Integrated crew management for rail freight

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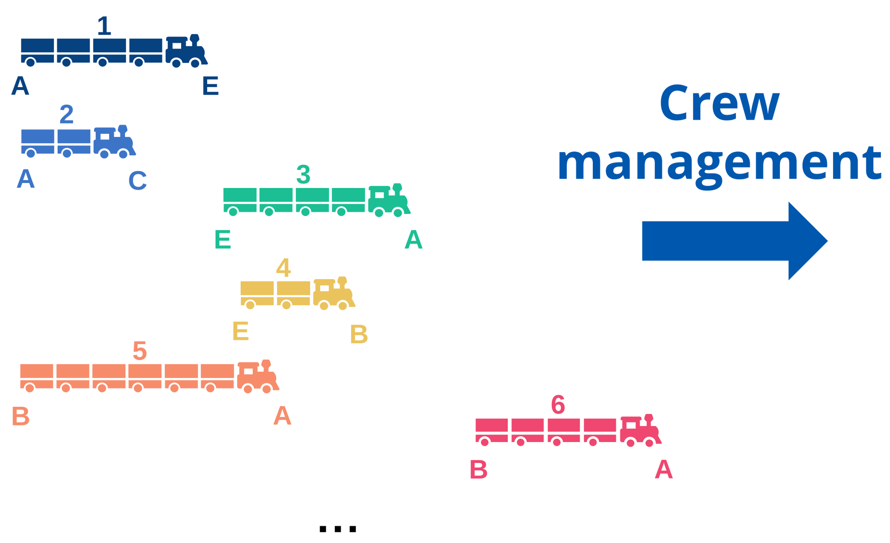
Context

Rail freight in France:
- 10% of overall freight: 1,800 to 2,000 trains per week
- Passenger traffic has priority over freight: trains mostly at night

Problem statement

Crew management problem
Input: Trains on a typical week
Output: Covering of trains by "rosters" with minimum cost, each roster assigned to a team



Team A:

mon	tue	wed	thu	fri	sat	sun
shift 1 12h-21h A - A	d	R	R	R	shift 5 11h-17h A - E	shift 6 5h-16h E - A
shift 2 12h-19h A - B	shift 3 5h-11h B - A	R	R	R	R	shift 7 10h-17h A - A

Team B:

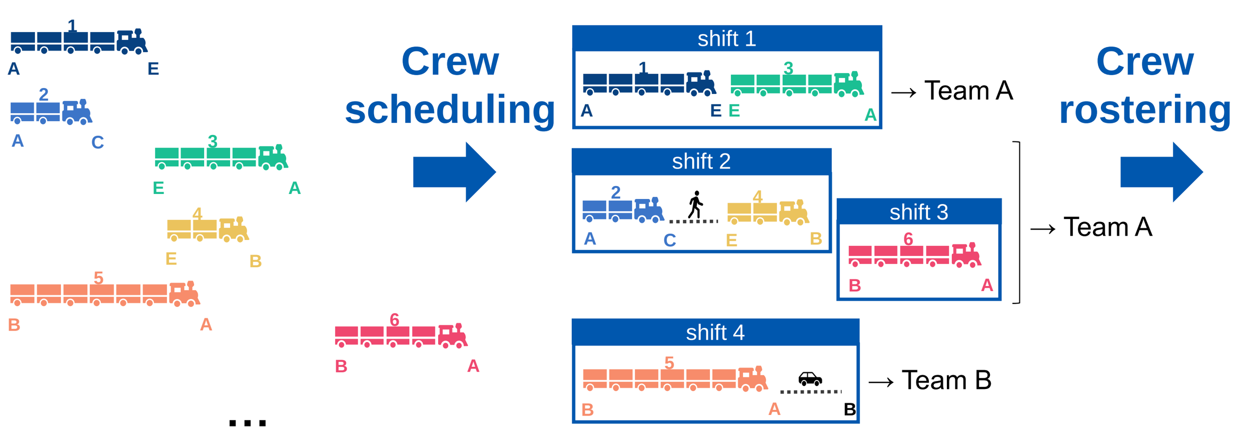
mon	tue	wed	thu	fri	sat	sun
shift 4 12h-20h B - B	shift 8 11h-17h B - B	shift 9 5h-12h E - B	R	R	R	R

cost = 10

Standard decomposition[1,2] (sub-optimal):

