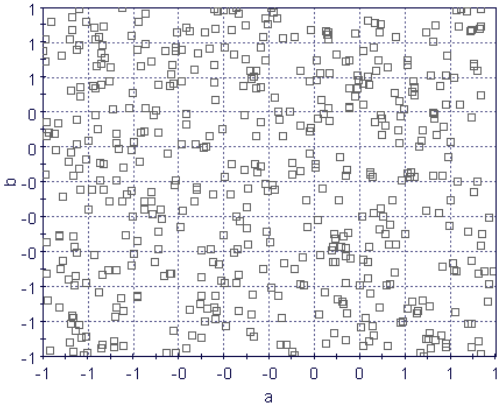
An important preliminary step of an optimisation process is the **initial (population) sampling of the design space**

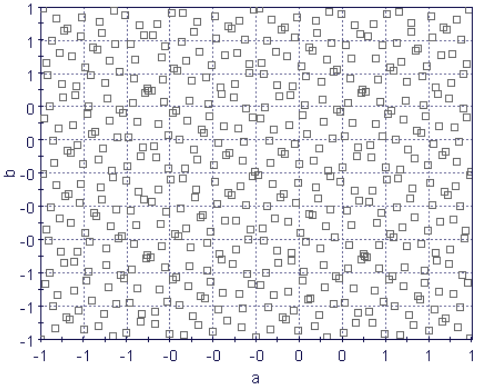
The initial population for Genetic Algorithm is given by Design of Experiments (DOE) Algorithms

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

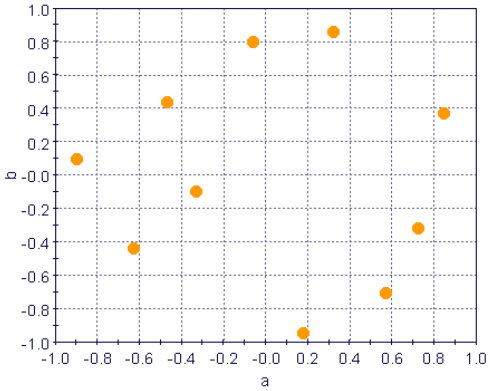


Random

Sobol



Uniform Latin Hypercube (ULH)



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Genetic algorithms: Selection

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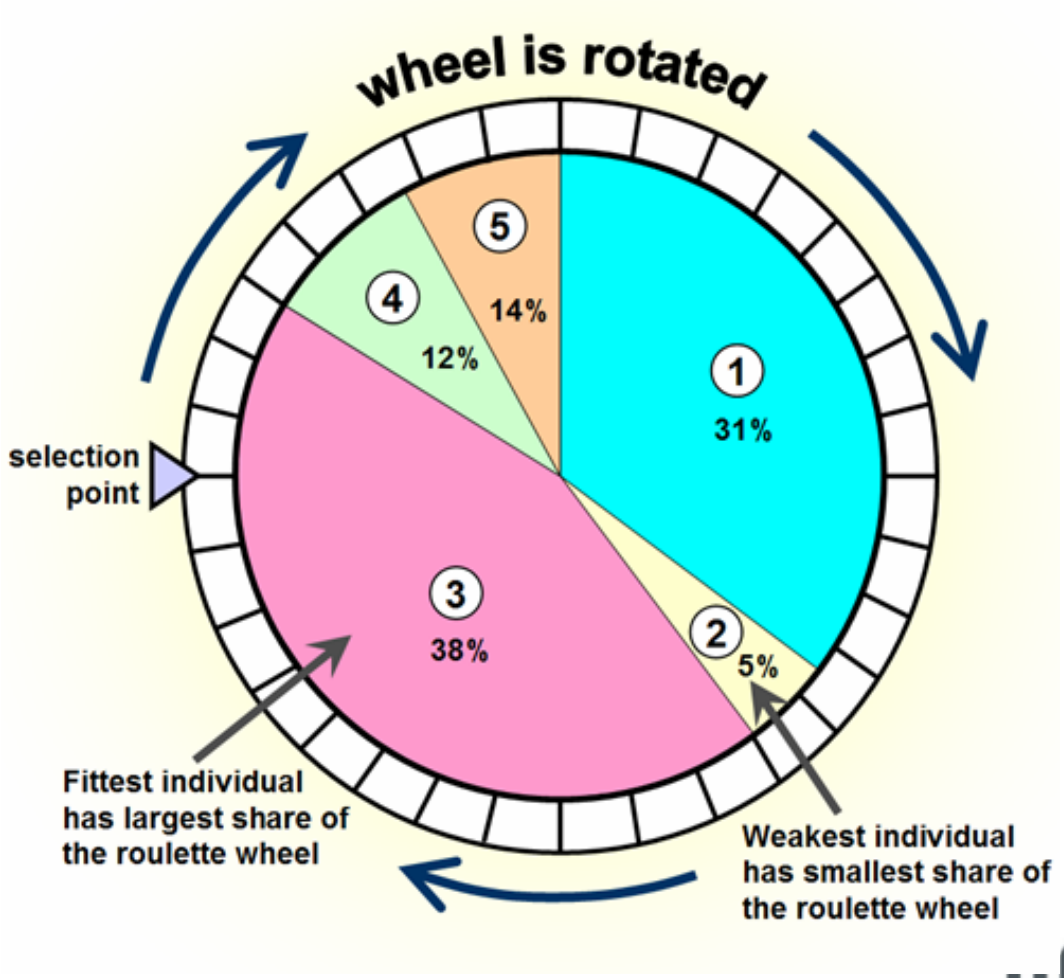
Best individuals are selected (by fitness or dominance criteria)



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Genetic algorithms: Reproduction

