






Design safer and greener road projects by using a multi-objective optimization approach

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ULB

Outline

Context
- Design process of a road project

Structuration of the problem

A multi-objective optimization approach
- Description of the problem
- Calculation of the solution set
- Pareto frontier

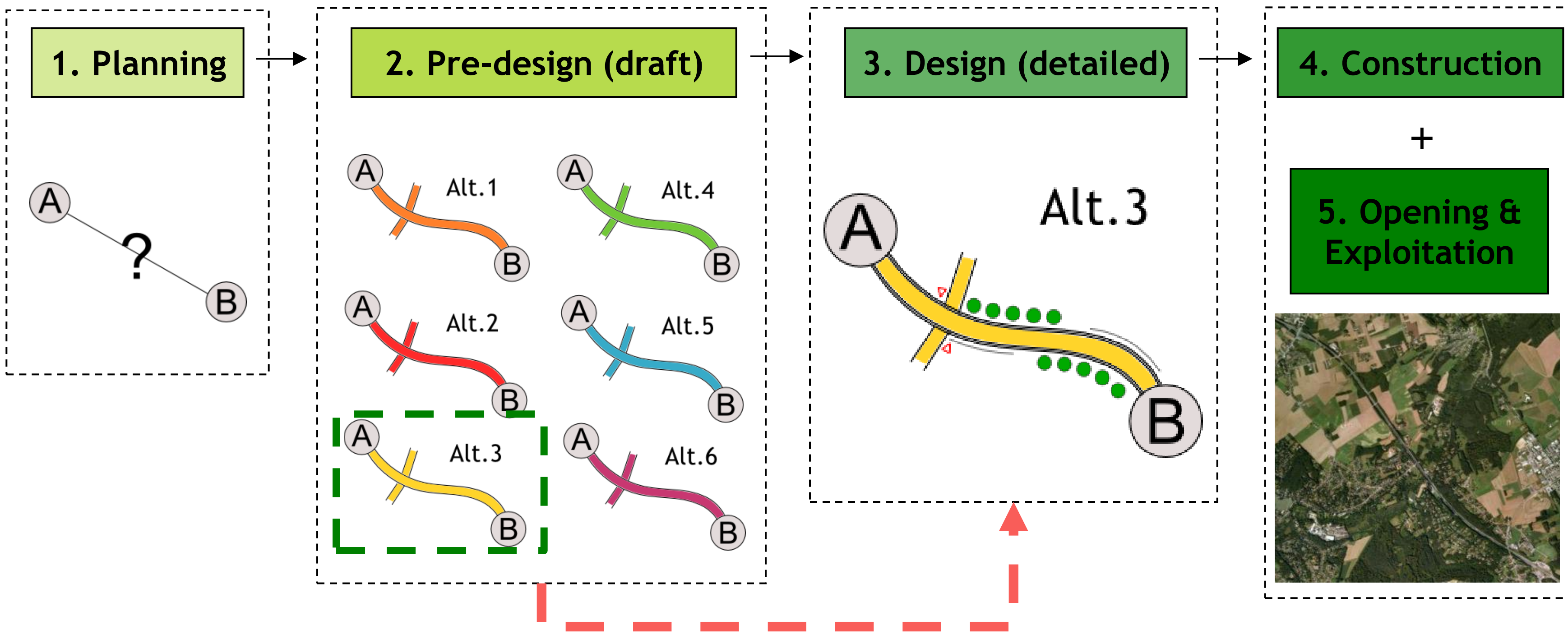
Analysis and solving of the problem
- PROMETHEE II

Conclusions
- Observations and conclusion

Outline

Context of the research

Design process of an infrastructure



OBJECTIVE: OFFER A SUPPORT IN THE EVALUATION AND THE SELECTION OF BEST ALTERNATIVE(S)

?

- € ONLY !
- DESIGNER EXPERTISE
- LACK OF INTEGRATED METHOLODOGY

Outline

Structuration of the problem

Multicriteria decision aid problem

$$Max(g_1(a), g_2(a), \ldots, g_n(a) | a \in A)$$

Set of criteria - g_i

- Road infrastructure performance
- Sustainable concerns
- Availability of the data at the design stage
- Consistent and *adaptive* evaluation

Set of alternatives - $a \in A$

- Draft alternatives of the road project (pre-design stage)
- Infrastructure design parameters
- Environmental parameters
- Combinatorial generation

→ Important stage of modelling and creation of data
→ Define the properties of the alternatives and criteria
→ Development of *new* criteria constitutes a full and complex problem

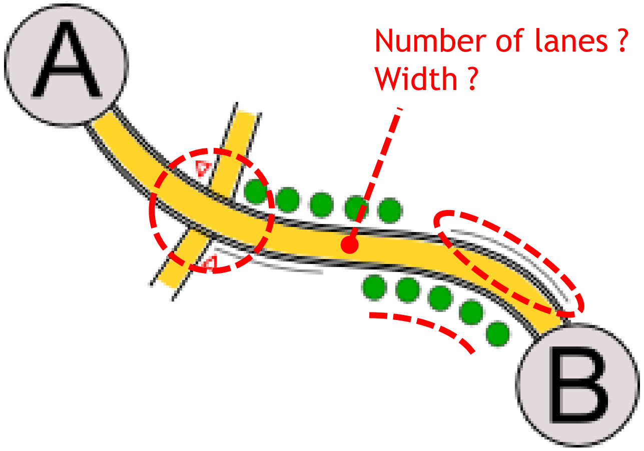
Structuration of the problem

Definition of the alternatives of the problem (*A*)

