Intelligent Earthworks Optimization System

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Overview

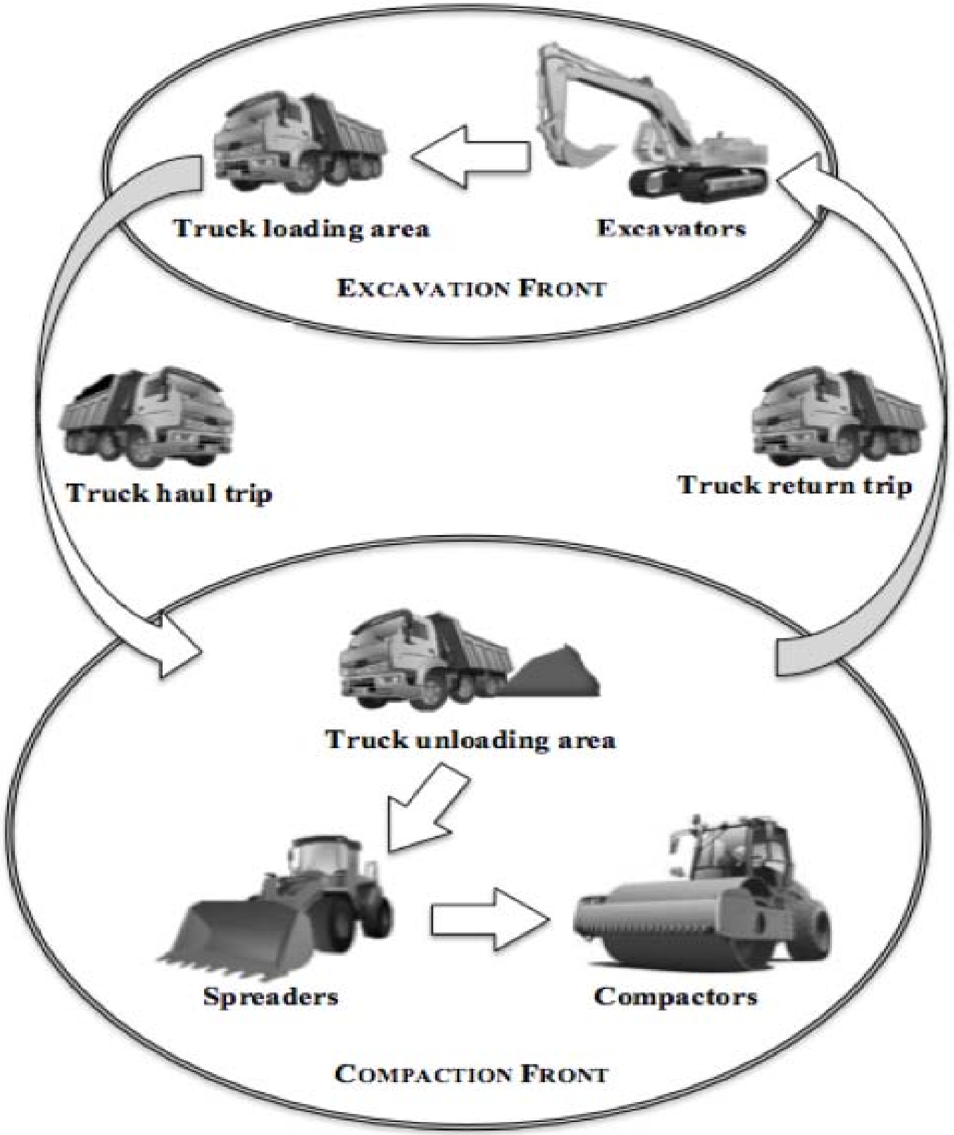
- Background: Earthworks as an optimization problem
- Soft Computing tools
  - Metaheuristics
  - Data Mining
  - Geographic Information Systems
- System architecture
  - Overview
  - Solution assessment
- Application results

Background
Earthworks as an optimization problem

Ground levelling in Engineering precedes any type of structural construction. Earthworks achieve this by:

- Excavating geomaterials from areas above the target height
- Transporting them to areas below target height, where they are spread into layers and compacted

As an optimization problem, earthworks can be translated into several production lines that require different types of resources (mechanical equipment).



Background
Earthworks as an optimization problem

An earthwork production line:

- Is associated with high construction costs and durations in transportation infrastructure projects;
- Involves repetitive sets of sequential and interdependent tasks, strongly based on mechanical equipment;
- Is highly susceptible to being optimized, even though few attempts have been carried out, due to their complex and dynamic nature.

Several production lines can be active simultaneously:
Where to start?
How to distribute the available equipment through construction site?

