A LAGRANGIAN HEURISTIC FOR A REAL-LIFE INTEGRATED PLANNING PROBLEM OF RAILWAY TRANSPORTATION RESOURCES

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AGENDA

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AGENDA

- Industrial Context
  - Railway Production
  - Integrated planning problem: An example
  - Objectives
  - Literature Review
- Modeling Problem
  - Mathematical Model
- A Lagrangian relaxation heuristic
  - Presentation
  - General scheme
  - Relaxation schemes
  - Industrial implementation
  - Preliminary computational results
- Conclusions and Perspectives

INDUSTRIAL CONTEXT

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RAILWAY PRODUCTION

Resources to Schedule

Train paths

↓

Rolling stock

↓

Train drivers

Current Process

Forecast demand + commercial offers

↓

Planning of railway Timetables

↓ **Train paths**

Train duty generation

↓

Rolling stock (locomotive) planning

↓

Driver duty generation

↓

Planning of train Drivers

→ **Set of working days**

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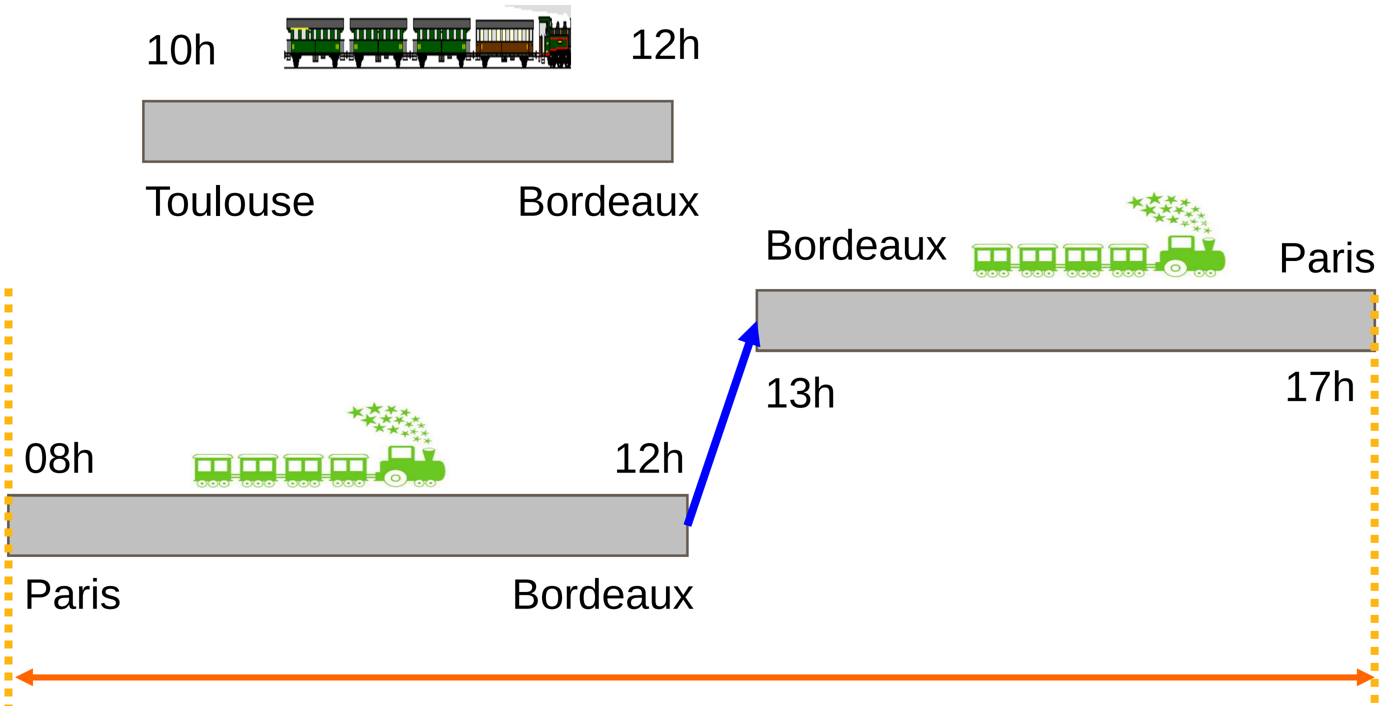
INTEGRATED PLANNING PROBLEM: AN EXAMPLE



