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

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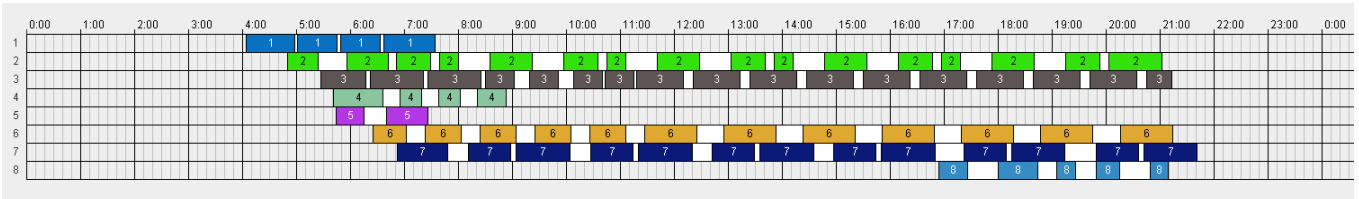
Problem Definition

- Assign bus drivers to 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

Tours



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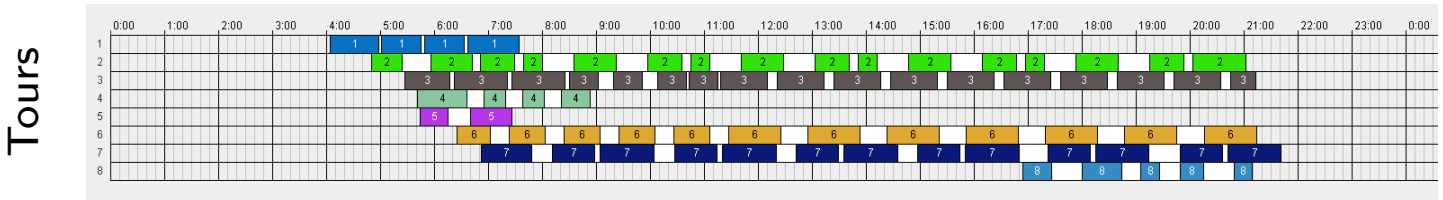
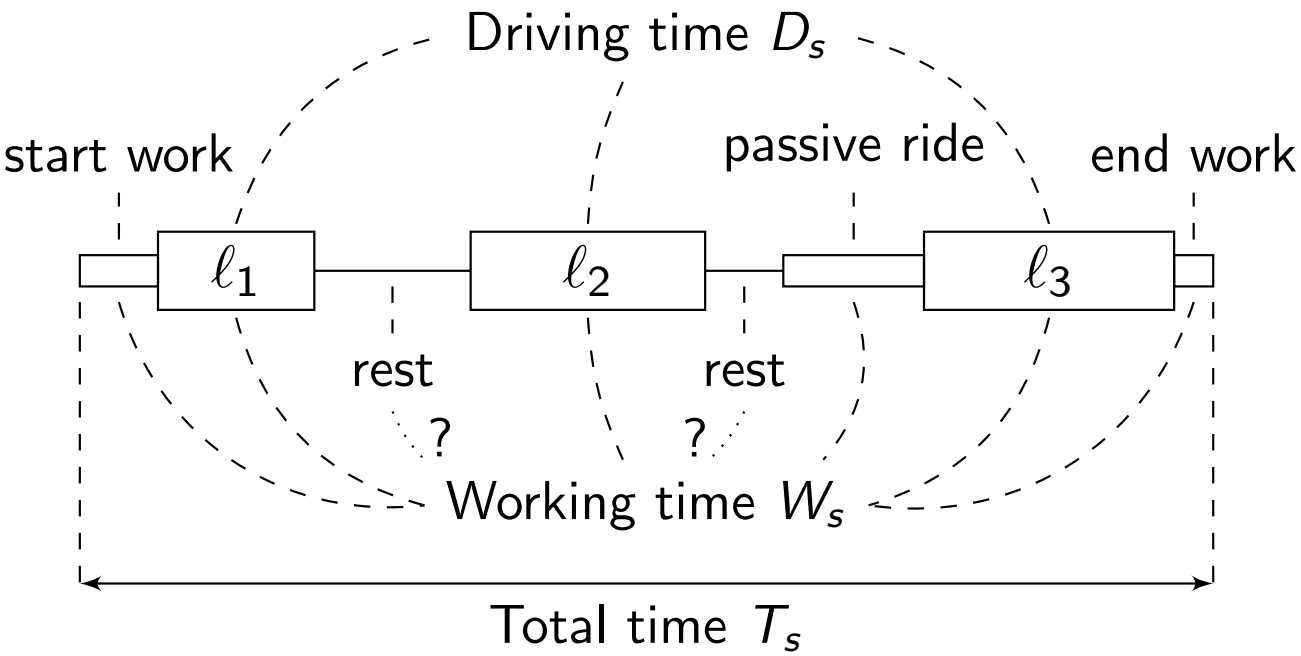