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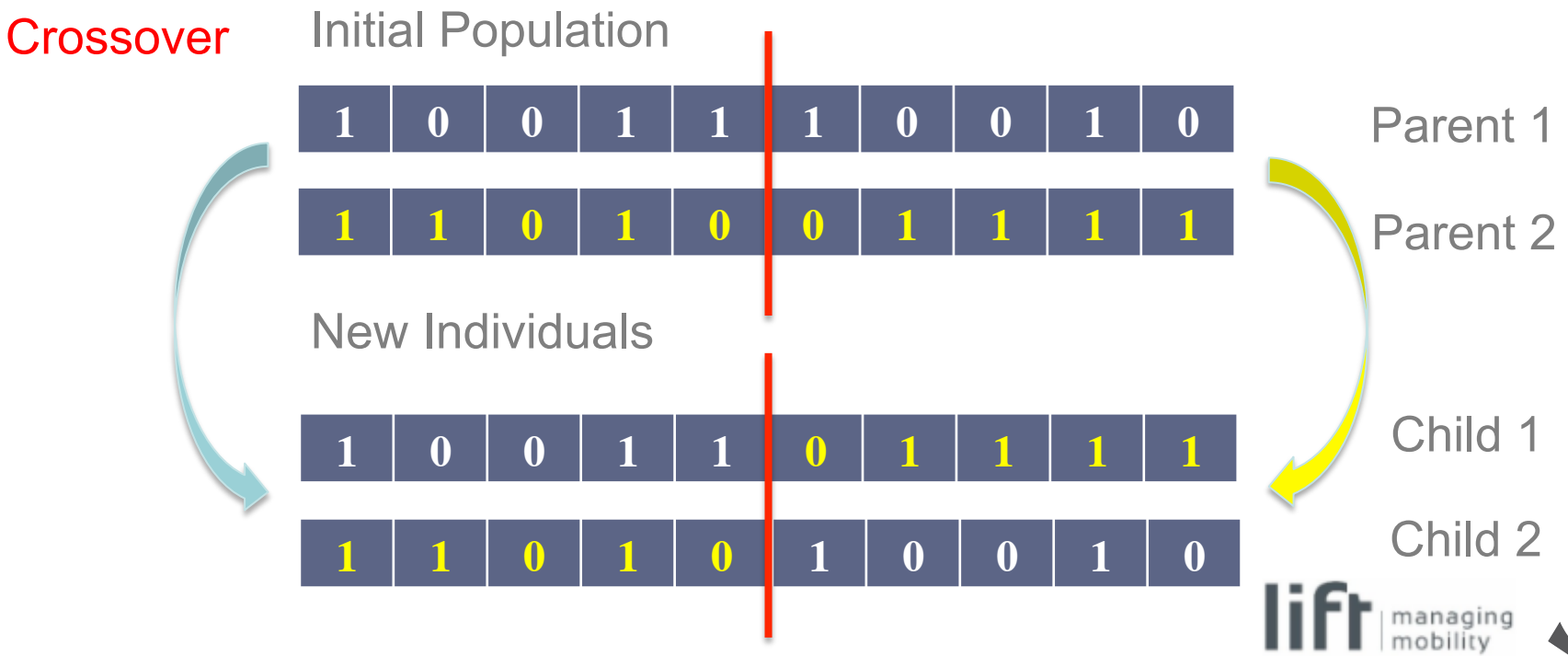
Each individual is coded by a binary string

1	0	0	1	1	1	0	0	1	0

Different operators are applied to generate a new population



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Genetic algorithms: Reproduction

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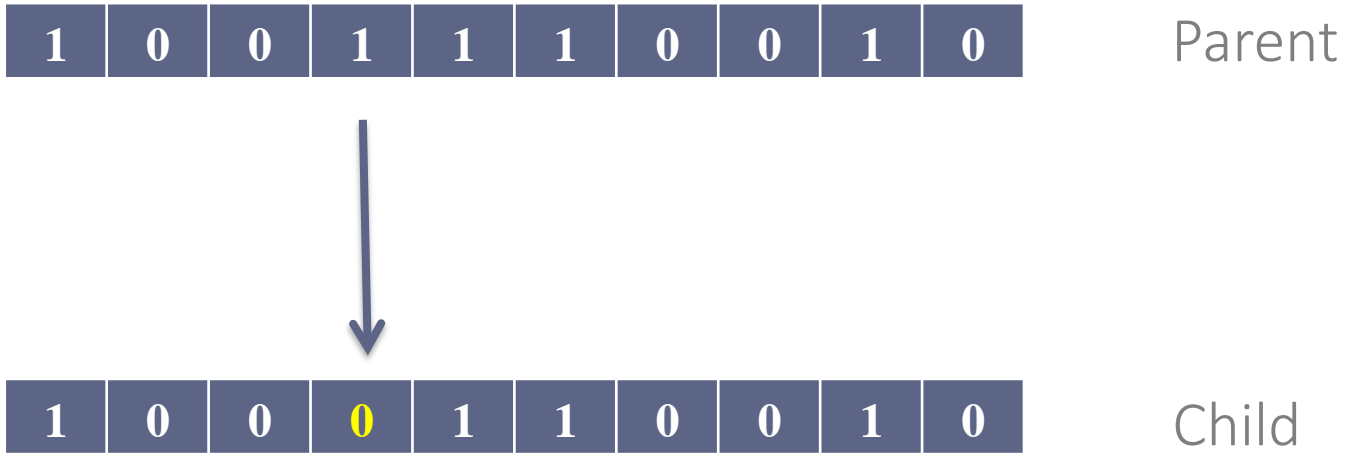
Mutation



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Test Case

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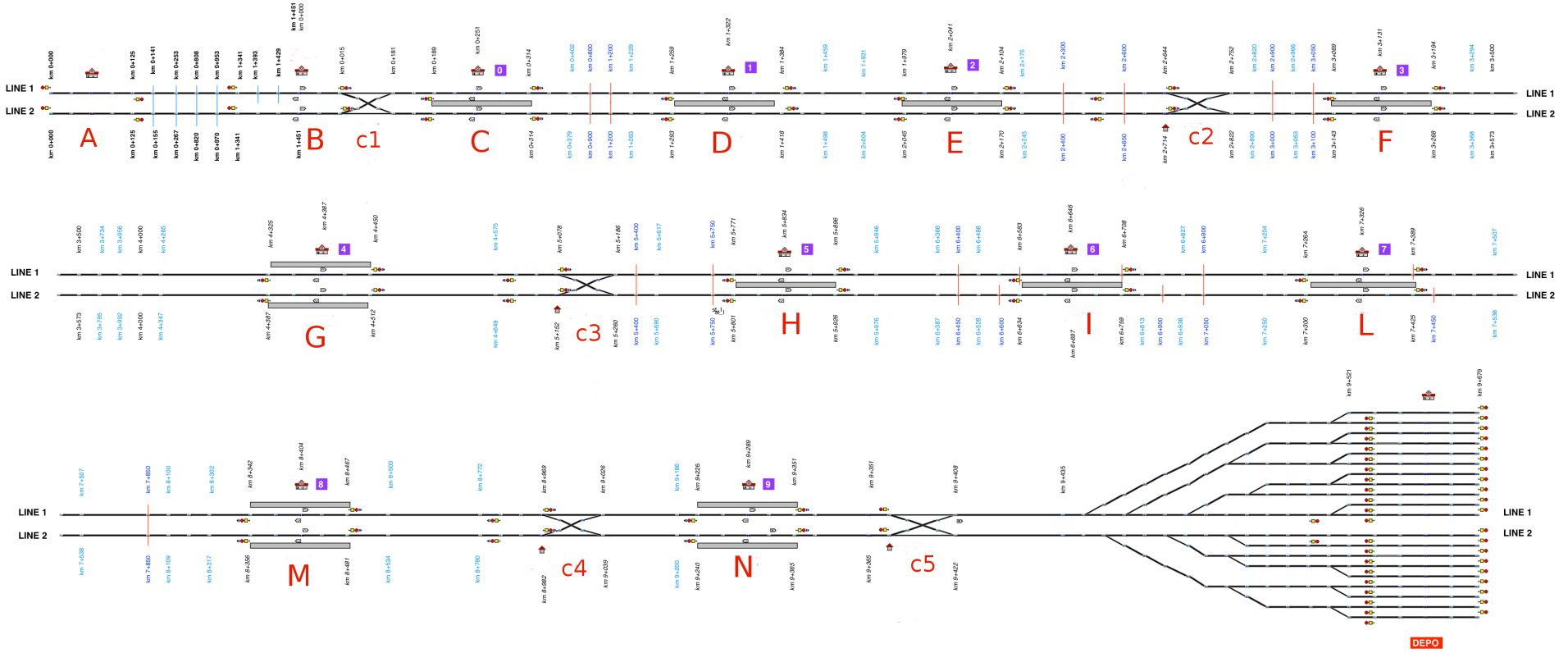