Too long to be covered by a single shift

⟶ 3 train drivers are required

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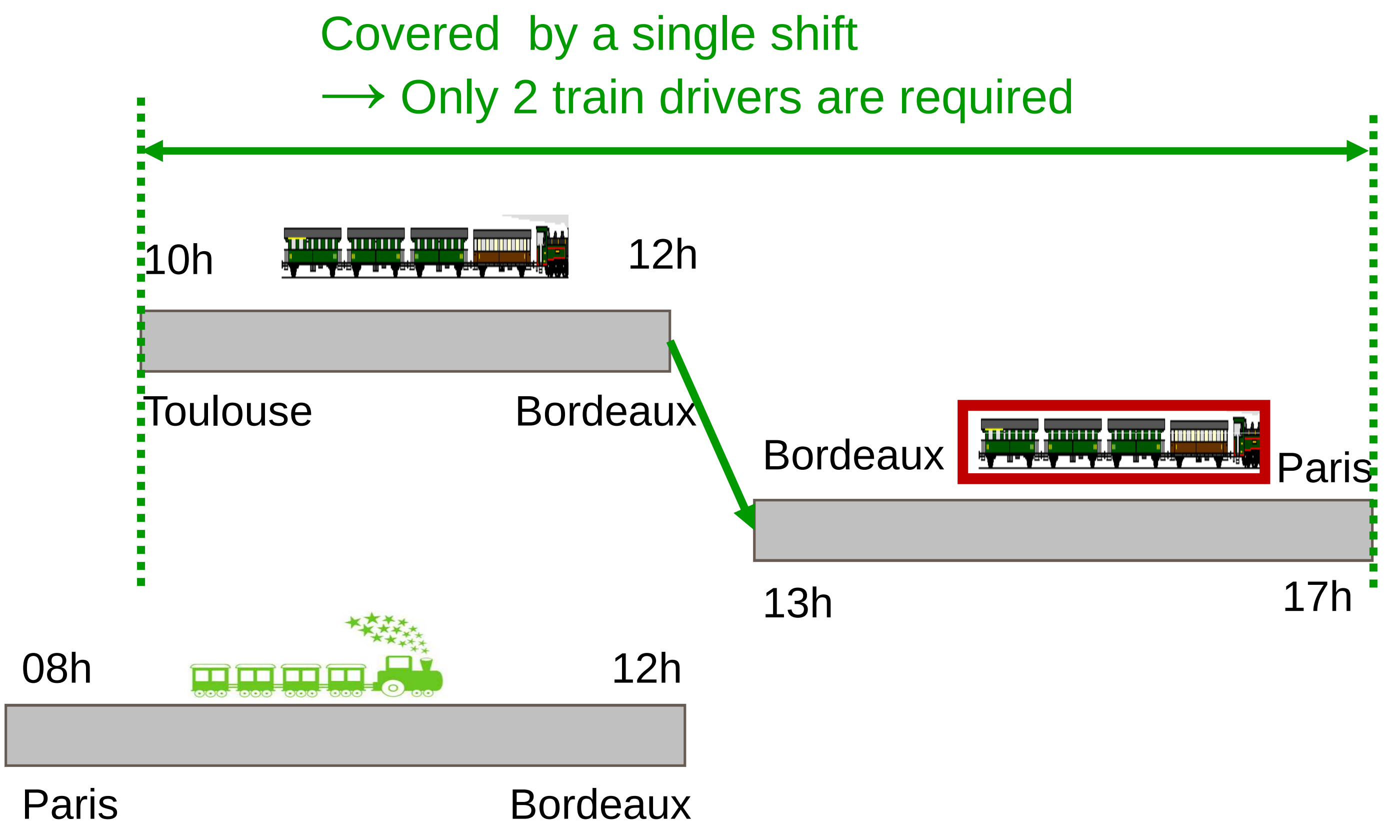
INTEGRATED PLANNING PROBLEM: AN EXAMPLE



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OBJECTIVES

- Study the feasibility of an integrated planning process
  - Definition of the planning problem(s)
  - Models / Algorithms / Performances
  - Software prototyping
- In order to increase
  - Competitiveness
    - Better use of resources
    - Cost minimization
  - Quality of service
    - Consistent transportation plans

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LITERATURE REVIEW

Airline

- **J-F. Cordeau, G. Stojkovic, F. Soumis, J. Desrosiers**. Benders decomposition for simultaneous aircraft routing and crew scheduling. *Transportation Science*, 35: 375-388, 2001.
- **M. Haouari, K.H. Bae**. Integrated airline schedule design and fleet assignment: Polyhedral analysis and Benders' decomposition approach. *European Journal of Operational Research*, 39(4): 491-502, 2010.
- **M. Lohatepanont, C. Barnhart**. Airline schedule planning: Integrated models and algorithms for schedule design and fleet assignment. *Transportation Science*, 38(1): 19-32, 2004.
- **A. Mercier, F. Soumis**. An integrated aircraft routing, crew scheduling and flight retiming model. *Computers & Operations Research*, 34: 2251-2265, 2005.
- **N. Papadakos**. Integrated airline scheduling: decomposition and acceleration techniques, 2006.
- **N. Papadakos**. Integrated airline scheduling. *Computers & Operations Research*, 36: 176-195, 2009.
- **R. Sandhu, D. Klabjan**. Integrated airline fleeting and crew-pairing decisions. *Operations Research*, 55(3): 439-456, 2007.