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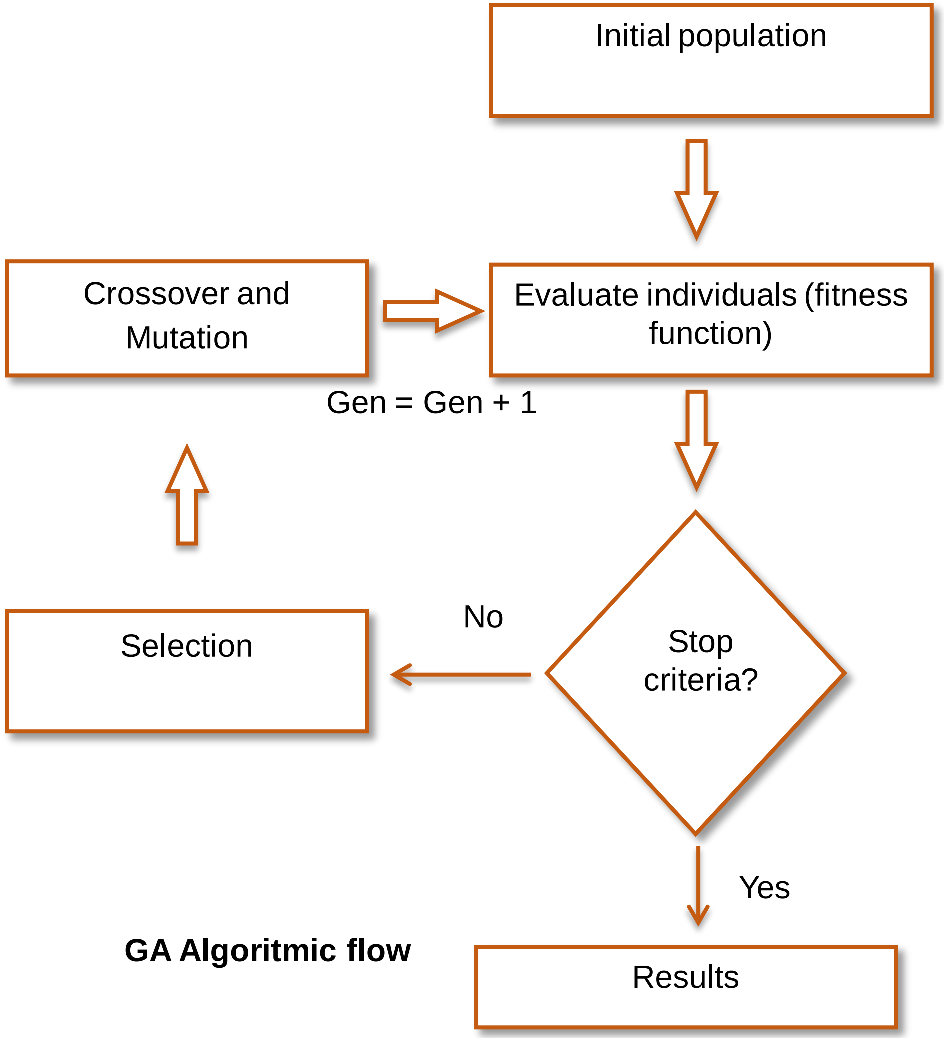
Soft Computing tools
Metaheuristics



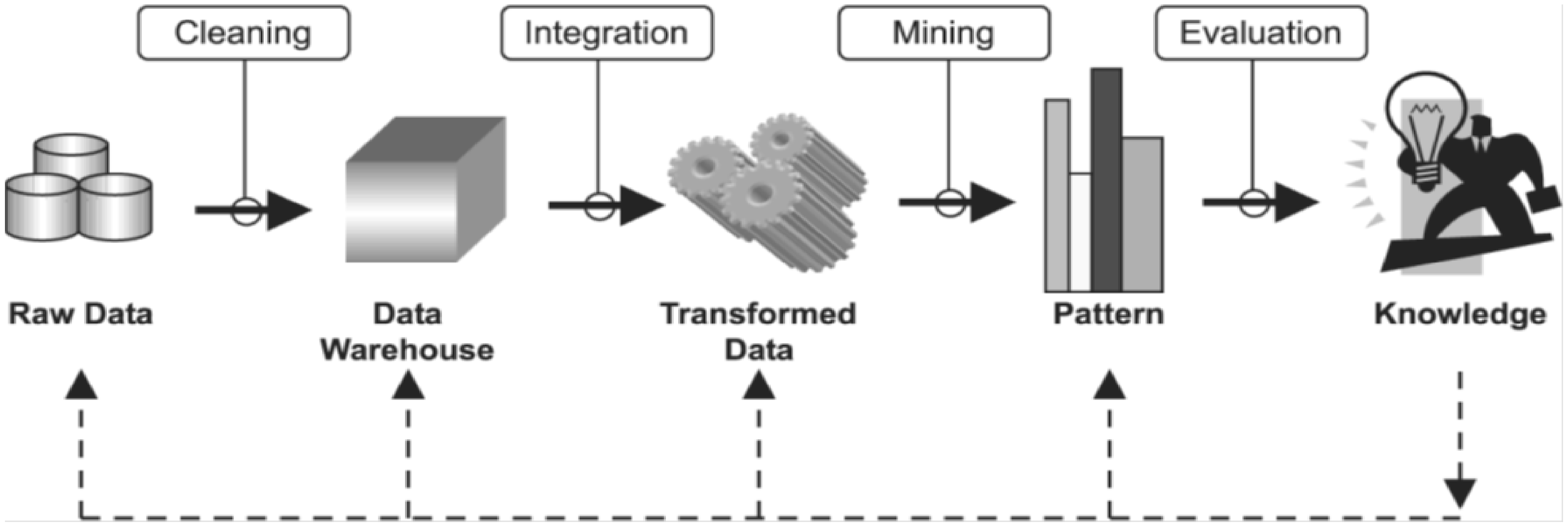
GA Algoritmic flow

Genetic algorithms (GA):

- Based on evolutionary ideas of natural selection and genetics
- Can deal with large search spaces within reasonable computational effort
- In each iteration, the GA improves on the best-found solutions of the previous one