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Test Case

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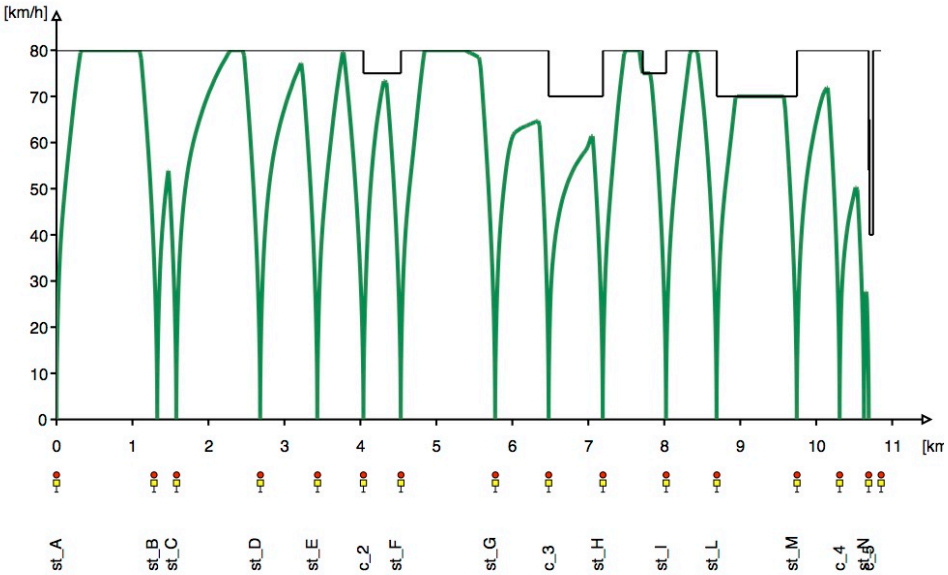
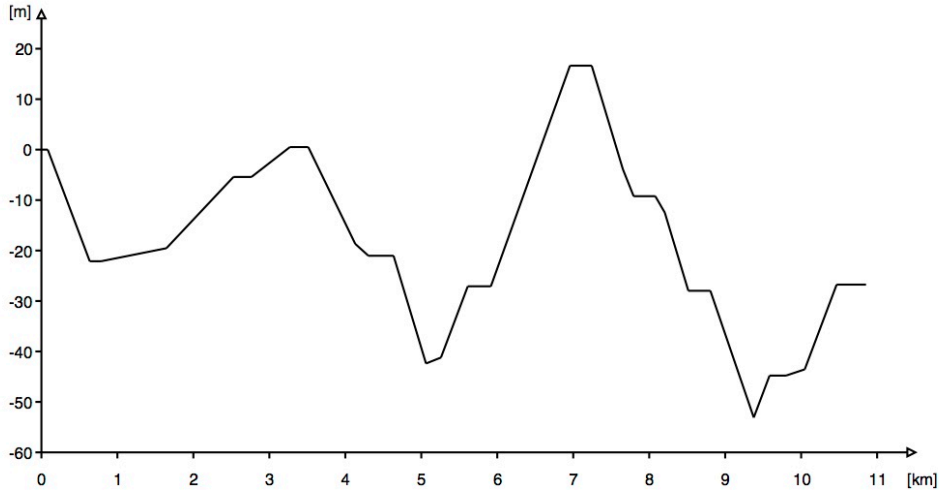
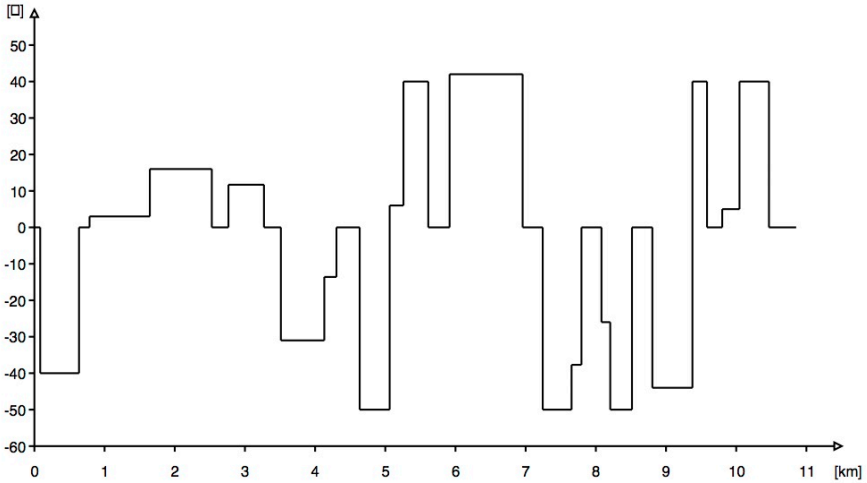




