Solving Large Real-Life Bus Driver Scheduling Problems with Complex Break Constraints

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ICAPS 2020
Problem Definition

- Assign bus drivers to predetermined bus tours

<table>
<thead>
<tr>
<th>ℓ</th>
<th>tour&lt;sub&gt;ℓ&lt;/sub&gt;</th>
<th>start&lt;sub&gt;ℓ&lt;/sub&gt;</th>
<th>end&lt;sub&gt;ℓ&lt;/sub&gt;</th>
<th>startPos&lt;sub&gt;ℓ&lt;/sub&gt;</th>
<th>endPos&lt;sub&gt;ℓ&lt;/sub&gt;</th>
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<td>4</td>
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<td>397</td>
<td>454</td>
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**Problem Definition**

- **Assign bus drivers to predetermined bus tours**

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**Distance matrix**

- $d_{i,i}$: Change vehicle at same position
- $d_{i,j}$ with $i \neq j$: Move to different position
Shift Constraints

Driving time $D_s$

Working time $W_s$

Total time $T_s$

Problem Definition

Problem Analysis

Results

Problem Input

Constraints

Solution

Start work $l_1$

Rest $\ell_1$

Passive ride $\ell_2$

Rest $\ell_2$

End work $\ell_3$

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Bus Driver Scheduling with Complex Break Constraints
Shift Constraints

- \( T_s \leq T_{\text{max}} = 14 \text{ hours} \)
Driving Time Constraints

- $D_s \leq D_{\text{max}} = 9 \text{ hours}$
- Regular driving breaks after at most 4 hours:

\[
\begin{align*}
\leq 4 \cdot 60 & \geq 30 \\
\geq 20 & \geq 20 \\
\geq 15 & \geq 15 & \geq 15
\end{align*}
\]
Working Time Constraints

- Working time $W_s$
- Driving time $D_s$
- Total time $T_s$
- Break $\geq 3$ hours: shift split

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**Working Time Constraints**

- Break $\geq 3$ hours: shift split

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Bus Driver Scheduling with Complex Break Constraints
Working Time Constraints

- $W_s \leq W_{max} = 10$ hours
- At least $W_{min} = 6.5$ hours is paid
- Required rest break:
  - $W_s < 6$ hours: no rest break
  - $6 \leq W_s \leq 9$ hours: at least 30 minutes
  - $W_s > 9$ hours: at least 45 minutes
- 1 part $\geq 30$ minutes + parts $\geq 15$ minutes
- First part no later than 6 hours
- Maximum amount of unpaid rest: 1 or 1.5 hours

\[\begin{array}{c}
2 \cdot 60 \\
paid rest
\end{array} \quad \begin{array}{c}
\text{unpaid rest} \\
\text{centered 30 min break}
\end{array} \quad \begin{array}{c}
2 \cdot 60 \\
paid rest
\end{array}\]
Solution

$$\text{objective} = \sum_s 2 \cdot W'_s + T_s + \text{ride}_s + 30 \cdot \text{change}_s + 180 \cdot \text{split}_s$$
Contributions

- Analysis of problem characteristics
- New benchmark data set
- Solution method based on construction heuristic and simulated annealing
- Evaluation of employee satisfaction criteria
Figure: Demand distribution for instance 100_50.
Many options to distribute split breaks

**Problem Definition**

**Problem Analysis**

**Results**

**Contributions**

**Characteristics**

**Benchmark Instances**

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Benchmark Instances

- New instance generator
- Publicly available instance set\(^1\)
- 50 instances
- 10 different sizes: 10 tours (about 70 legs) to 100 tours (almost 1000 legs)

\(^1\)https://cdlab-artis.dbai.tuwien.ac.at/papers/sa-bds/
Importance of Employee Satisfaction

<table>
<thead>
<tr>
<th></th>
<th>Working time</th>
<th>Span</th>
<th>Passive ride</th>
<th>Tour changes</th>
<th>Shift splits</th>
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<tbody>
<tr>
<td>Combined</td>
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<td>4611</td>
<td>66</td>
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<tr>
<td>Working time Change</td>
<td>−3.3%</td>
<td>+83.7%</td>
<td>+468.2%</td>
<td>+850%</td>
<td>+∞%</td>
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<tr>
<td>Working time</td>
<td>4680</td>
<td>8470</td>
<td>375</td>
<td>19</td>
<td>13</td>
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</table>
Solution Method

- **Construction Heuristic**
  - Assign to employee with least cost increase
  - Assign consecutive bus legs to same employee
  - Rebalance shifts

- **Simulated Annealing**
  - Swap single / multiple bus legs
  - High probabilities for shifts with high penalties
  - Simulated Annealing or Randomized Hill Climber
## Results

<table>
<thead>
<tr>
<th>Instances</th>
<th>Construction Heuristic</th>
<th>Simulated Annealing</th>
<th>Hill-climbing</th>
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<tbody>
<tr>
<td></td>
<td>Time</td>
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<td>Value</td>
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</table>

- 4 out of 5 best results for size 10 are optimal
- Gap of 3-5 % to optimum for medium size instances
- 4 % improvement to human expert solutions for very large instance with 2700 bus legs
- Improving 4 out of 10 instances on problem from Brasil
Summary

- Formalization of complex Bus Driver Scheduling Problem
- Analysis of problem characteristics
- Benchmark data set for future comparison
- Real-life objective including employee satisfaction
- Meta-heuristic for high-quality solutions
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Thank you for your attention.
Are there any questions?