Crew scheduling problem +
Input: Trains on a typical week
Output: Covering of trains by daily shifts with minimum cost, each shift assigned to a team

Crew rostering problem
Input: Shifts, each assigned to a team
Output: Covering of trains by "rosters" with minimum cost, each roster assigned to a team



Team A:

mon	tue	wed	thu	fri	sat	sun
shift 1 12h-21h A - A	d	R	R	R	shift 5 11h-17h A - E	shift 6 11h-18h E - A
shift 2 12h-19h A - B	shift 3 5h-11h B - A	R	R	R	d	shift 7 5h-14h A - A

Team B:

mon	tue	wed	thu	fri	sat	sun
shift 4 12h-20h B - B	shift 8 11h-17h B - B	shift 9 5h-12h E - B	R	R	R	R

cost = 11

Contributions

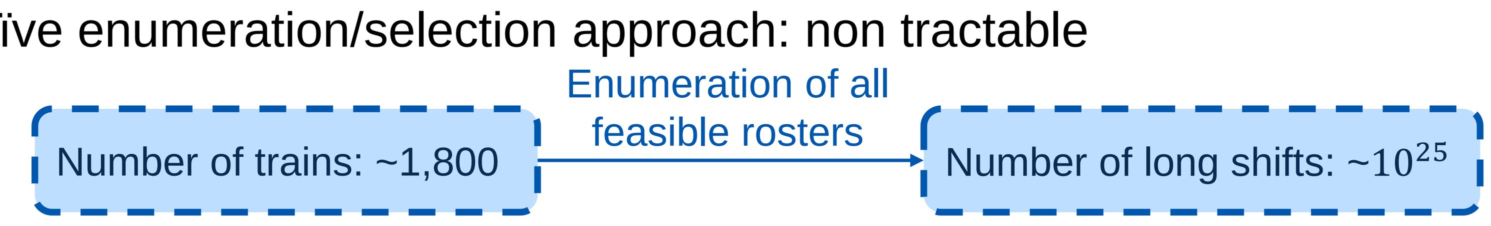
Optimal decomposition:
- Covering of trains by "long shifts" with minimum cost, each assigned to a team ("long shifts" = working period between two days off)
- Construction of rosters with these long shifts

Trains' covering problem:

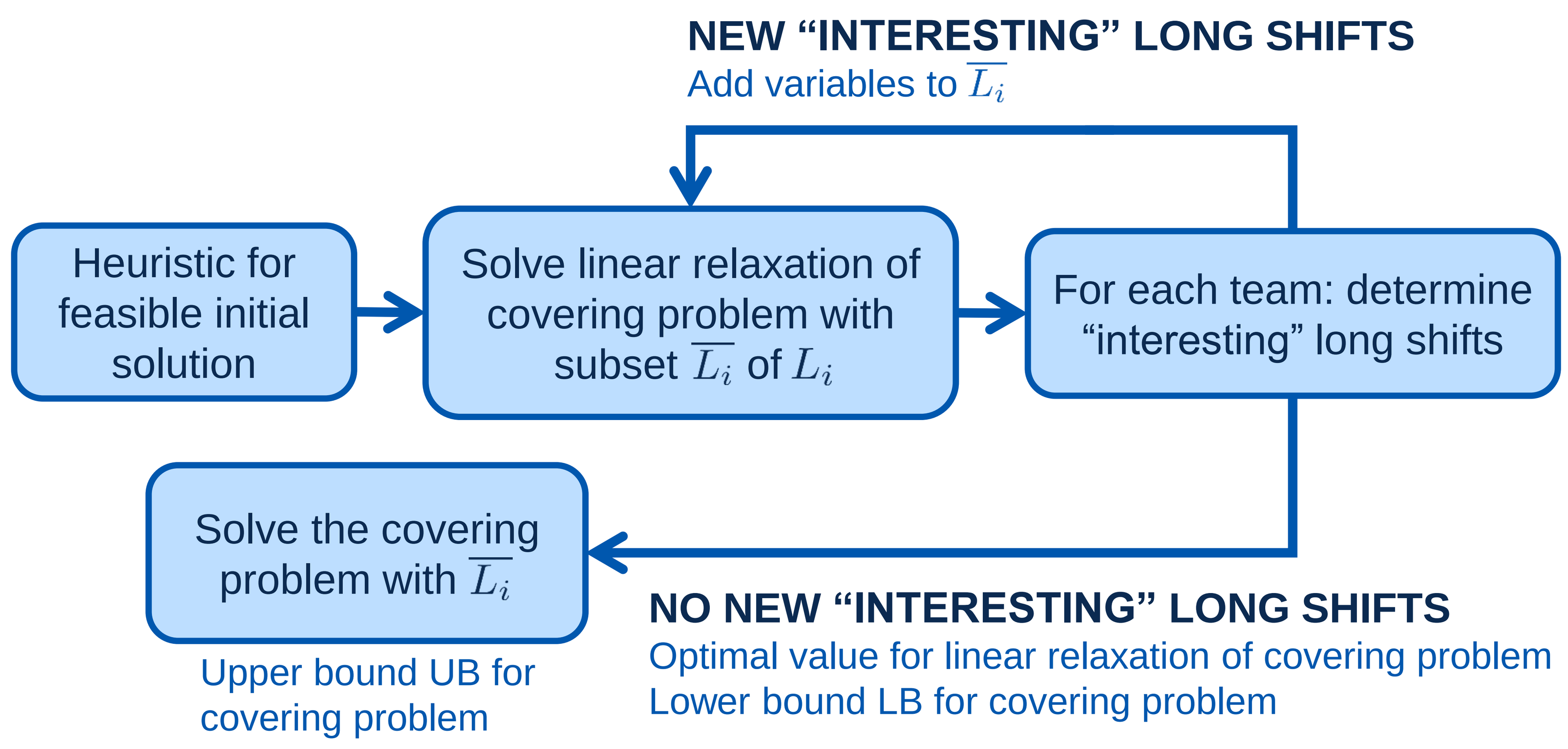
$$\begin{aligned} \text{Min} \quad & \sum_{i \in I} \sum_{\ell \in L_i} c_\ell x_{\ell,i} \\ \text{s.t.} \quad & \sum_{i \in I} \sum_{\substack{\ell \in L_i \\ t \in \ell}} x_{\ell,i} \geq 1 \quad \forall t \in T \\ & x_{\ell,i} \in \{0,1\} \quad \forall i \in I, \forall \ell \in L_i \end{aligned}$$

$t \in T$: train
$x_{\ell,i}$: the long shift $\ell \in L_i$ is selected for team $i \in I$
L_i : set of all feasible long shifts for team $i \in I$

Naïve enumeration/selection approach: non tractable



Resolution of the relaxation of the covering problem using **column generation**
- Determining "interesting" long shifts = solving the pricing sub-problem
- Pricing sub-problem = optimization problem with
  - Objective = "reduced costs"
  - Shift feasibility constraints
  - Long shift feasibility constraints