Identify the elements/parameters which characterize the alternatives of the road project and its direct environment at the design stage (experts consultation) ;

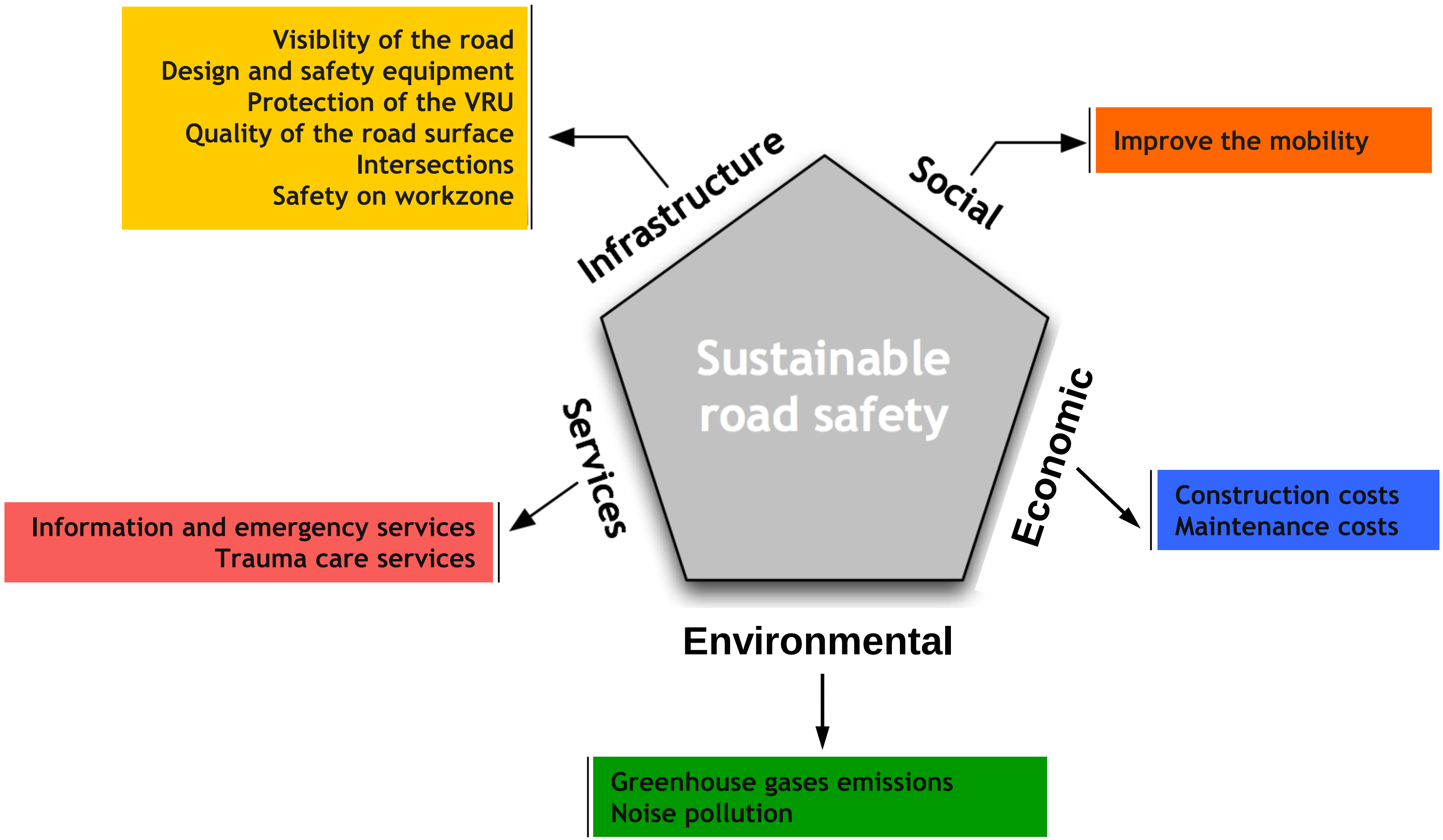
Define the feasibility constraint(s) of a road project (e.g. maximum width) ;

Apply a bottom-up approach to identify the key parameters which may have a strong influence on the evaluation of the criteria ;



Structuration of the problem

Definition of the criteria of the problem (g_i)



Outline

A multi-objective optimization approach

Description of the problem

Large amount of calculation parameters!
Environmental parameters (fixed)
Alternative parameters (variable)