Public transport

- **D. Huisman, R. Freling, A. P. M. Wagelmans**. Multiple-depot integrated vehicle and crew scheduling. *Transportation Science*, 39(4): 491-502, 2005.

MODELING PROBLEM

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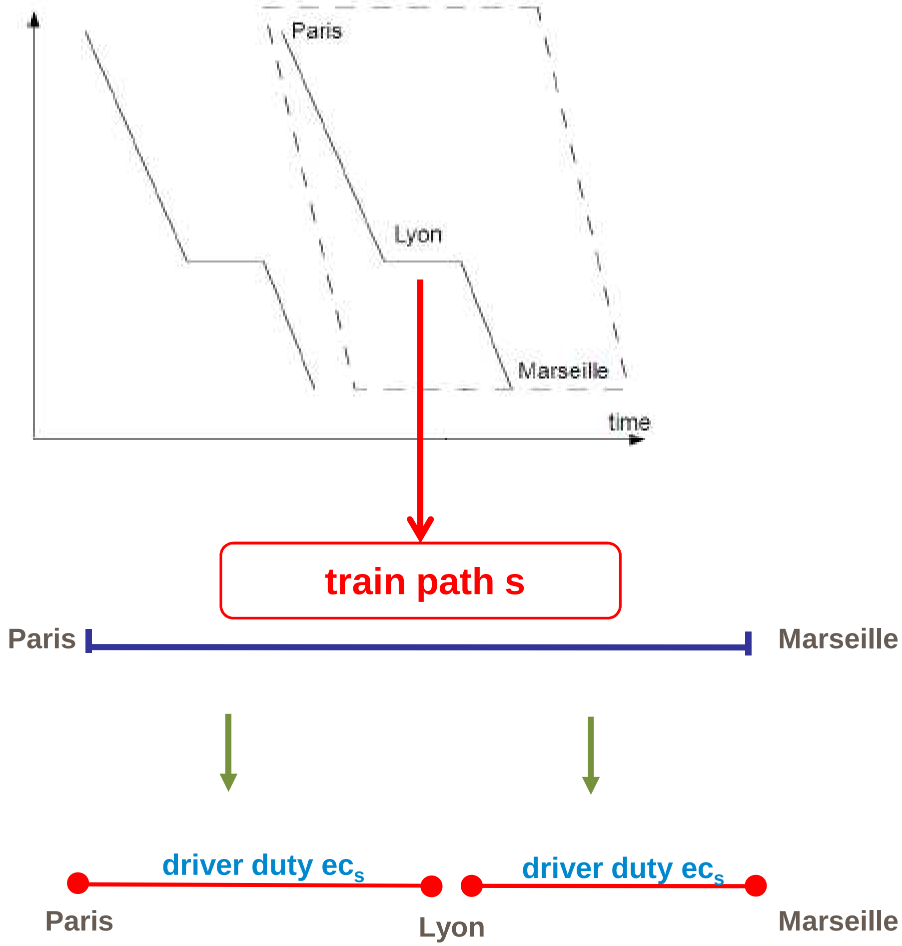
MODELING PROBLEM

MATHEMATICAL MODEL



Rolling stock model

Coupling constraints

Driver duty generation

Train driver model

MODELING PROBLEM

MATHEMATICAL MODEL

- Rolling stock planning subproblem
  - Constraints
    - Covering constraints of a train-path by rolling stock *only*
    - Capacity constraints…
  - Objectives
    - Production costs (number of units, total distance…)
    - Penalties when train paths are not covered by rolling stock units
- Train driver planning subproblem (*crew pairing problem*)
  - Constraints
    - Driver duty covering constraints
    - Capacity constraints
    - Legal labor constraints…
  - Objectives
    - Production costs (number of drivers, density of the shifts)
    - Penalties when driver duties are not covered by drivers

