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

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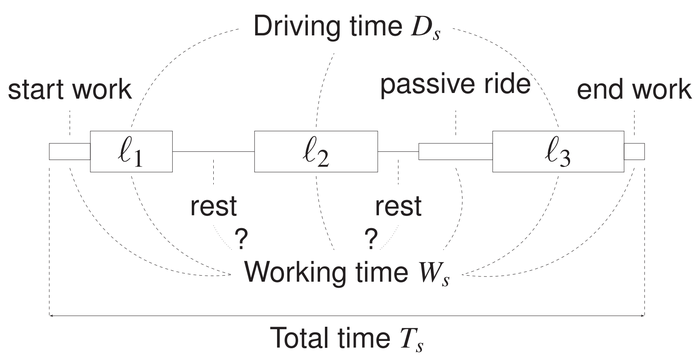
Problem Definition

- Input: Predetermined bus tours

ℓ	$tour_\ell$	$start_\ell$	end_ℓ	$startPos_\ell$	$endPos_\ell$
1	1	244	298	0	5
2	1	301	345	5	5
3	1	349	393	5	5
4	1	397	454	5	0

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



- **Goal:** Assign drivers to all bus legs satisfying all constraints
- **Objective function:**
  $\sum_s 2 \cdot W'_s + T_s + ride_s + 30 \cdot change_s + 180 \cdot split_s$
- **Contributions:**
  - Analysis of problem characteristics
  - New benchmark data set
  - Solution method based on construction heuristic and Simulated Annealing
  - Evaluation of employee satisfaction criteria

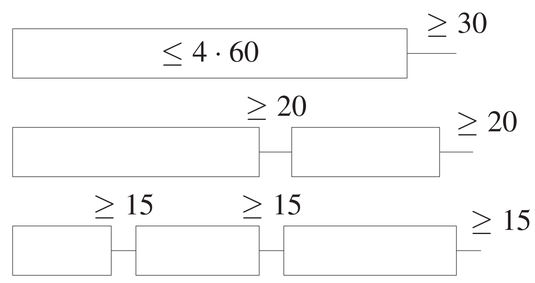
Constraints

Total Time

- $T_s \leq T_{max} = 14$ hours

Driving Time

- $D_s \leq D_{max} = 9$ hours
- Different options for regular driving breaks after at most 4 hours:

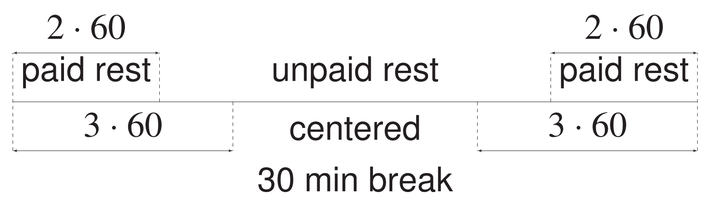


Shift Splits

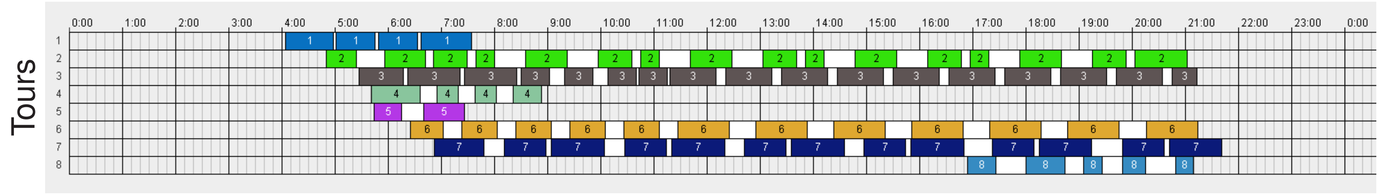
- Break ≥ 3 hours: shift split

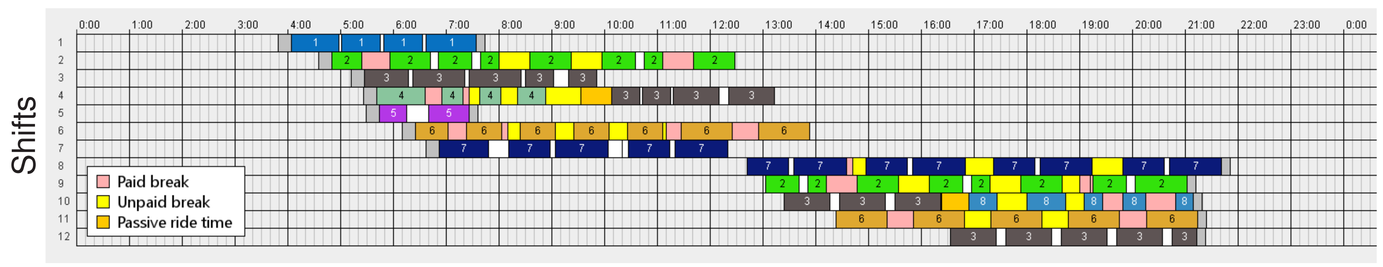
Working Time

- $W_s \leq W_{max} = 10$ hours
- At least $W_{min} = 6.5$ hours is paid
  - $W'_s = \max\{W_s, 390\}$
- Required rest break:
  - $W_s < 6$ hours: no rest break
  - 6 hours $\leq W_s \leq 9$ hours: at least 30 minutes
  - $W_s > 9$ hours: at least 45 minutes
- 1 part ≥ 30 minutes + additional parts ≥ 15 minutes
- First part no later than 6 hours
- Max. 1 or 1.5 hours unpaid rest depending on position of 30 min break



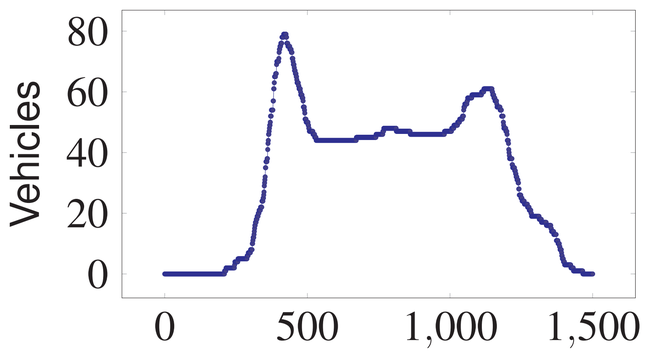
Solution





Instances

- Typical demand distribution:



- Many options to distribute split breaks due to idle times in vehicle tours

Benchmark Instances

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

Evaluation

Solution Method

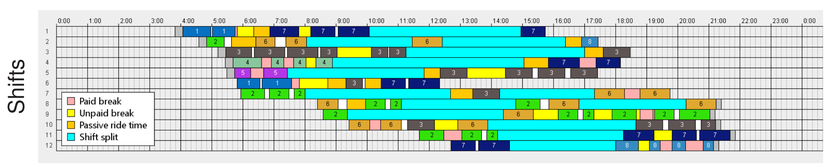
- Construction Heuristic
  - Assign to employee with least cost increase
  - Assign consecutive bus legs to same employee
  - Rebalance shifts
- Simulated Annealing
  - Swap single / multiple bus legs
  - High probabilities for shifts with high penalties
  - Simulated Annealing or Randomized Hill Climber

Successful Application

- 4 % improvement to human expert solutions for very large instance with 2700 bus legs
- Improving 4 out of 10 instances on problem from Brasil

Importance of Employee Satisfaction

- Only optimizing working time objective has huge cost on other objectives:



Results on Benchmark Instances

	Construction Heuristic			Simulated Annealing				Hill-climbing			
Instances	Time	Empl.	Value	Time	Empl.	Best	Mean	Time	Empl.	Best	Mean
10	0.2	12.2	15747.2	22.8	11.6	**14717.4**	14740	7.8	12	14904.4	14988
20	0.54	24.2	32627.8	62.2	22.6	**30860.6**	30971	28	22.8	30931.4	31276
30	1.68	41	54141.6	108.8	38.4	**50947.4**	51258	99.4	38.8	51544.2	51917
40	3.1	55	73417	267	52.2	**69119.8**	69380	151.2	52	69533.6	71338
50	6.26	68.2	91372.8	329	66	87013.2	87557	295.4	65.8	**86718.6**	87263
60	10.62	80.8	109293.8	543.6	78.8	103967.6	104333	432.8	79	**103780**	104296
70	18	92.8	130024.2	751.4	90.4	**122753.6**	123226	718.6	90.4	122912.8	123304
80	26.54	107	148889	1140.2	104.6	140482.4	140914	959.4	104	**139765.2**	140508
90	37.62	120.2	165171.6	1453	118	156385	157426	1516.6	117.2	**156239.4**	156863
100	48	130.4	183456.4	1449.4	128.2	173524	174502	1483.2	127.4	**172327.8**	172909

- 4 out of 5 best results for size 10 are optimal
- Gap of 3-5 % to optimum for medium size instances

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