Example : 12 fixed parameters
12 variable parameters
1 design constraint: roadway width ≤ maximum width (*w_max*)

w_max = 08m > 140.800 alternatives
w_max = 10m > 386.560 alternatives
w_max = 12m > 798.720 alternatives
w_max = 15m > 1.620.480 alternatives

- Exhaustive exploration of the design space is impossible
- **Multi-objective evolutionary algorithm to solve this problem (NSGA-II)**

A multi-objective optimization approach

Solving of the problem (NSGA-II)

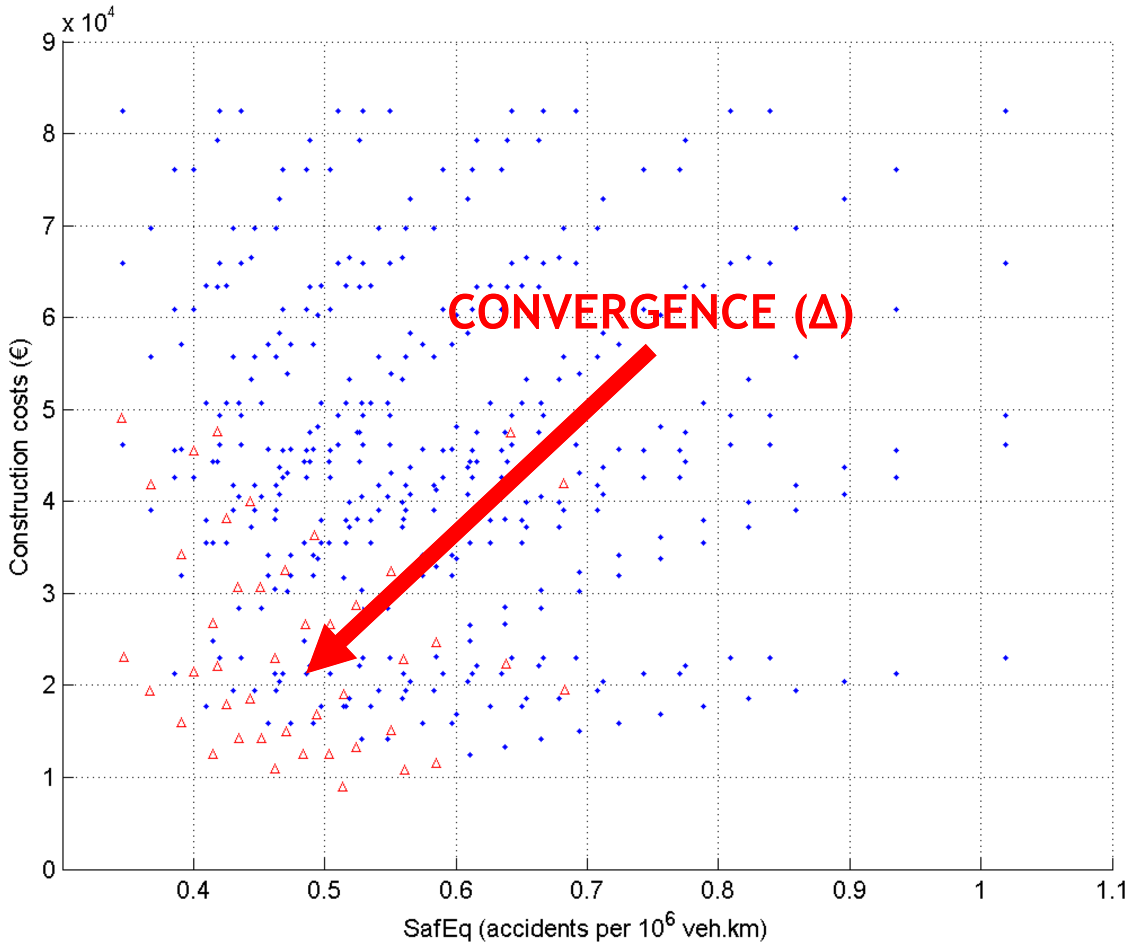
NSGA-II algorithm (Deb, 2002)

1. Generate a limited set of alternatives of size *n* (**initial population**) ;
2. Calculate the evaluation table ;
3. Assign rank level (pareto dominance) and crowding distance ;
4. Generate **parent population** (size *n*);
5. Loop at each generation:
   - 5a. Genetically generate **child population** (size *n*) ;
   - 5b. Combine parent and child population (size 2*n*) ;
   - 5c. Calculate the evaluation table ;
   - 5d. Assign rank level and crowding distance ;
   - 5e. Constitute a **new parent population** from best solutions (size *n*) ;
6. End of the genetic process (**final population**) ;

At the end, **non-dominated solutions of the problem have been identified.**
Fast and efficient algorithm to deal with large design space.