Gradually tend towards an optimal solution for the problem

Soft Computing tools Data Mining



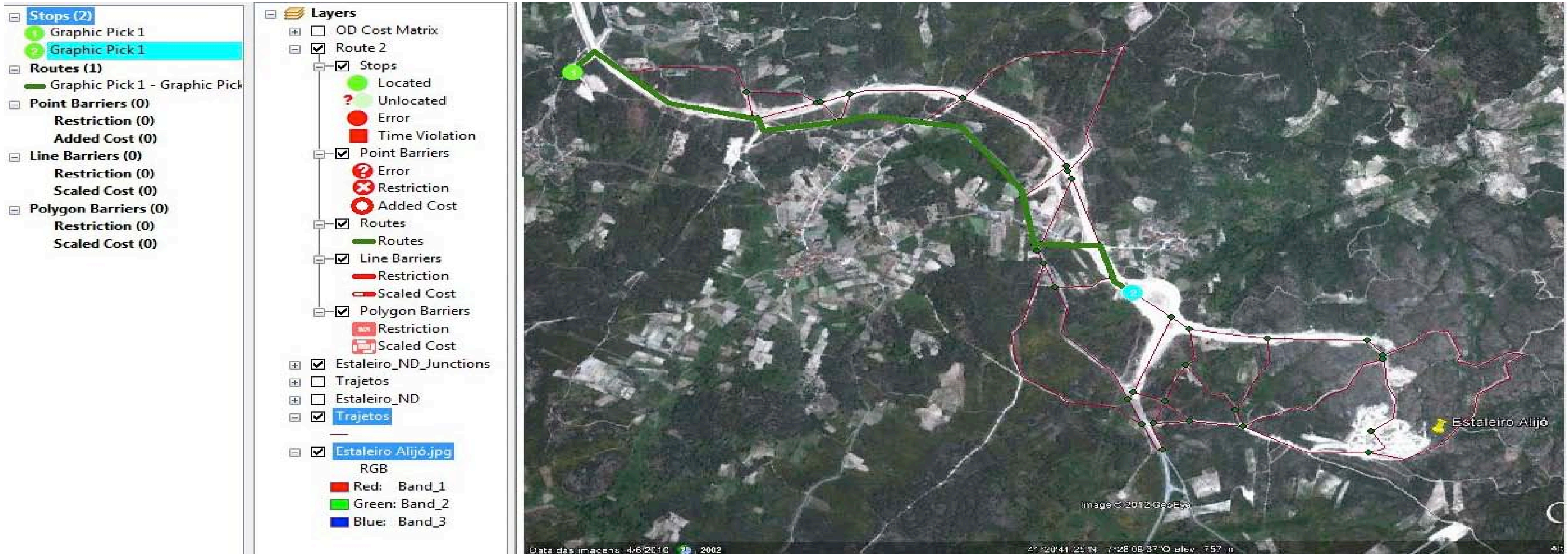
DM Process

Data Mining (DM):

- Applied to databases where results are known
- Can be used to predict the behaviour of new data in similar conditions/situations

Prediction of unknown earthworks parameters (e.g. equipment productivity)

Soft Computing tools Geographic Information Systems



Route optimization

Geographic information systems (GIS):

- Path finder algorithms are an effective and efficient means of finding the best trajectories in a network

Optimization of earthworks transportation routes

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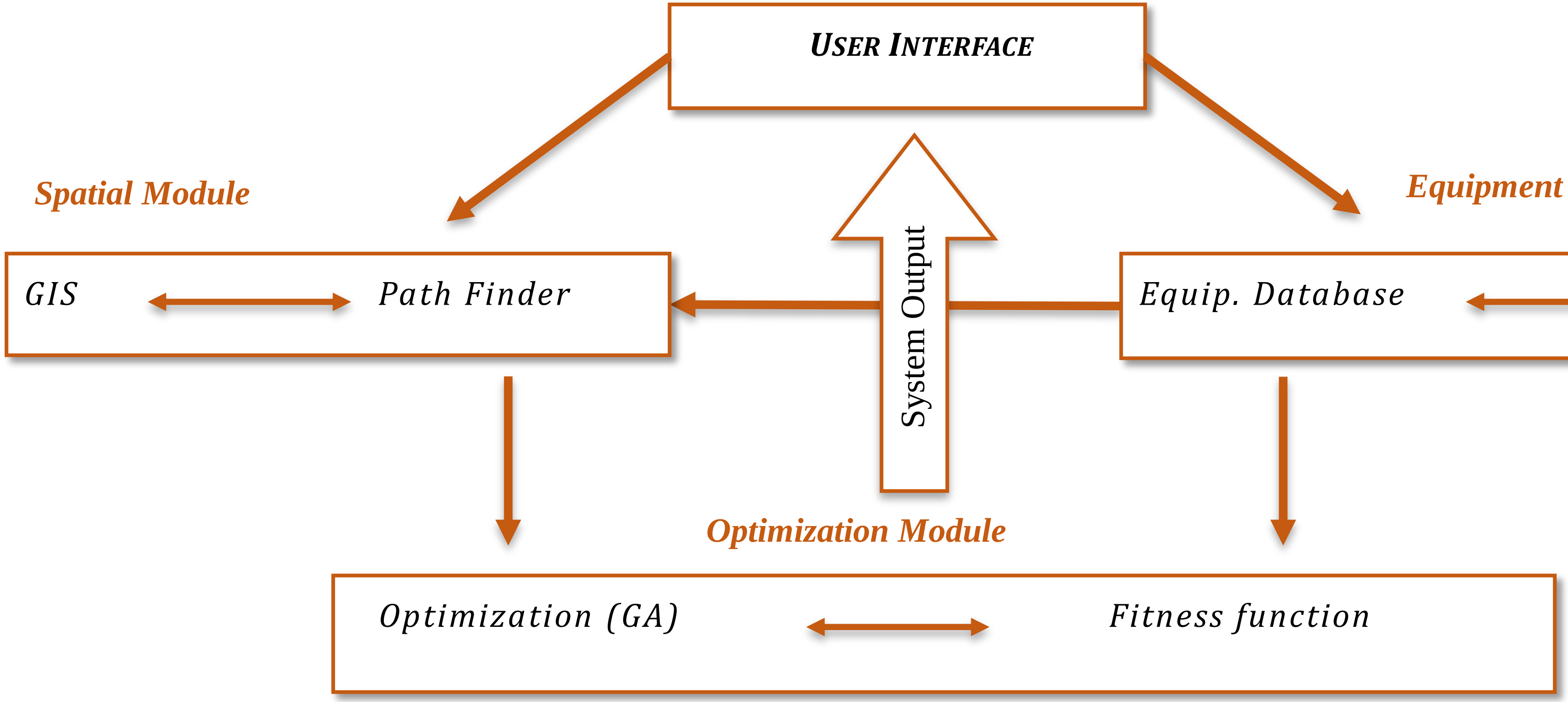
System architecture Overview