MODELING PROBLEM

MATHEMATICAL MODEL

- Coupling constraints
  - Train-path covering constraints related to rolling stock
  - Train-path covering constraints related to drivers (*i.e. if any driver duty of a train-path is not covered, the train-path is not covered*)
  - Consistency constraints between rolling stock unit(s) and the driver assigned to each train-path
- An additional term in the global objective function
  - Penalties when train-paths are not covered with both rolling stock unit(s) and a driver

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PRESENTATION

- New approach to solve the integrated planning model: Lagrangian Relaxation
  - Relaxation of the coupling constraints
    $\longrightarrow$ **Different possible relaxation schemes**
  - Roll these constraints in the objective function with multipliers
  - **Use of dedicated industrial tools** to solve the relaxed rolling stock planning problem and driver planning problem
  - **Lagrangian heuristic** by using industrial tools to determine a feasible integrated rolling stock and driver plan

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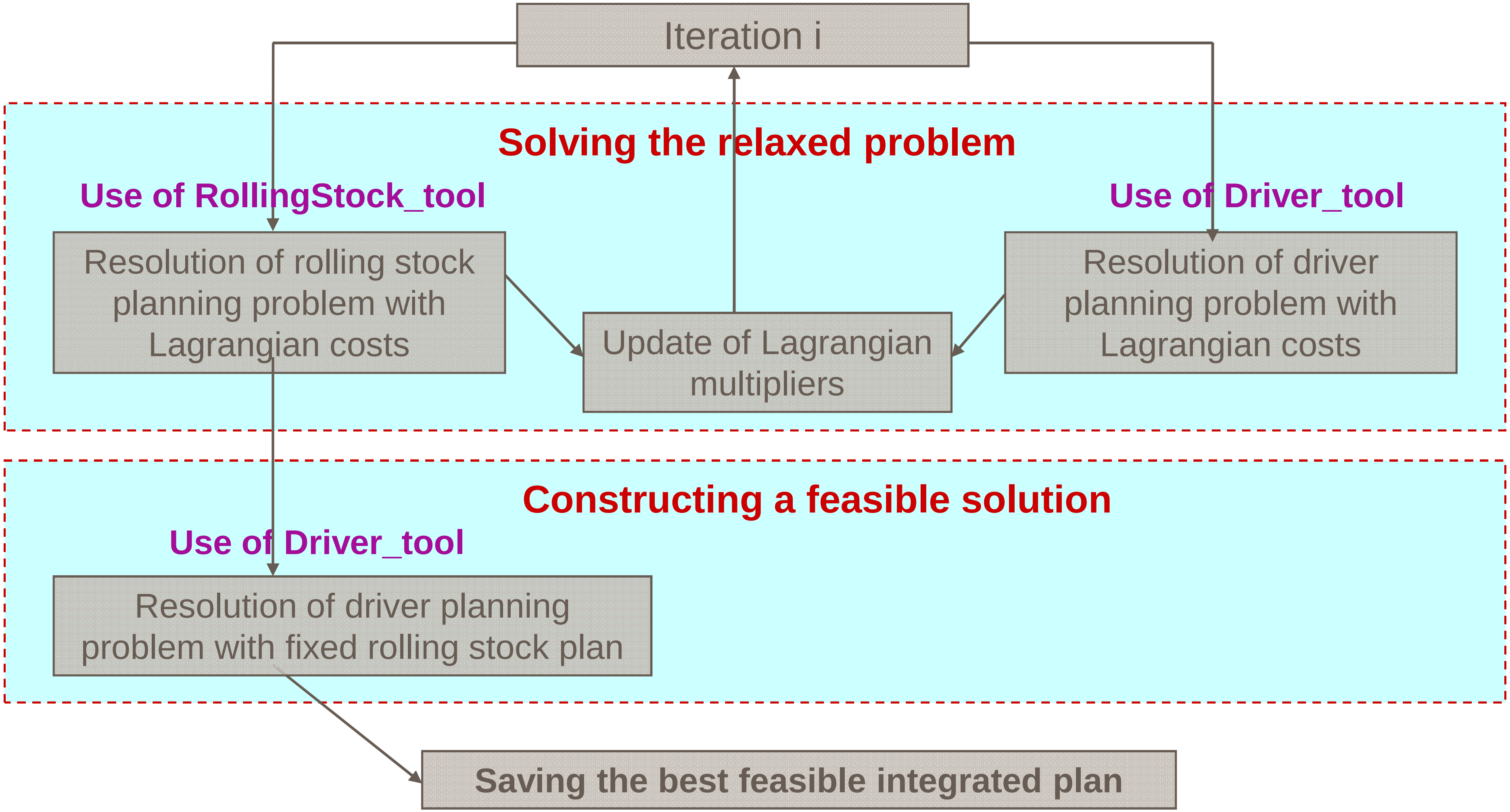
GENERAL SCHEME