A multi-objective optimization approach

Solving of the problem (NSGA-II)



8 criteria
50 alternatives (pop)
100 generations (NSGA-II)

2-axis representation

Δ : final population
● : previous populations

A multi-objective optimization approach

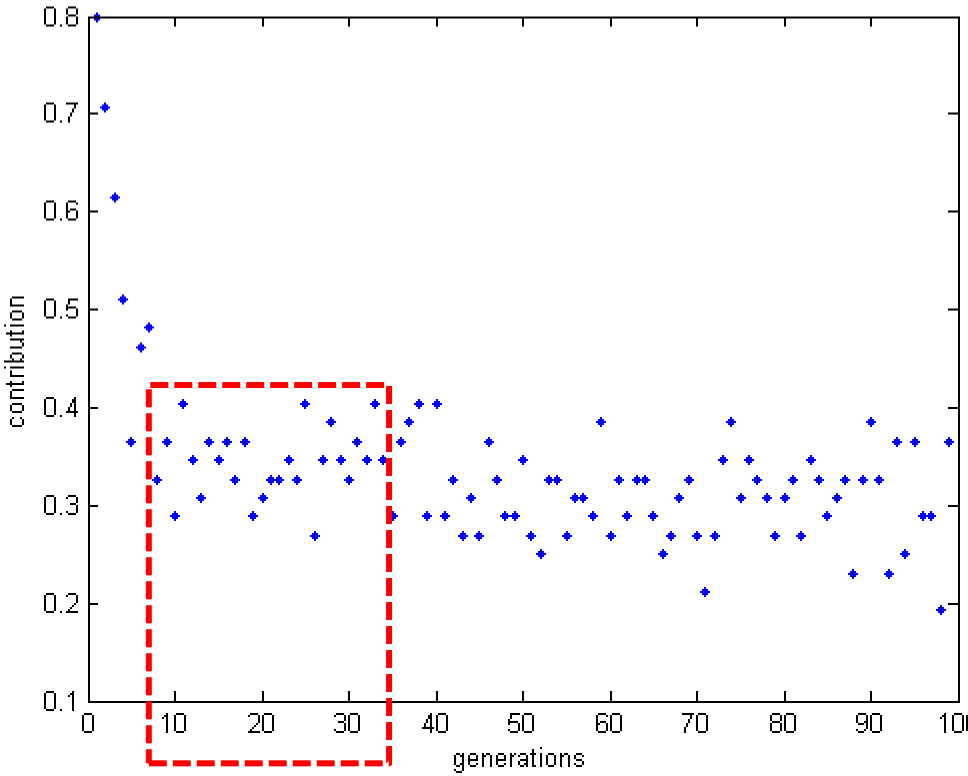
Quality indicators – Convergence

- **Contribution (Talbi, 2009)**

$$Cont(PO_1/PO_2) = \frac{\left\|\frac{PO}{2}\right\| + \|W_1\| + \|N_1\|}{\|PO^*\|}$$

PO_1: approximation set 1
PO_2: approximation set 2
PO^*: solutions of $PO_1 \cup PO_2$
PO: solutions in $PO_1 \cap PO_2$

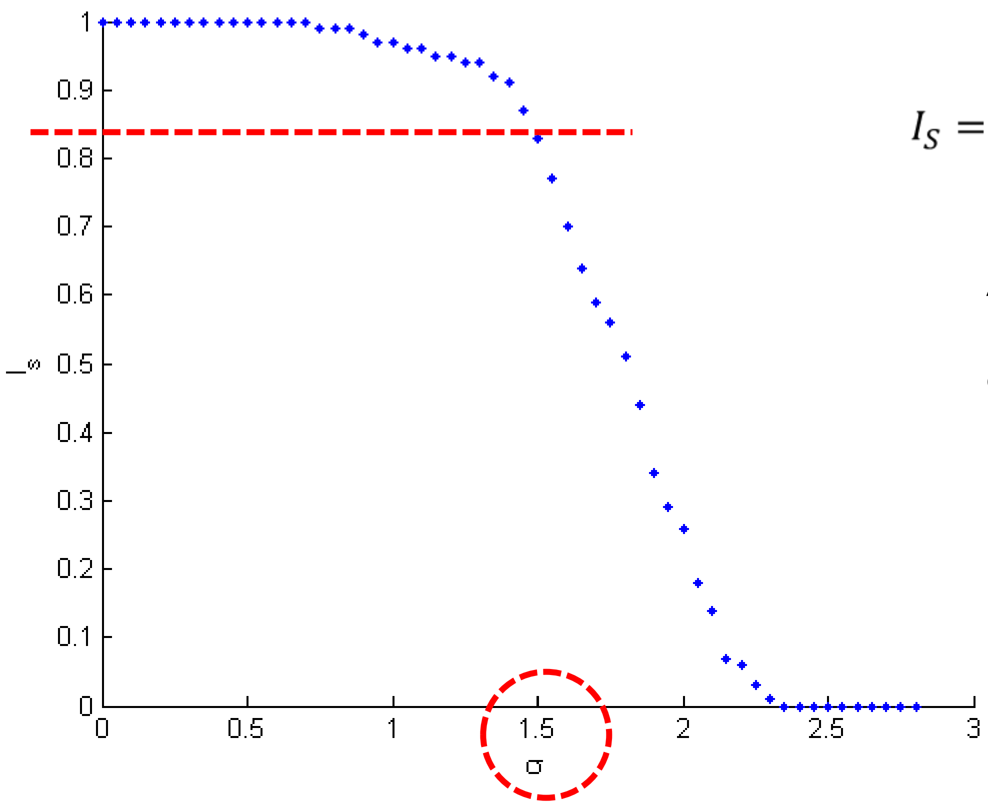
W_1: set of solutions in PO_1 that dominates some solutions in PO_2
N_1: set of non-comparable solutions of PO_1