- Altitude



- Slope

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Test Case: Details

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Station	Speed Limit
A	80 km/h
B	80 km/h
C	80 km/h
D	80 km/h
E	80 km/h
c_2	75 km/h
G	80 km/h
c_3	80 km/h
h	70 km/h
I	80 km/h
L	70 km/h
M	80 km/h
c_4	80 km/h
N	80 km/h
c_5	

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Test Case

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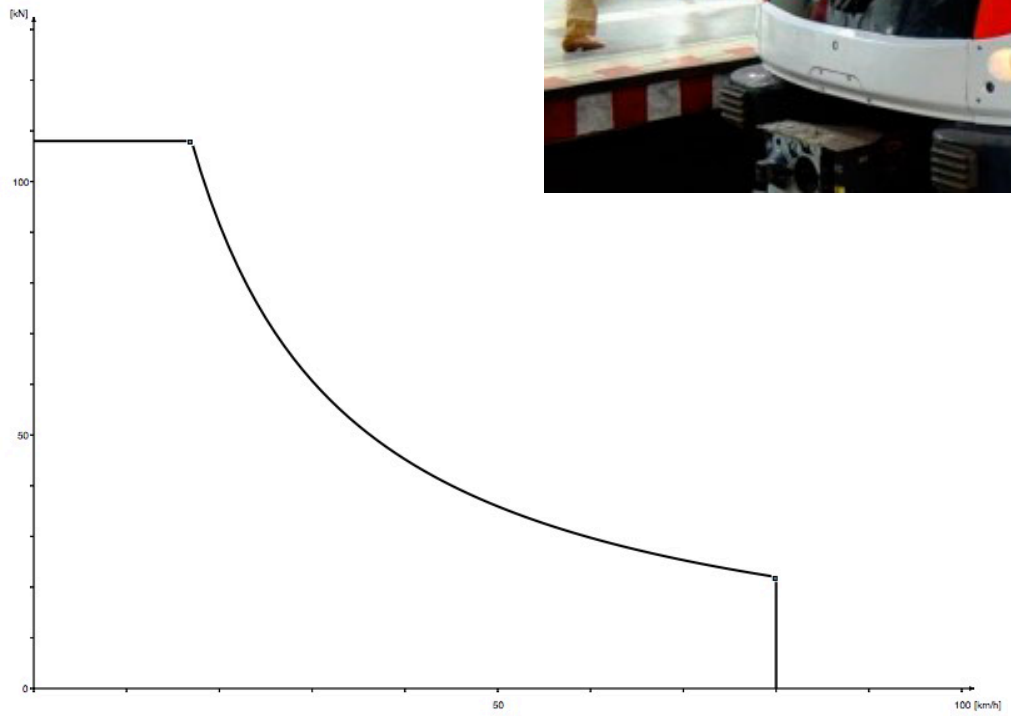

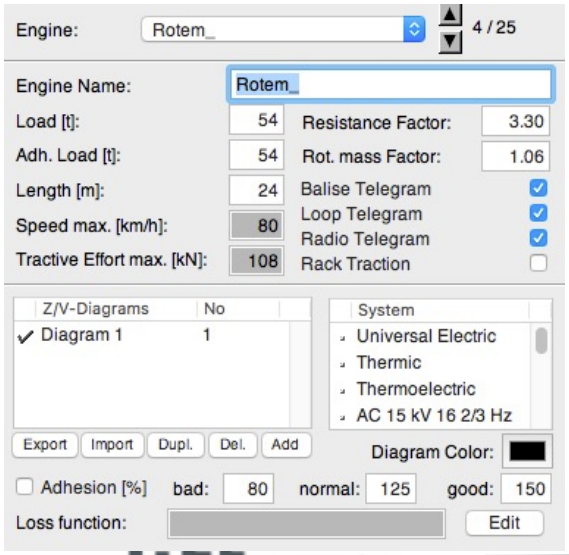

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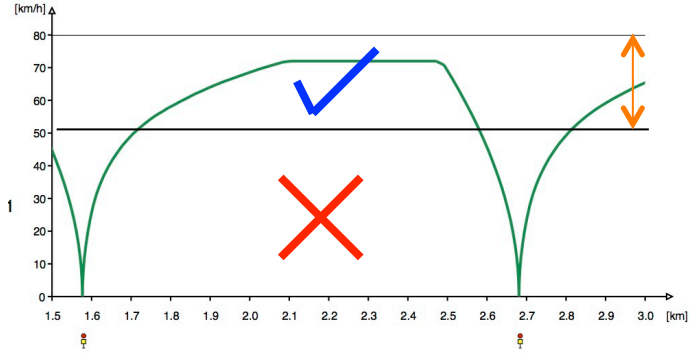
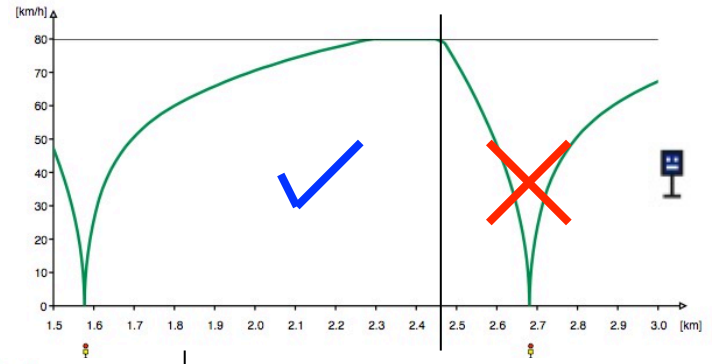
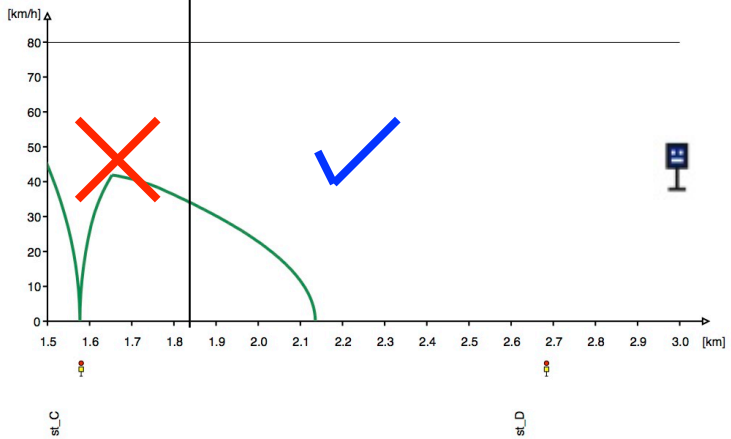