Intelligent earthwork optimization system:

- 3 modules
- Each module is based on a different technology
- Integrated modules

Module	Technology	Implementation tool	Function
Equipment	Data Mining	R/rminer	• user inputs; • estimation of productivity & costs
Spatial	Geographic Information Systems	R, QGIS, ArcGIS	• modelling of construction site; • path finder
Optimization	Metaheuristics	R/mco	• (near) optimal selection of equipment fleet depending on availability; • (near) optimal equipment fleet allocation throughout construction phase; • return output to user.

System architecture Overview



Module integration

System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

Construction phase 1

PL1 = 10000 m^3

PL2 = 10000 m^3

System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

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Population generation (compactor distribution)

Construction phase 1

PL1 = 10000 m^3


Q_{PL1} = 1000 m^3/h

PL2 = 10000 m^3

Q_{PL2} = 500 m^3/h

System architecture

Solution assessment

Load DM models for compactor productivity

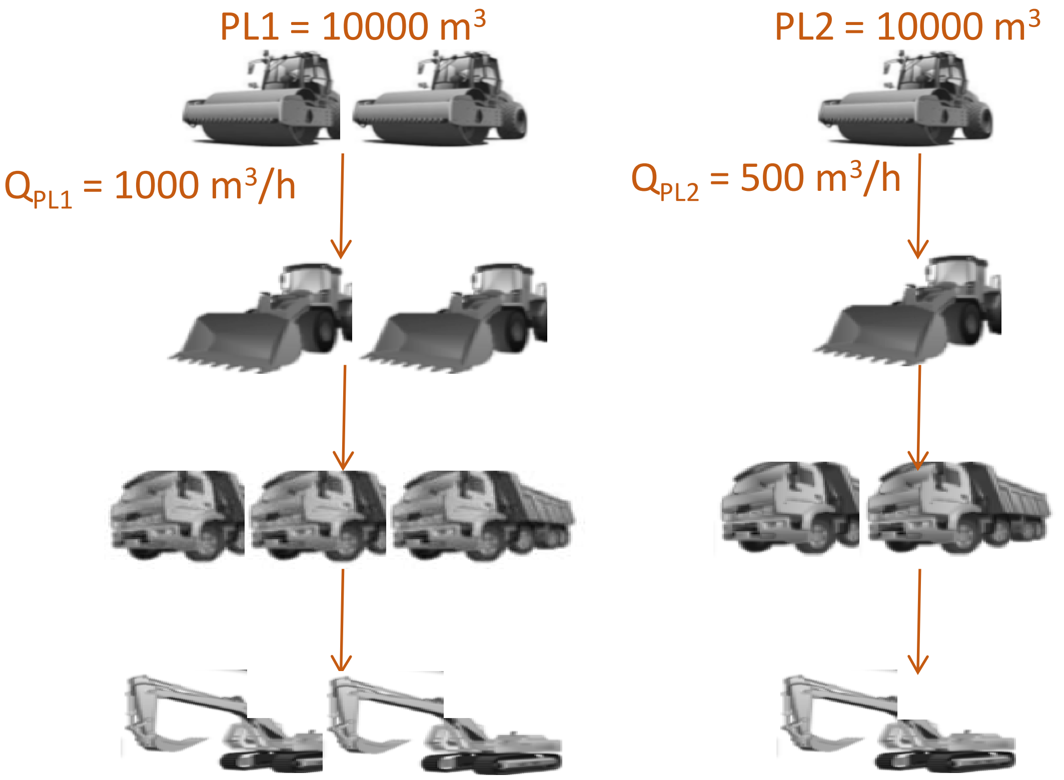
GIS data / OD cost matrix

Population generation (compactor distribution)

Fitness evaluation (for each solution)

