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

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AGENDA
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• 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
INDUSTRIAL CONTEXT
RAILWAY PRODUCTION

Resources to Schedule

- Train paths
- Rolling stock
- Train drivers

Current Process

1. Forecast demand + commercial offers
2. Planning of railway Timetables
   - Train paths
3. Train duty generation
4. Rolling stock (locomotive) planning
5. Driver duty generation
6. Planning of train Drivers
   → Set of working days
INDUSTRIAL CONTEXT

INTEGRATED PLANNING PROBLEM: AN EXAMPLE

Too long to be covered by a single shift
→ 3 train drivers are required
INDUSTRIAL CONTEXT

INTEGRATED PLANNING PROBLEM: AN EXAMPLE

Covered by a single shift
→ Only 2 train drivers are required
INDUSTRIAL CONTEXT

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
INDUSTRIAL CONTEXT

LITERATURE REVIEW

Airline


Public transport

MODELING PROBLEM
MATHEMATICAL 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
A LAGRANGIAN RELAXATION HEURISTIC
A LAGRANGIAN RELAXATION HEURISTIC

PRESENTATION

• New approach to solve the integrated planning model: Lagrangian Relaxation
  • Relaxation of the coupling constraints
    → 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

Iteration $i$

Solving the relaxed problem

- Use of RollingStock_tool
  - Resolution of rolling stock planning problem with Lagrangian costs

- Use of Driver_tool
  - Resolution of driver planning problem with Lagrangian costs

- Update of Lagrangian multipliers

Constructing a feasible solution

- Use of Driver_tool
  - Resolution of driver planning problem with fixed rolling stock plan

Saving the best feasible integrated plan
## A Lagrangian Relaxation Heuristic

### Relaxation Schemes

<table>
<thead>
<tr>
<th>Relaxation schemes</th>
<th>Coupling constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Covering constraints (rolling stock)</strong></td>
</tr>
<tr>
<td><strong>Total relaxation</strong></td>
<td>Relaxed</td>
</tr>
<tr>
<td><strong>Partial driver relaxation</strong></td>
<td>Not relaxed</td>
</tr>
<tr>
<td><strong>Partial rolling stock relaxation</strong></td>
<td>Relaxed</td>
</tr>
<tr>
<td><strong>Lagrangian decomposition</strong></td>
<td>Not relaxed</td>
</tr>
</tbody>
</table>
A LAGRANGIAN RELAXATION HEURISTIC
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

<table>
<thead>
<tr>
<th></th>
<th>Instance 1</th>
<th>Instance 2</th>
<th>Instance 3</th>
<th>Instance 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling stock</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
</tr>
<tr>
<td>Drivers</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>Train paths</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Driver duties</td>
<td>32</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Rolling stock types</td>
<td>12</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Driver types</td>
<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
A LAGRANGIAN RELAXATION HEURISTIC

RELAXATION SCHEMES

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

<table>
<thead>
<tr>
<th>Relaxation schemes</th>
<th>(UB-LB)/UB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Instance 1</td>
</tr>
<tr>
<td>Total relaxation</td>
<td>0.05%</td>
</tr>
<tr>
<td>Partial driver relaxation</td>
<td>0.00%</td>
</tr>
<tr>
<td>Partial rolling stock relaxation</td>
<td>0.01%</td>
</tr>
<tr>
<td>Lagrangian decomposition</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
A LAGRANGIAN RELAXATION HEURISTIC
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:
→ Additional terms in the objective functions were required,
→ 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.
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
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.

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Instance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time horizon</td>
<td>1 week</td>
</tr>
<tr>
<td>Train paths</td>
<td>416</td>
</tr>
<tr>
<td>Rolling stock types</td>
<td>7</td>
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<tr>
<td>Rolling stock units</td>
<td>73</td>
</tr>
<tr>
<td>Driver depots</td>
<td>7</td>
</tr>
<tr>
<td>Drivers</td>
<td>81</td>
</tr>
</tbody>
</table>
Results are promising and significant gains are obtained.

<table>
<thead>
<tr>
<th>Results for one scenario</th>
<th>Iteration 1</th>
<th>Iteration 23</th>
<th>Iteration 24</th>
<th>Iteration 53</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling stock units</td>
<td>23</td>
<td>23</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Driver shifts</td>
<td>208</td>
<td>217</td>
<td>218</td>
<td>228</td>
</tr>
<tr>
<td>Uncovered train paths</td>
<td>25</td>
<td>13</td>
<td>7</td>
<td>2</td>
</tr>
</tbody>
</table>

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
CONCLUSIONS 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