80 km/h
50 km/h

Speed limit range



Maximum time to engine off (before breaking)



Minimun time to engine off (to reach the following station)

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Results

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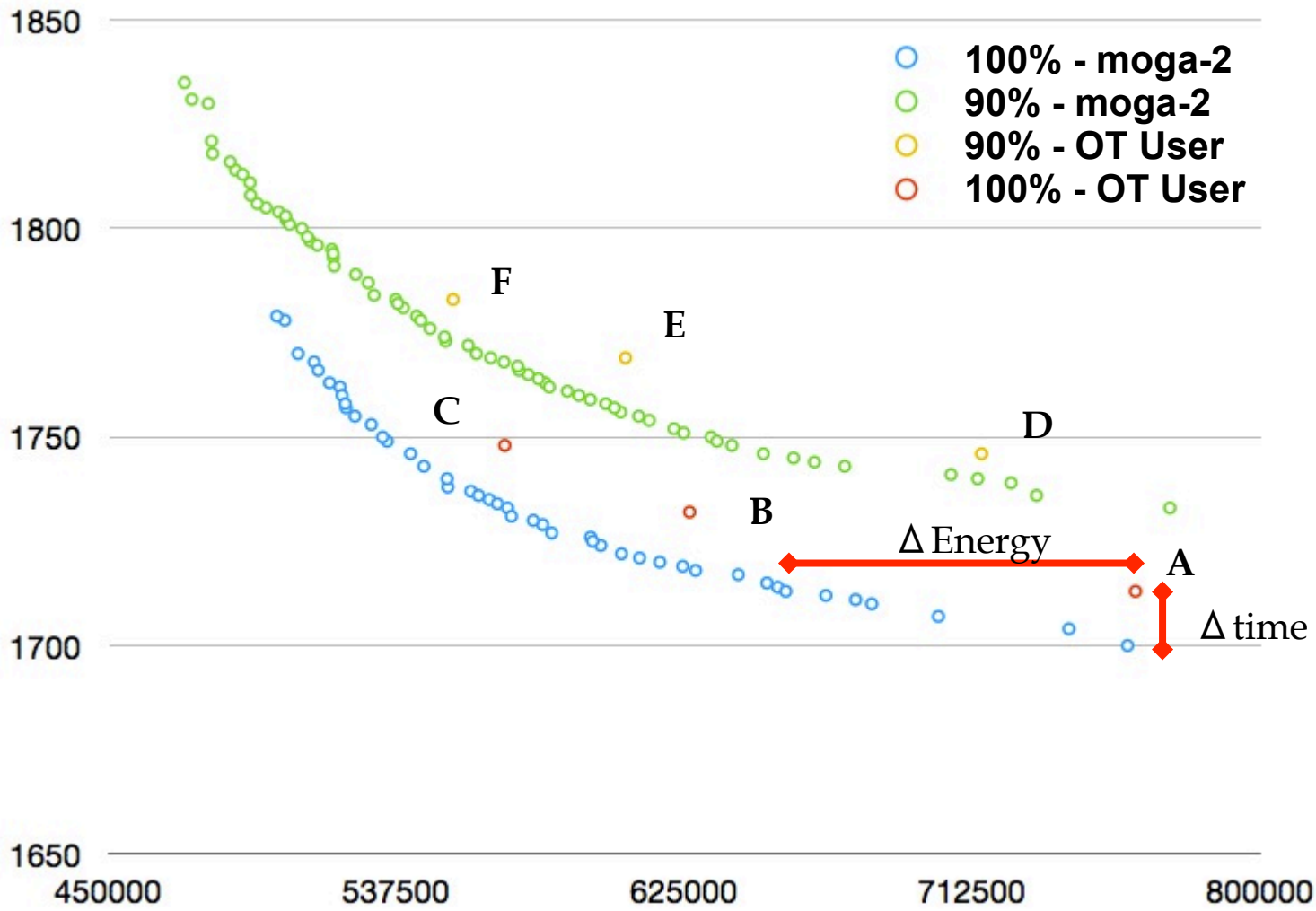

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Comparison

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Performance 100%								
	User OT		moga-2					
Point	Energy	Time	Energy	Time	ΔTime %	Energy	Time	ΔEnergy %
A	762028	1713	759631	1700	0.76	655783	1713	13.94
B	626552	1732	624460	1719	0.75	572404	1731	8.64
C	570388	1748	568163	1734	0.80	534674	1749	6.26

Performance 90%								
	User OT		moga-2					
Point	Energy	Time	Energy	Time	ΔTime %	Energy	Time	ΔEnergy %
D	715276	1746	714079	1740	0.34	648951	1746	9.27
E	607052	1769	605612	1756	0.73	566103	1769	6.75
F	554677	1783	552414	1773	0.56	537253	1783	3.14

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	Performances 100%			Example Solution Moga-2			
STATION	Time			Time		Margins	ΔTime %
A		01:00:00			01:00:00		
B	01:01:22	01:02:22		01:01:27	01:02:27	00:00:05	5.81%
C	01:02:54	01:03:54		01:03:00	01:04:00	00:00:01	1.16%
D	01:05:09	01:06:09		01:05:28	01:06:28	00:00:13	15.12%
E	01:07:08	01:08:08		01:07:43	01:08:43	00:00:16	18.60%
C2	01:09:00	01:10:00		01:09:40	01:10:40	00:00:05	5.81%
F	01:10:44	01:11:44		01:11:26	01:12:26	00:00:02	2.33%
G	01:13:03	01:14:03		01:13:55	01:14:55	00:00:10	11.63%
C3	01:15:00	01:16:00		01:15:54	01:16:54	00:00:02	2.33%
H	01:17:04	01:18:04		01:18:00	01:19:00	00:00:02	2.33%
I	01:19:05	01:20:05		01:20:08	01:21:08	00:00:07	8.14%
L	01:20:58	01:21:58		01:22:09	01:23:09	00:00:08	9.30%
M	01:23:12	01:24:12		01:24:29	01:25:29	00:00:06	6.98%
C4	01:25:00	01:26:00		01:26:24	01:27:24	00:00:07	8.14%
N	01:26:38	01:27:38		01:28:04	01:29:04	00:00:02	2.33%
C5	01:27:54			01:29:20		00:00:00	0.00%
TOTAL	00:27:54			00:29:20		00:01:26	