A multi-objective optimization approach

Quality indicators - Diversity

- **Spread (Talbi, 2009)**



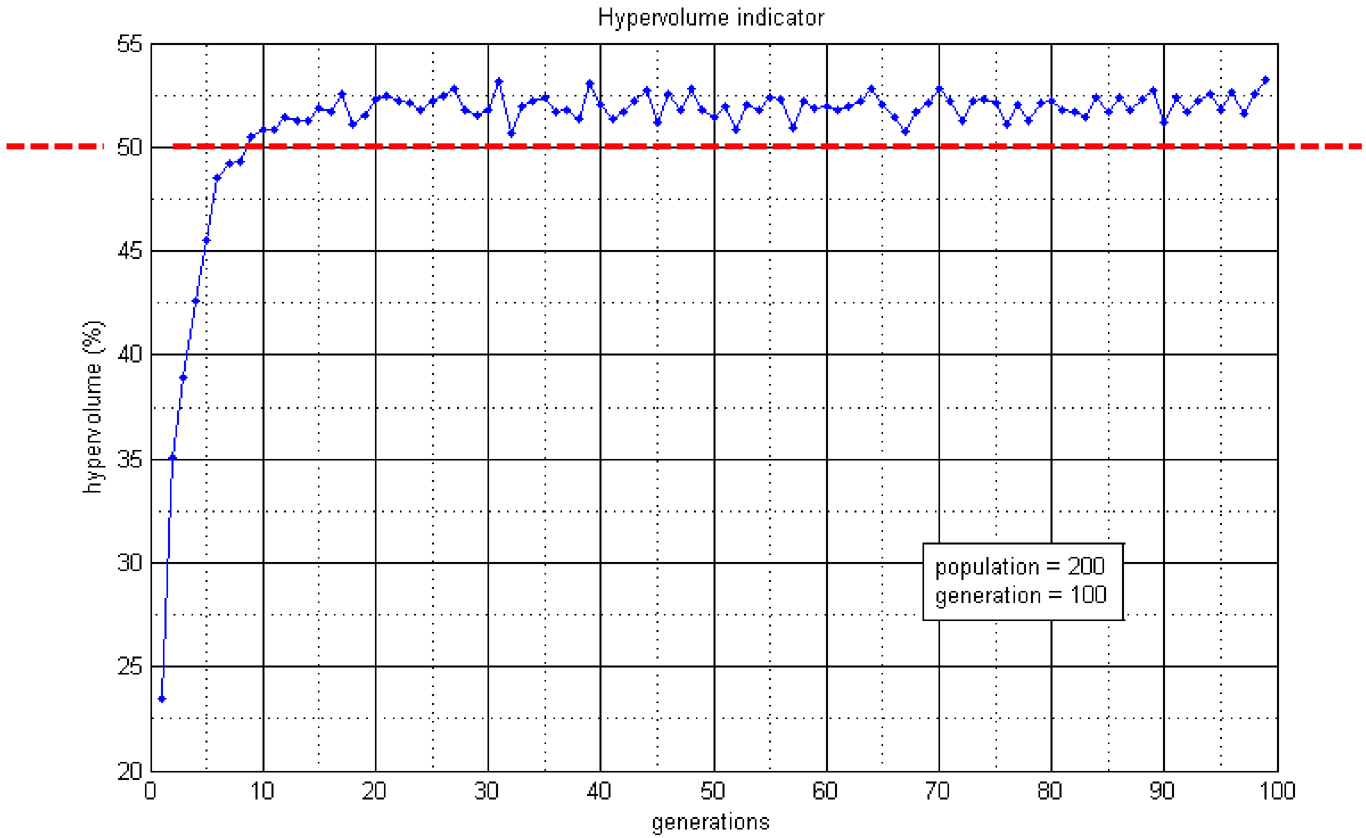
$$I_S = \frac{\sum_{u \in A} |\{u' \in A : \|F(u) - F(u')\| > \sigma\}|}{|A| - 1}$$

A : approximated set of solutions
F(u) : fitness function
σ : neighborhood parameter (> 0)