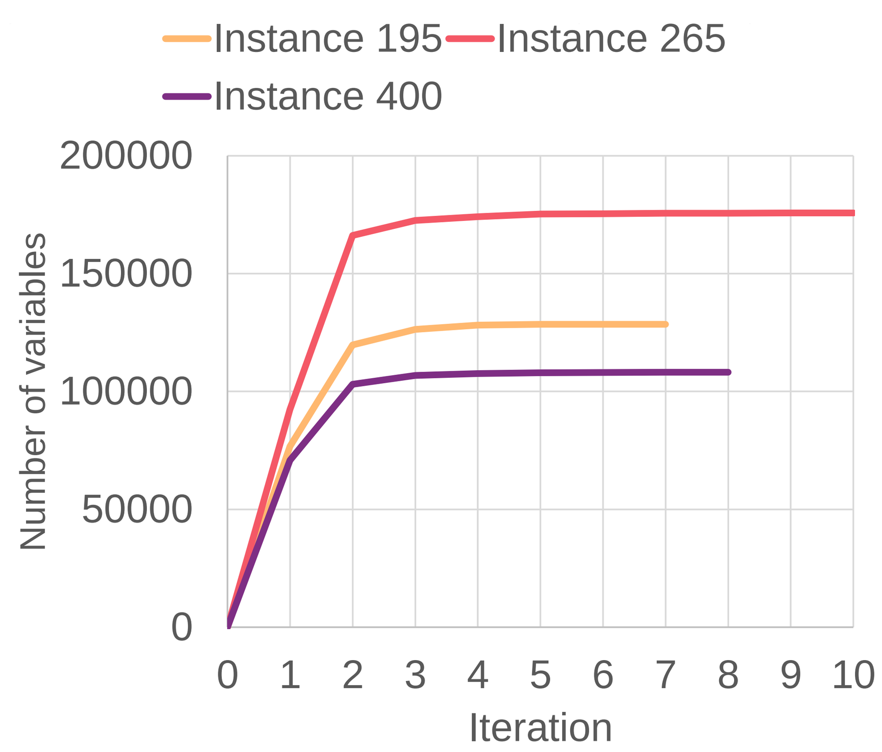


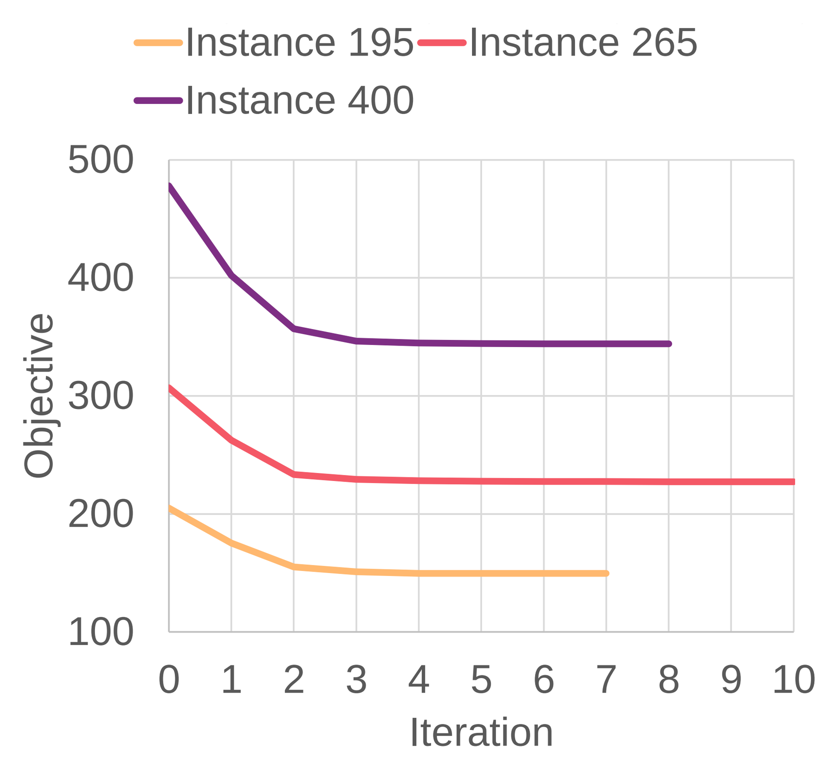
Solving the pricing sub-problem: contribution = modeling as Shortest Path with Constraints Problem
- Shortest Path with Constraints
  - NP-hard, bound-discarding enumeration algorithms[3]

Results

Results obtained on 3 instances:
- 195 trains, 265 trains: extracted from a national dataset with 1,805 trains
- 400 trains: regional dataset

	Crew scheduling + Crew rostering decomposition		Integrated Crew management					
	Objective	Total time	LB	UB	Total time	Number iterations	Number variables
Instance 195 trains	**176**	2s	149.9	**151 (-14%)**	15min31	8	128,527
Instance 265 trains	**261**	3s	227.3	**229 (-12%)**	28min13	11	175,719
Instance 400 trains	**402**	5s	344.2	**347 (-13%)**	32min46	9	108,150





Convergence of column generation with:
- Average gain of 13%
- Increased computation time
- Quality lower bound
- Tractable number of variables

Perspectives

- Speeding up the total computation time:
  - Analysis of the parameters in the column generation
    - Number of variables added at each iteration
    - Stopping sub-problem resolution before finding best path
  - Implicit description of graph in Shortest Path with Constraints for pricing sub-problem
- Running the algorithm on a full national dataset

Bibliography

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