Equipment allocation in other tasks

Construction phase 1



System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

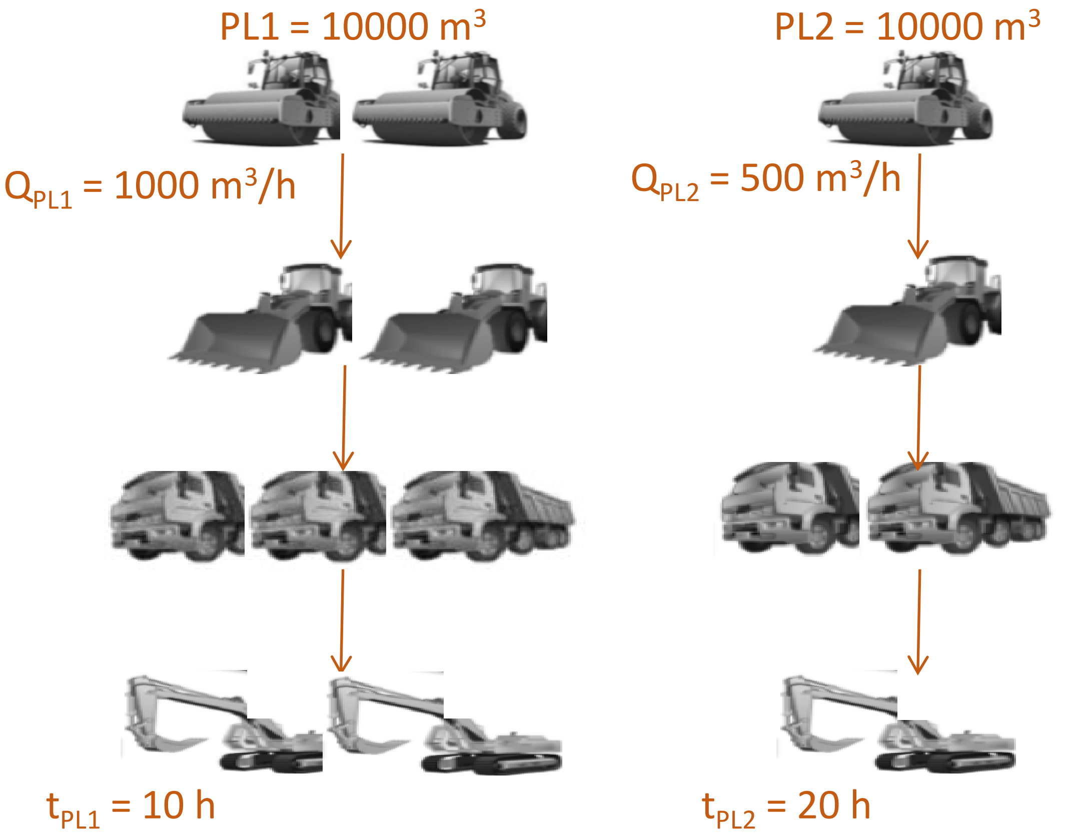
Population generation (compactor distribution)

Fitness evaluation (for each solution)

Equipment allocation in other tasks

Calculate compaction duration and costs

Construction phase 1



System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

Population generation (compactor distribution)

Fitness evaluation (for each solution)

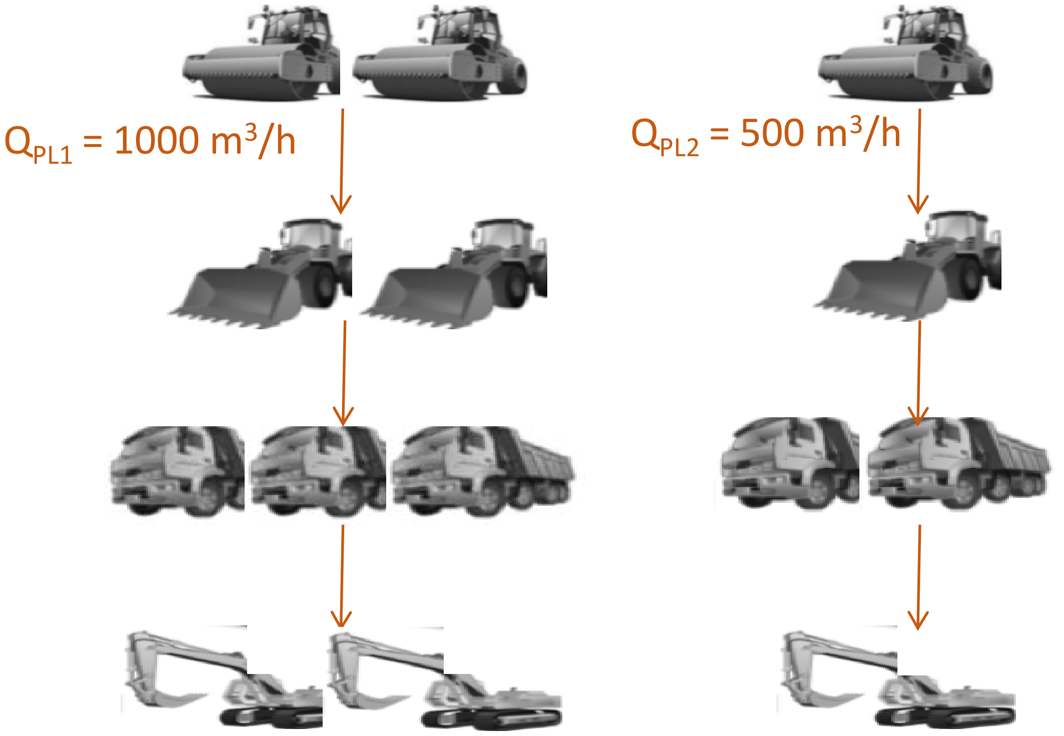
Equipment allocation in other tasks

Calculate compaction duration and costs

Update material volumes in all fronts

Construction phase 1

PL1 = 10000 m^3 PL2 = 10000 m^3



t_{PL1} = 10 h t_{PL2} = 20 h

PL1 = 0 m^3 (Completed)