- Distance matrix
  - $d_{i,i}$: Change vehicle at same position
  - $d_{i,j}$ with $i \neq j$: Move to different position

Shift Constraints



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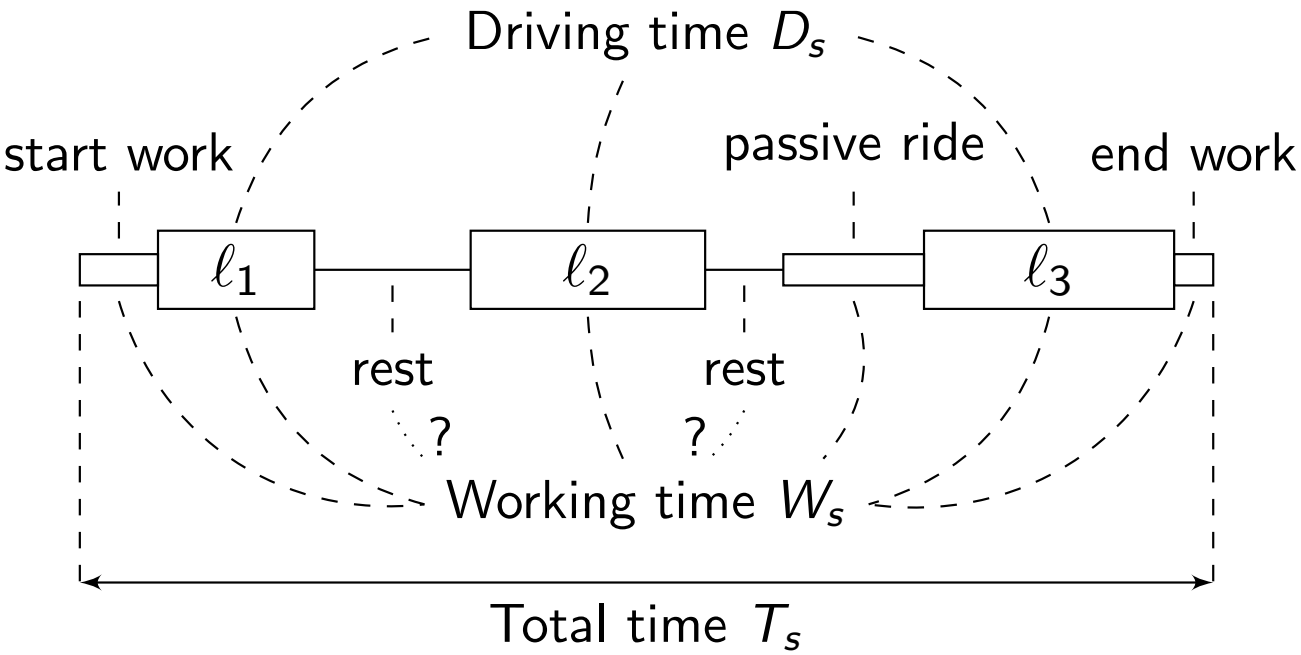
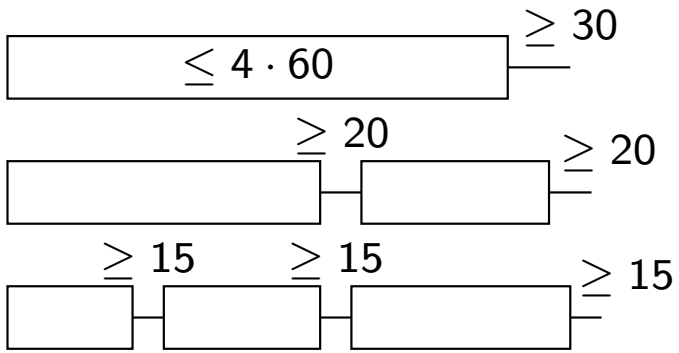