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RELAXATION SCHEMES

Relaxation schemes	**Coupling constraints**		
	Covering constraints (rolling stock)	***Covering constraints (drivers)***	***Consistency constraints***
Total relaxation	Relaxed	Relaxed	Relaxed
Partial driver relaxation	***Not relaxed***	Relaxed	Relaxed
Partial rolling stock relaxation	Relaxed	***Not relaxed***	Relaxed
Lagrangian decomposition	***Not relaxed***	***Not relaxed***	Relaxed

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RELAXATION SCHEMES

- **Experimental validation of the 4 relaxations schemes** on 4 selected small instances based on industrial data.
  - First prototype software developed with IBM ILOG OPL Studio and CPLEX for a simplified MIP model

	Instance 1	Instance 2	Instance 3	Instance 4
Rolling stock	**40**	**30**	**20**	**10**
Drivers	**20**	**10**	**10**	**20**
Train paths	32	32	32	32
Driver duties	32	32	32	32
Rolling stock types	12	12	12	12
Driver types	6	6	6	6

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RELAXATION SCHEMES

The scheme for the industrial implementation was selected to ensure a trade-off between performance and complexity of implementation.

Relaxation schemes	(UB-LB)/UB			
	Instance 1	Instance 2	Instance 3	Instance 4
Total relaxation	0.05%	1.40%	3.15%	10.03%
Partial driver relaxation	0.00%	0.21%	0.23%	0.01%
Partial rolling stock relaxation	0.01%	0.09%	0.20%	8.51%
Lagrangian decomposition	0.00%	0.85%	0.03%	0.08%

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INDUSTRIAL IMPLEMENTATION

Properties of our Lagrangian heuristic:

- The feasible solution determined in the first iteration corresponds to a sequential use of the two existing rolling stock and train driver software,
- By construction, the best feasible solution found by the iterative heuristic necessarily improves the feasible solution found at the first iteration.

The two existing proprietary software had not been designed for a coordinated use:

$\longrightarrow$ Additional terms in the objective functions were required,

$\longrightarrow$ Existing constraints had to be modified.

The return on investment (development costs vs. quality of solutions) of all modifications was significant and **all the necessary adjustments were implemented.**

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MODELING PROBLEM

INDUSTRIAL IMPLEMENTATION

- Modifications of the industrial **rolling stock** planning module
  - Add an additional term in the objective function, computed from the values of the dual multipliers corresponding to the relaxation of the consistency constraints
- Modifications of the industrial **train driver** planning module
  - Specify some costs and penalties
    - The cost of a shift also depends on the depot (*not only on its density*)
    - The penalty for not covering a train duty is specific (*not a constant*)
  - Update two terms in the objective function, according to the values of the dual multipliers corresponding to the relaxation of the covering constraints by drivers) and the consistency constraints

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PRELIMINARY COMPUTATIONAL RESULTS

A real-life instance is used *(the transportation plan of a French region)*. Because data are not generated, collecting industrial data was time-consuming and tricky, in particular the parameters that connect rolling stock and drivers.

Different scenarios (different costs) were created from the real-life instance.

Characteristics	Instance
Time horizon	1 week
Train paths	416
Rolling stock types	7
Rolling stock units	73
Driver depots	7
Drivers	81

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PRELIMINARY COMPUTATIONAL RESULTS

Results are promising and significant gains are obtained.

Results for one scenario	Iteration 1	Iteration 23	Iteration 24	Iteration 53
Rolling stock units	23	23	24	24
Driver shifts	208	217	218	228
Uncovered train paths	25	13	7	2

→ The industrial implementation has to be finalized, in particular :

- The choice of the initial Lagrangian multipliers
- The choice of the initial costs and penalties of the objective functions of the two modules, in order to reach a *good* trade-off between rolling stock and drivers costs

CONLUSIONS AND PERSPECTIVES

CONCLUSIONS AND PERSPECTIVES

- Conclusions
  - Development of a **Lagrangian relaxation heuristic** for an integrated planning problem of railway transportation resources
  - **Industrial implementation** of the Lagrangian heuristic, with different modifications.
  - **First numerical experiments on industrial instances** are promising. Several additional industrial instances from other French regions are being created.
- Perspectives
  - **Tuning** the Lagrangian relaxation approach
  - Including the integration of **additional levels of integration** ; e.g. the possibility of slightly changing the times of train paths

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