PL2 = 5000 m^3

System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

Population generation (compactor distribution)

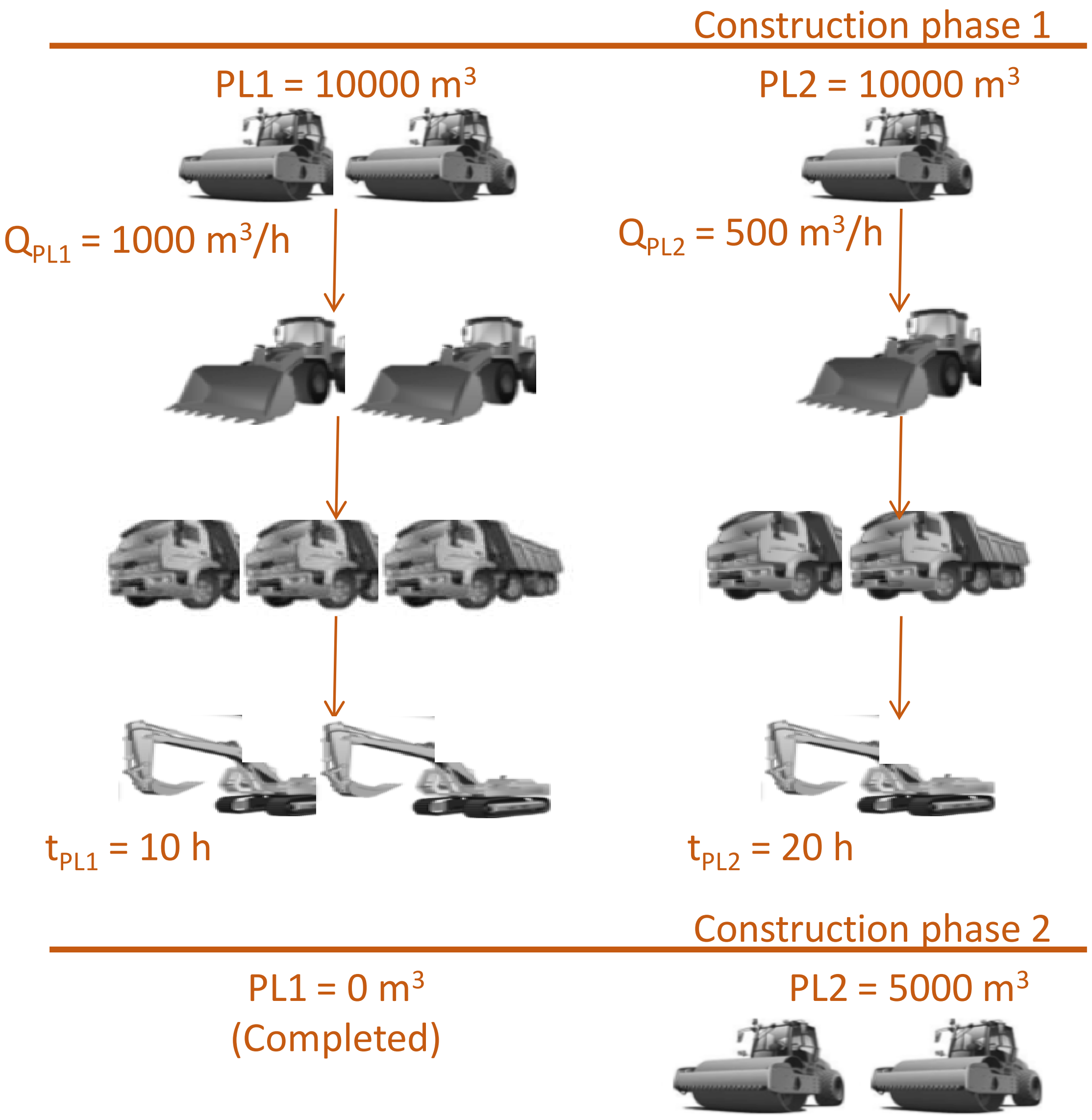
Fitness evaluation (for each solution)

Repeat fitness function for each construction phase:

Equipment allocation in other tasks

Calculate compaction duration and costs

Update material volumes in all fronts



System architecture

Solution assessment

Load DM models for compactor productivity

GIS data / OD cost matrix

Population generation (compactor distribution)

Fitness evaluation (for each solution)

Crossover & mutation for new population generation

Stop criteria?