A multi-objective optimization approach

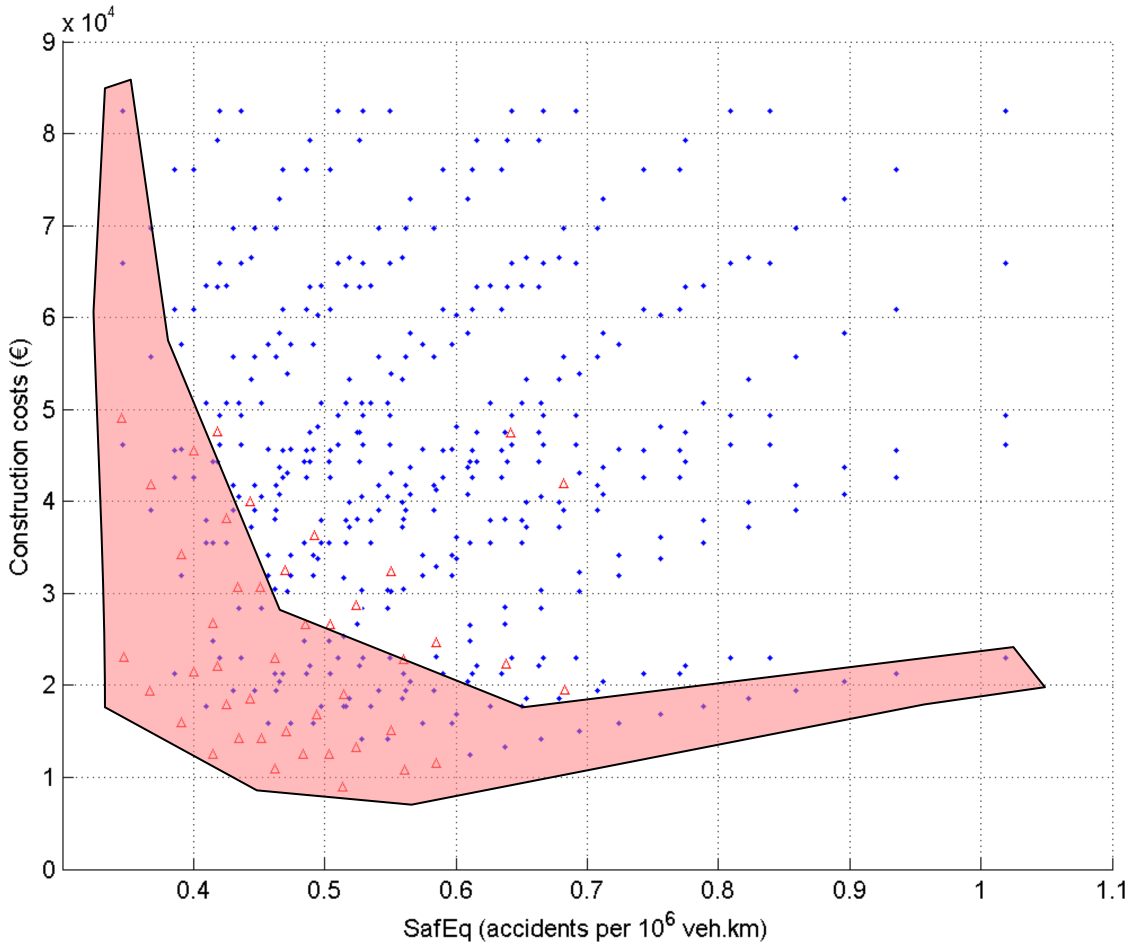
Quality indicators – Hybrid

- **Hypervolume (Talbi, 2009)**



A multi-objective optimization approach

Pareto frontier - Definition



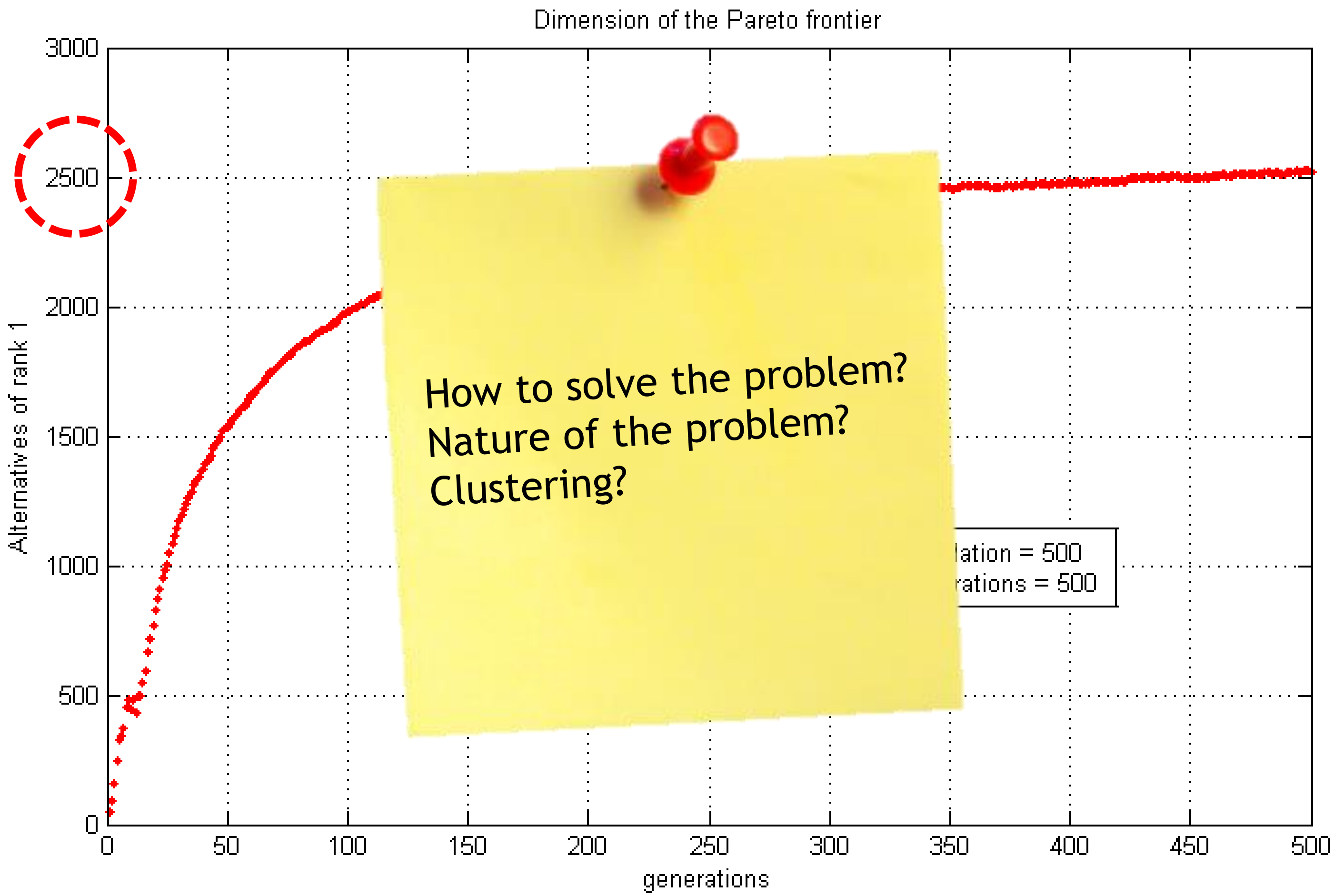
8 criteria ; 5×10^5 alt.
50 alternatives (pop)
100 generations (NSGA-II)

2-axis representation

Δ : final population
● : previous populations

A multi-objective optimization approach

Pareto frontier - Dimension



Outline