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MOGA-II Results

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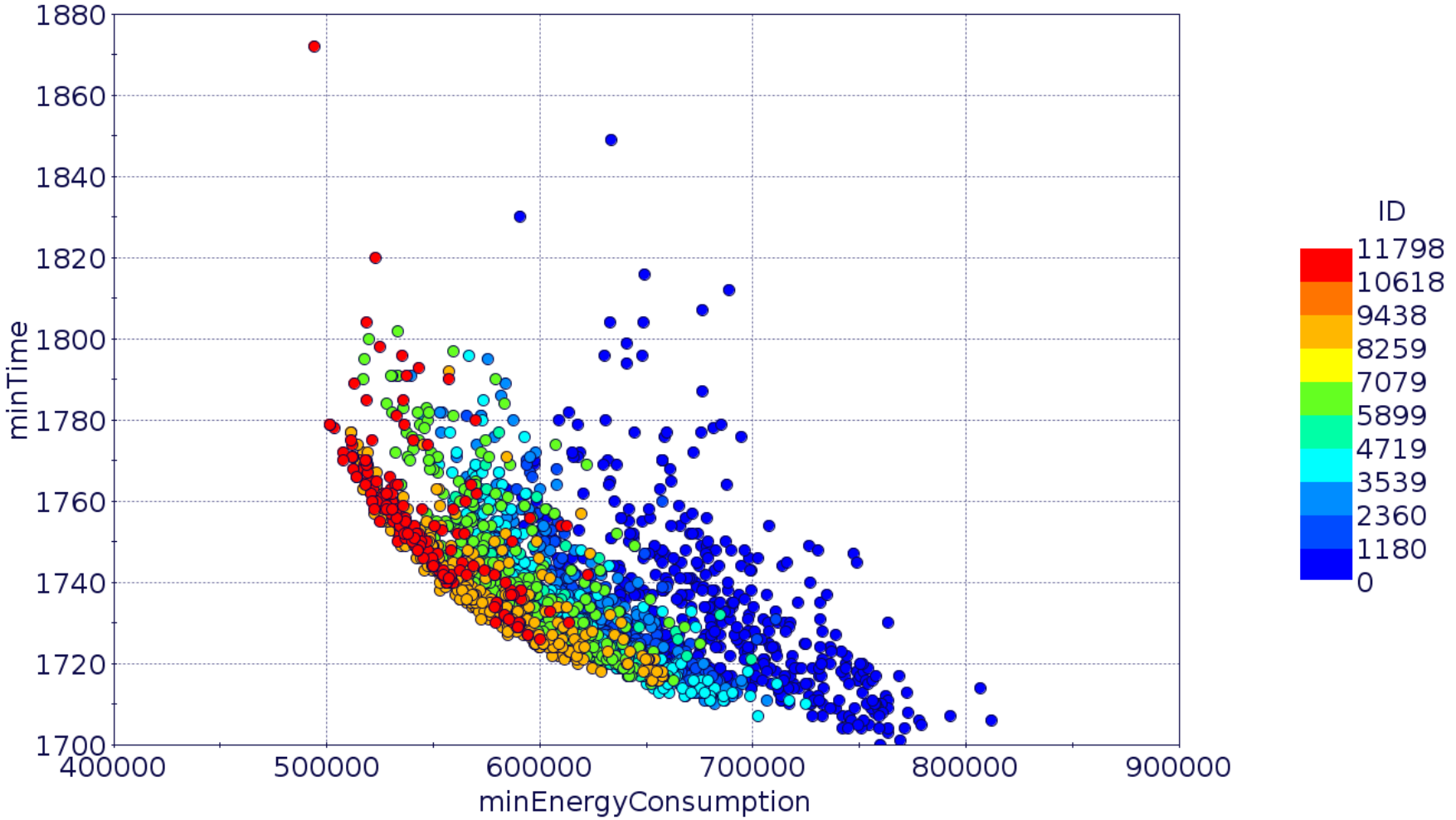

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NSGA-II Results

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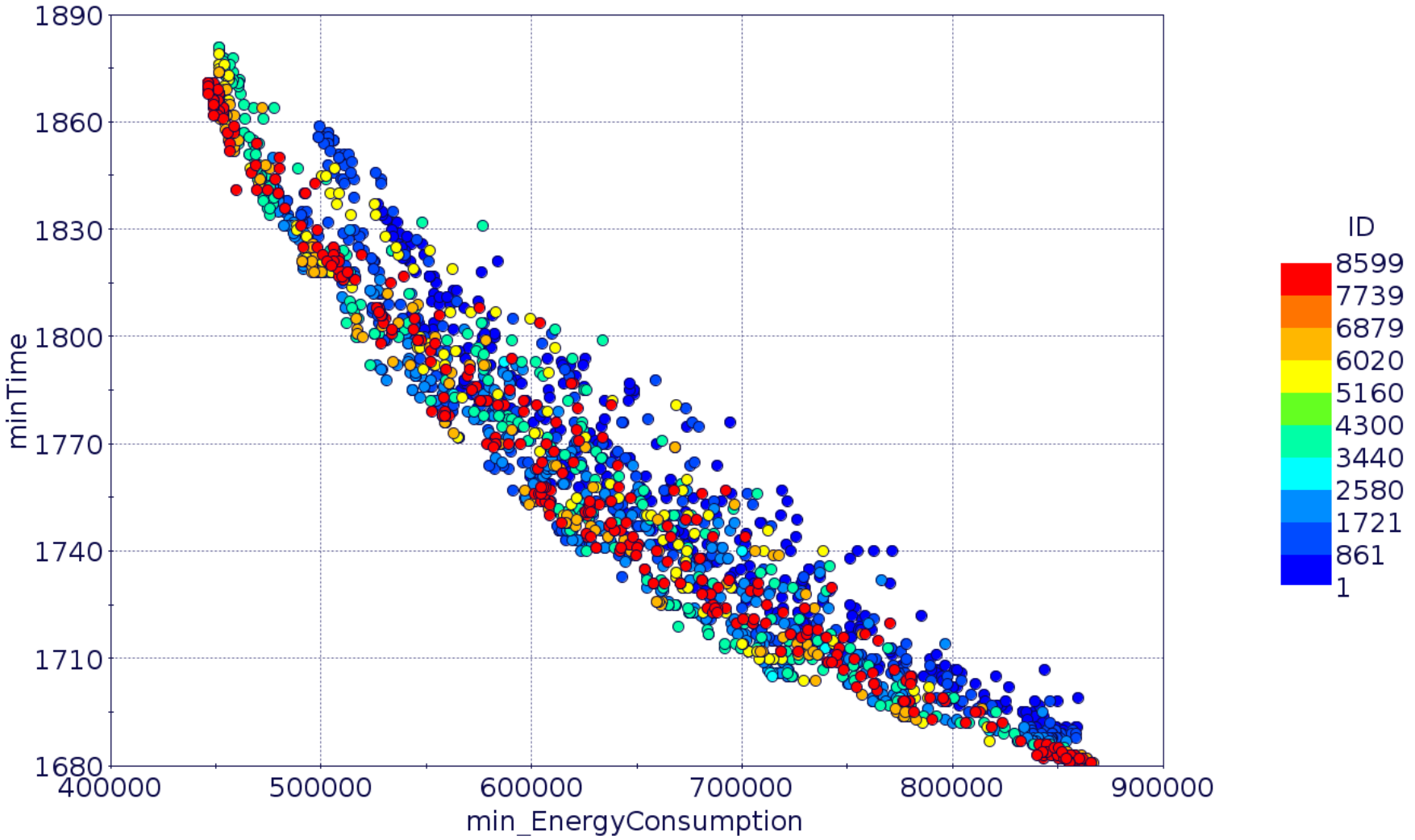