No

Yes

Output

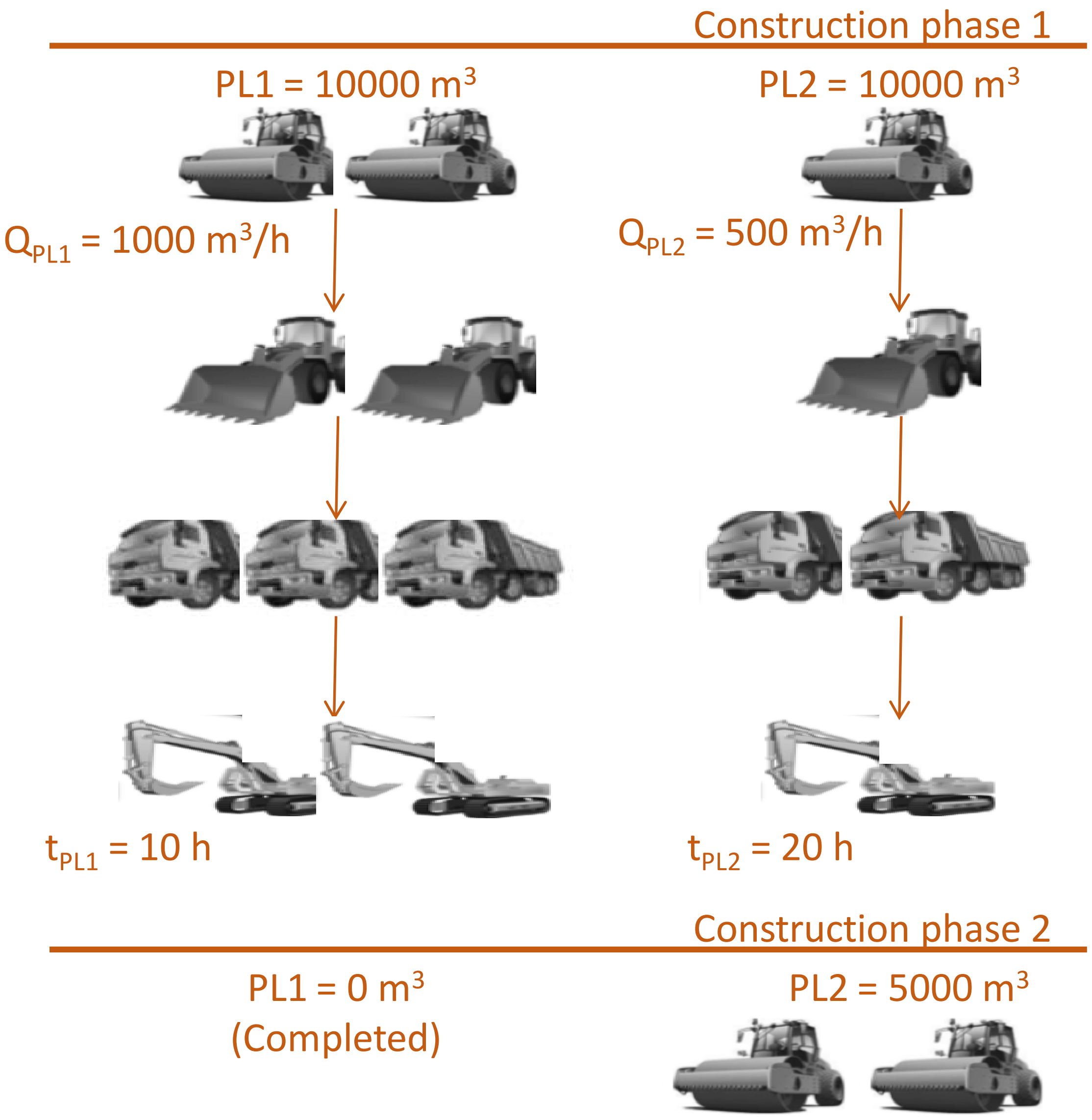
Repeat fitness function for each construction phase:

Equipment allocation in other tasks

Calculate compaction duration and costs

Update material volumes in all fronts

System **algoritmic flow**



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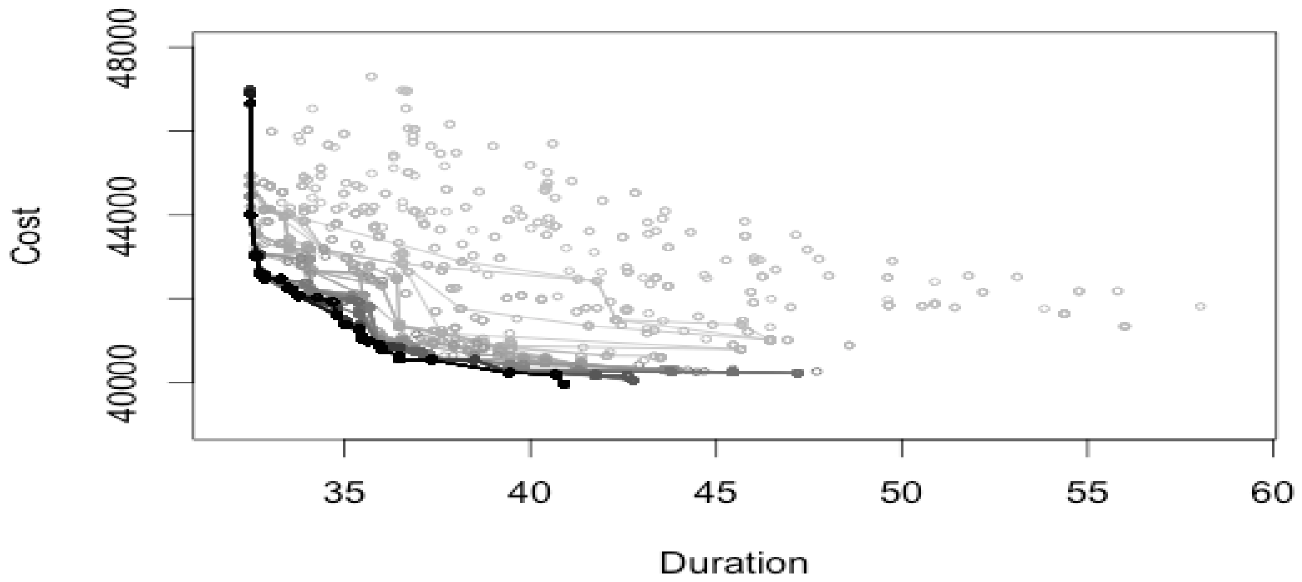
Application results

Implementation of the system has been successfully achieved, including validation with real construction data from a Portuguese construction site.