Analysis and solving of the problem

Use of PROMETHEE II

Large size of the Pareto frontier
How to select interesting/representative solutions from the Pareto frontier?

- Construction of clusters based on the **k-means procedure**
- Solving of the *reduced* problem by using PROMETHEE II

k-means

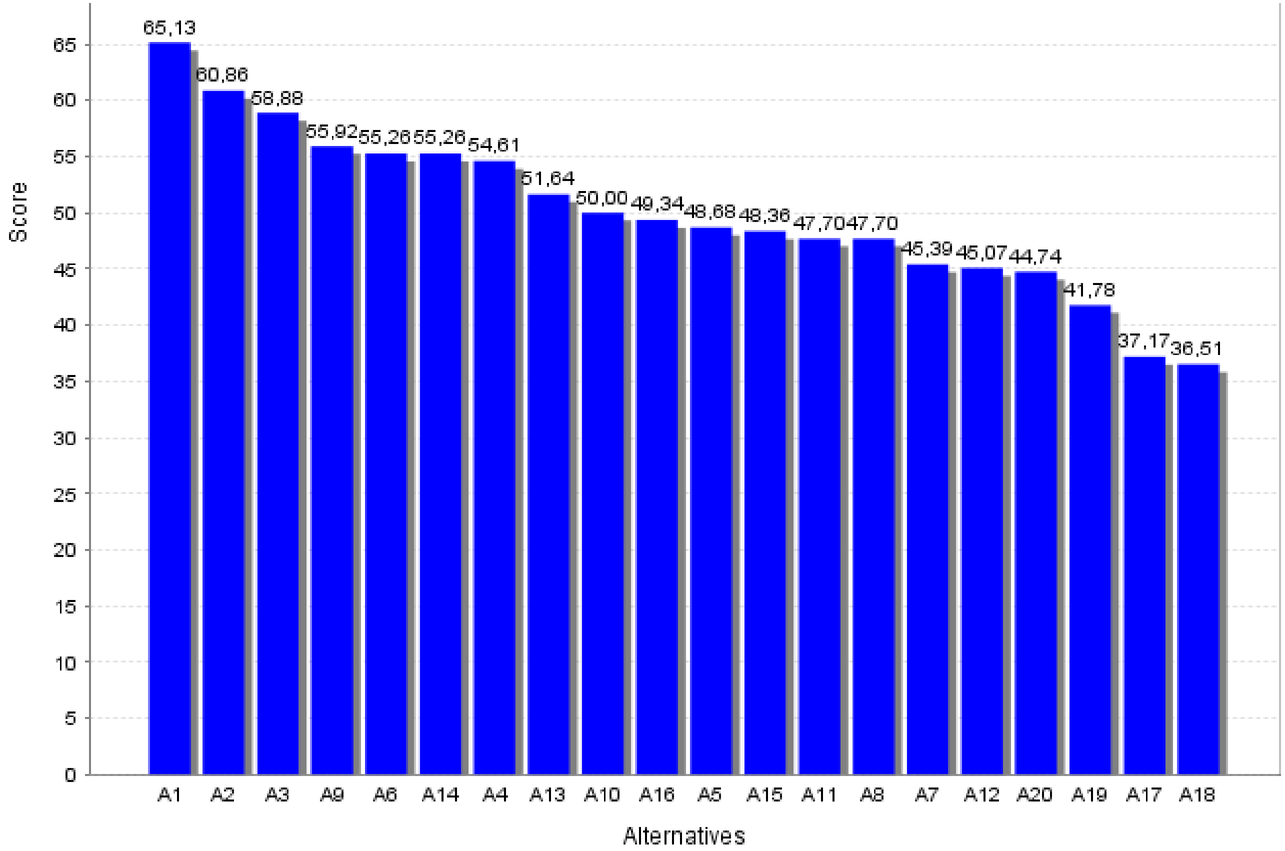
$(x_1, x_2, \ldots, x_n)$: *n* solutions composing the Pareto frontier
$S = \{S_1, S_2, \ldots, S_k\}$: *k* clusters to construct
μ_i : mean of all the elements in S_i