MOGA-2 and NSGA-2 Comparison

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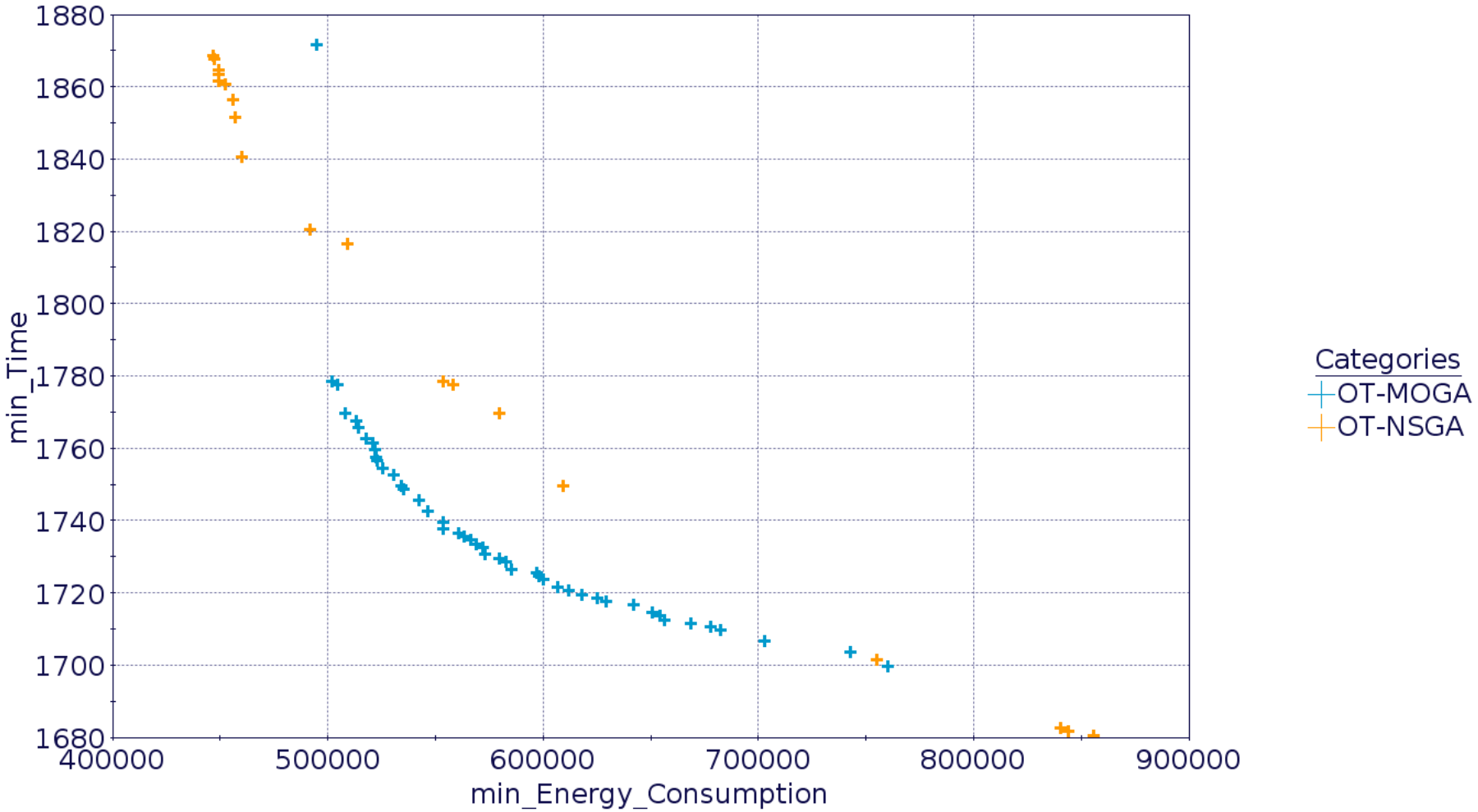

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Regeneration

File *.tsvP

```
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[7]) );
    }
}
public void calcMacPower(double value) {
    consumi = consumi + value;
}
```