Assessment of optimization algorithm convergence towards Pareto-optimal front:



This type of solution representation increases the versatility of the system from the designer point of view

Algorithm convergence – Cost in euro; Duration in hours.

Application results

Parameter	Conventional allocation	Optimized allocation
Approximate distance to excavation front (m)	500	
Number of compactors	1	1
Compactor work rate (m^3/h)	683	683
Number of spreaders	1	1
Spreader work rate (m^3/h)	675	820
Number of dumper trucks	3	2
Dumper truck work rate (m^3/h)	1280	880
Number of excavators	1	2
Excavator work rate (m^3/h)	540	743

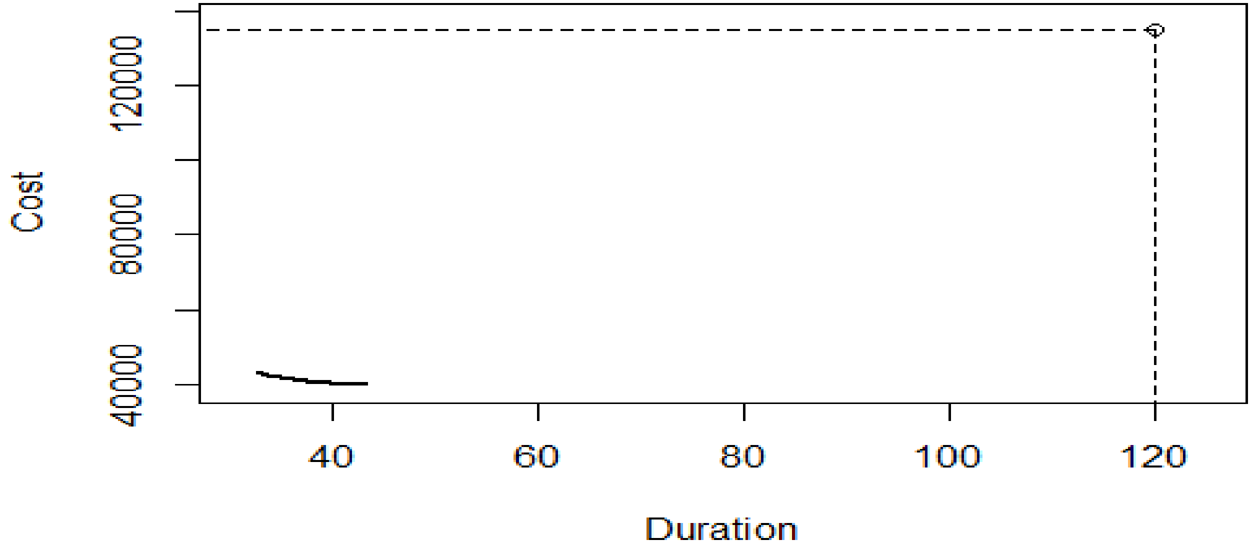
Example – comparison between the optimized solution and the conventional solution obtained by manual design:

- Conventional allocation:
  - Limited by the excavation team work rate
  - Over-allocation of dumper trucks
- The optimized allocation finds the most homogeneous allocation solution given the available resources

Resources are used at full efficiency (e.g. no idle time)

Application results

Overall comparison between the obtained Pareto-optimal solutions and the original manual solution adopted by the designer:



***Dot*: Original human solution**
***Line*: Obtained Pareto front of solutions**

Competitive results were achieved by the proposed system (reduction of 20-50% in project cost and duration when compared with human solution), stressing the advantages of intelligent optimization tools in the design of earthworks.

Publications

Data mining applications	Parente, M., Correia, A., & Cortez, P. (2014). Use of DM techniques in earthworks management: a case study. In S.-E. Chen, D. T.-T. Chang, & Y.-L. Lee (Eds.), *ASCE Geotechnical Special Publication (GSP), GeoHubei 2014 International Conference - Earthwork Project Management, Slope Stability Analysis, and Wave-Based Testing Techniques* (pp. 1–8). Yichang, Hubei, China: American Society of Civil Engineers. doi:10.1061/9780784478523.001 Parente, M., Gomes Correia, A., & Cortez, P. (2014). Artificial Neural Networks Applied to an Earthwork Construction Database. In D. Toll, H. Zhu, A. Osman, W. Coombs, X. Li, & M. Rouainia (Eds.), *Second International Conference on Information Technology in Geo-Engineering* (pp. 200–205). Durham, UK: IOS Press.
Optimization algorithm	Parente, M., Cortez, P., & Gomes Correia, A. (2015). An evolutionary multi-objective optimization system for earthworks. *Expert Systems with Applications*, *42*(11), 6674–6685.
System development and application	Parente, M., Cortez, P., & Gomes Correia, A. (2015). Combining Data Mining and Evolutionary Computation for Multi-Criteria Optimization of Earthworks. In A. Gaspar-Cunha, C. H. Antunes, & C. Coello (Eds.), *Lecture Notes in Computer Science Vol: 9019. 8th International Conference on Evolutionary Multi-Criterion Optimization (EMO 2015)*. Guimarães, Portugal: Springer. Parente, M., Gomes Correia, A., & Cortez, P. (2015). Modern optimization in earthwork construction. In M. G. Winter, D. M. Smith, P. J. L. Edlred, & D. G. Toll (Eds.), *Proceedings of the XVI ECSMGE* (pp. 343–348). ICE Publishing. doi:10.1680/ecsmge.60678

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Thank you