$$\underset{S}{\operatorname{argmin}} \sum_{i=1}^{k} \sum_{x_j \in S_i} \left\| x_j - \mu_i \right\|^2$$

Analysis and solving of the problem

Use of PROMETHEE II

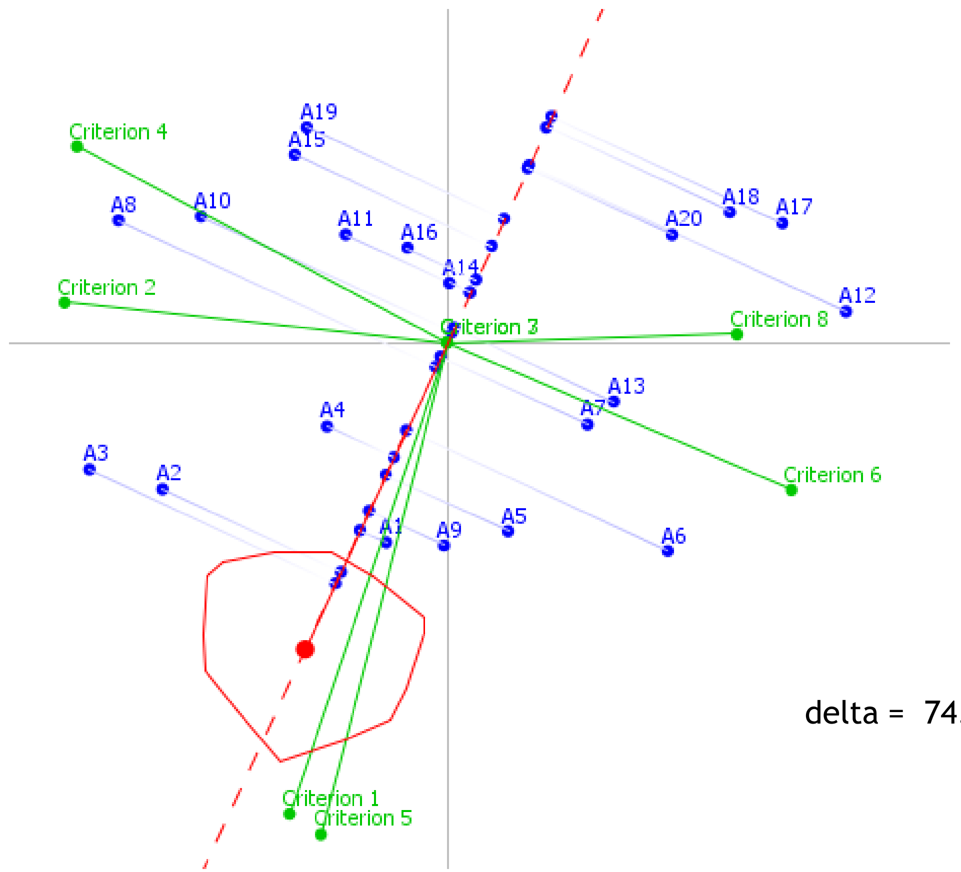
Example – sample of 20 clusters centroids (ranking)



Analysis and solving of the problem

Use of PROMETHEE II

Example – sample of 20 solutions (visual analysis)



delta = 74.2%

Outline

Conclusions

Observations

Innovative concept (preventive approach and recognition of sustainability)
Added value in this application field
Promising results

Interesting observation of the performance indicators:

- (Fast) convergence of the model (contribution, hypervolume, archive)
- Good diversity of the solution (spread, hypervolume)
- Convexity of the Pareto set

Use of k-means procedure to select representative solutions (clustering)
Analysis of the nature of the problem

Future prospects

Characterize more precisely the multicriteria problem
Improvement of the clusters construction (consider the multicriteria nature)
Order of the clusters?

Thank you for your attention

Questions, remarks, discussion.

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