Mech. Power

Power In

```
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

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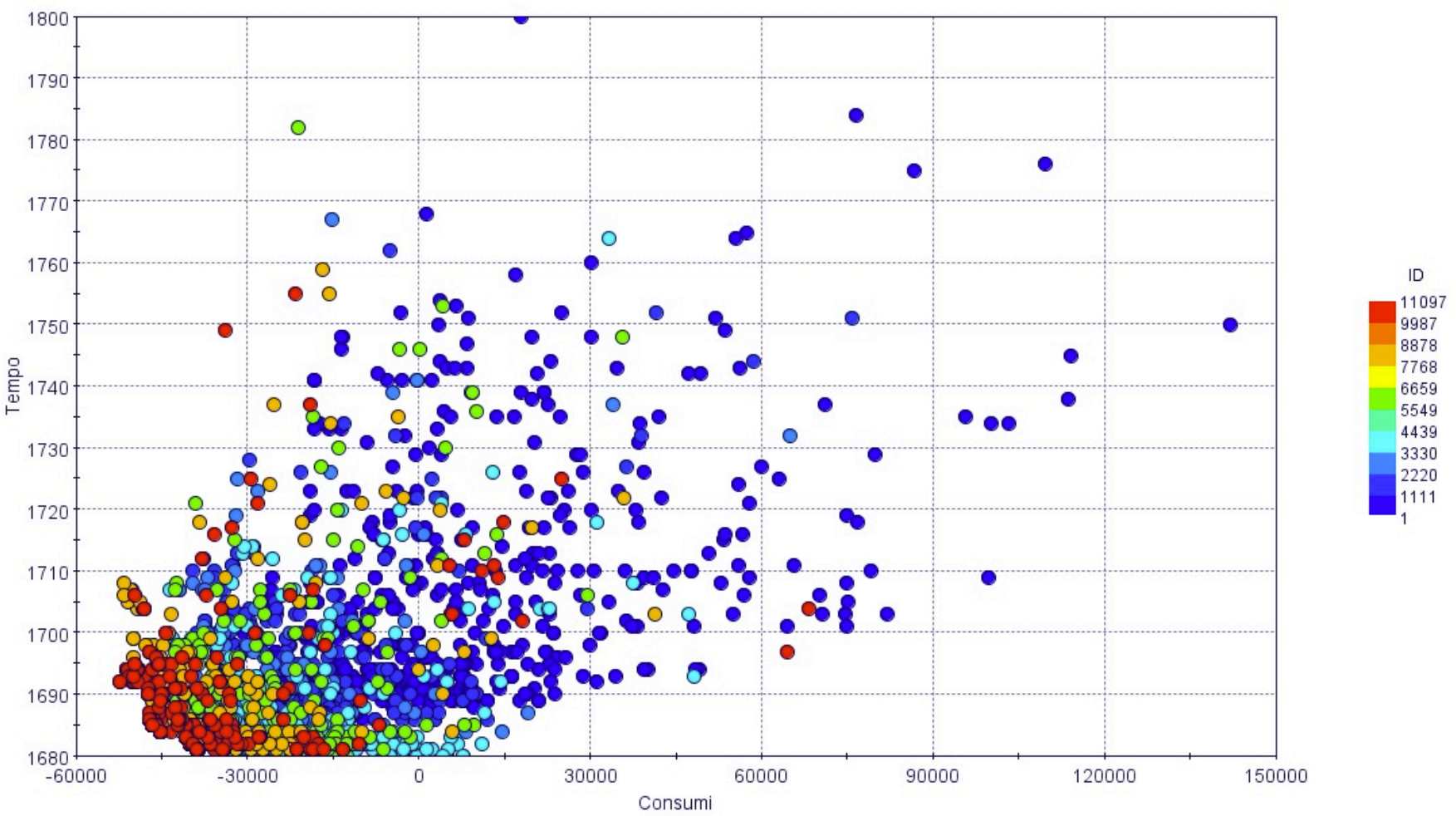

Rigenerazione pura

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Results

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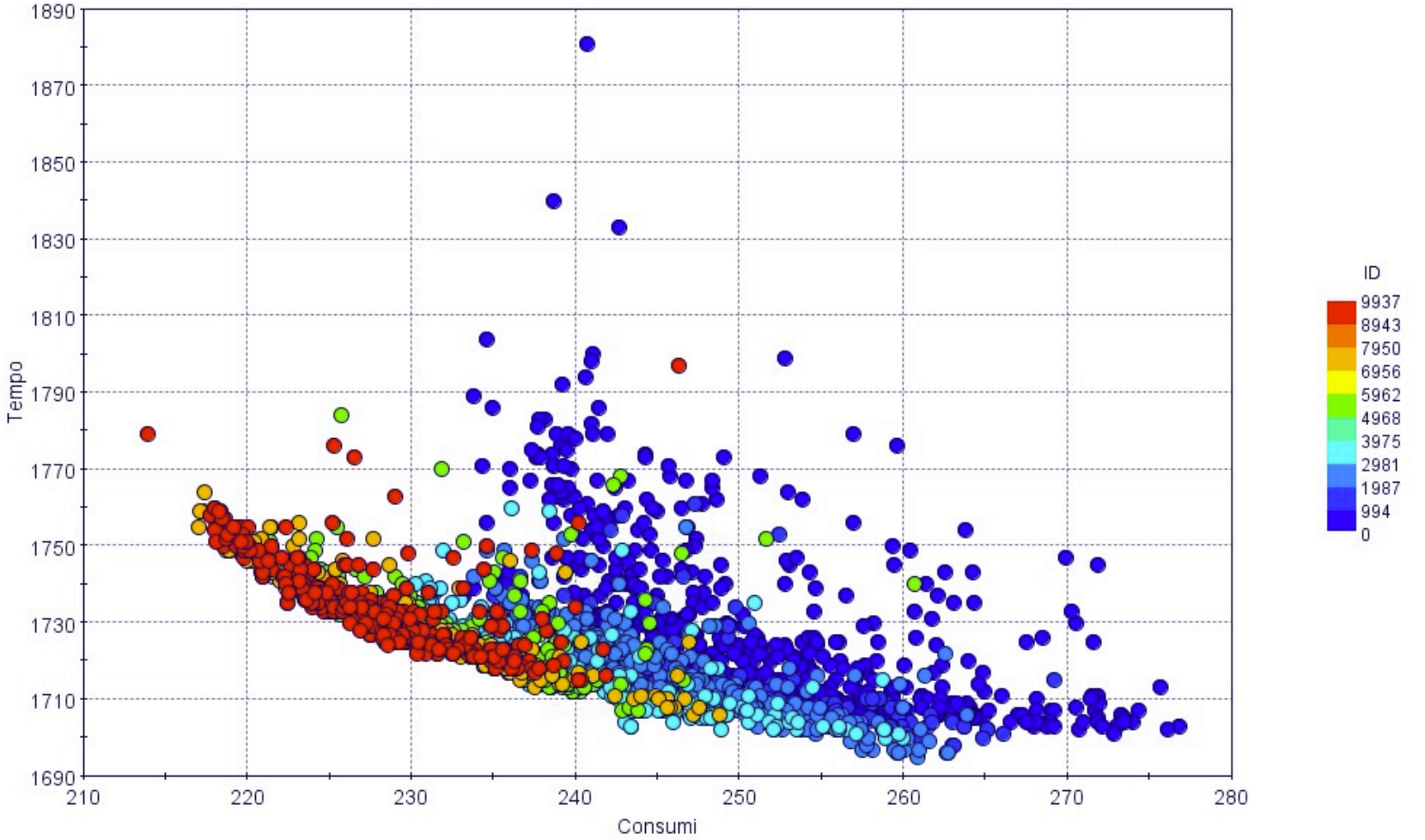

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Conclusions

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- 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

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Further developments

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- 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

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