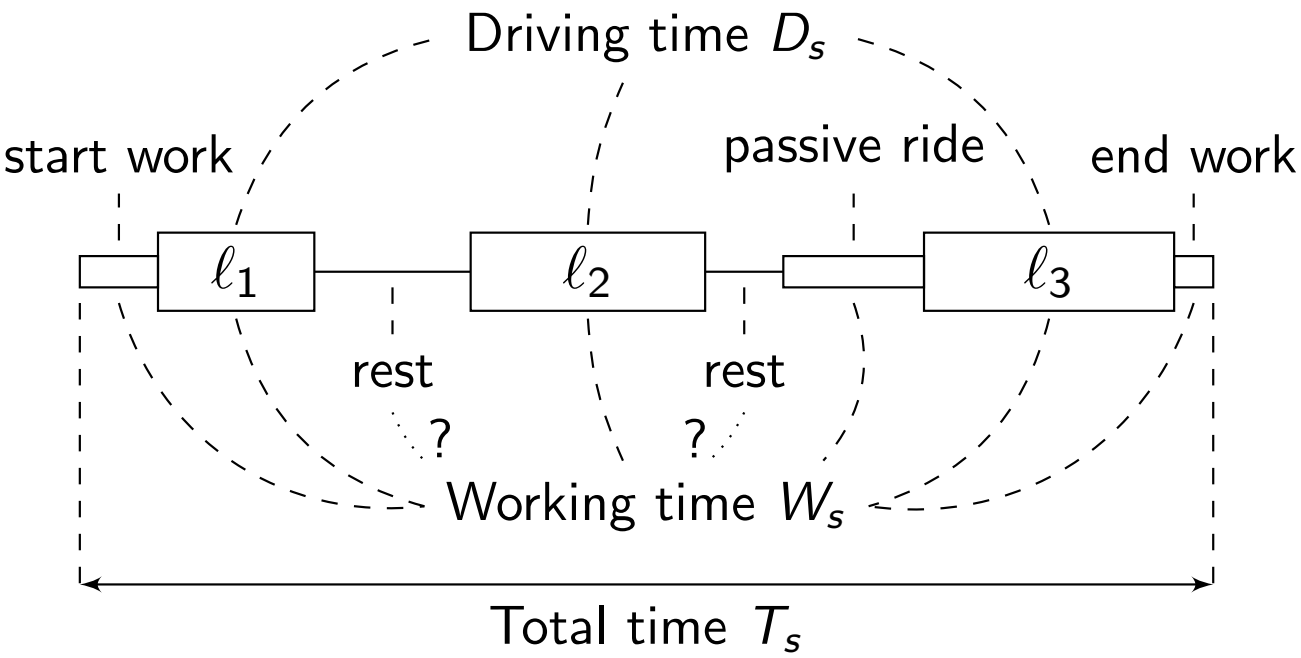
- $T_s \leq T_{max} = 14$ hours

Driving Time Constraints

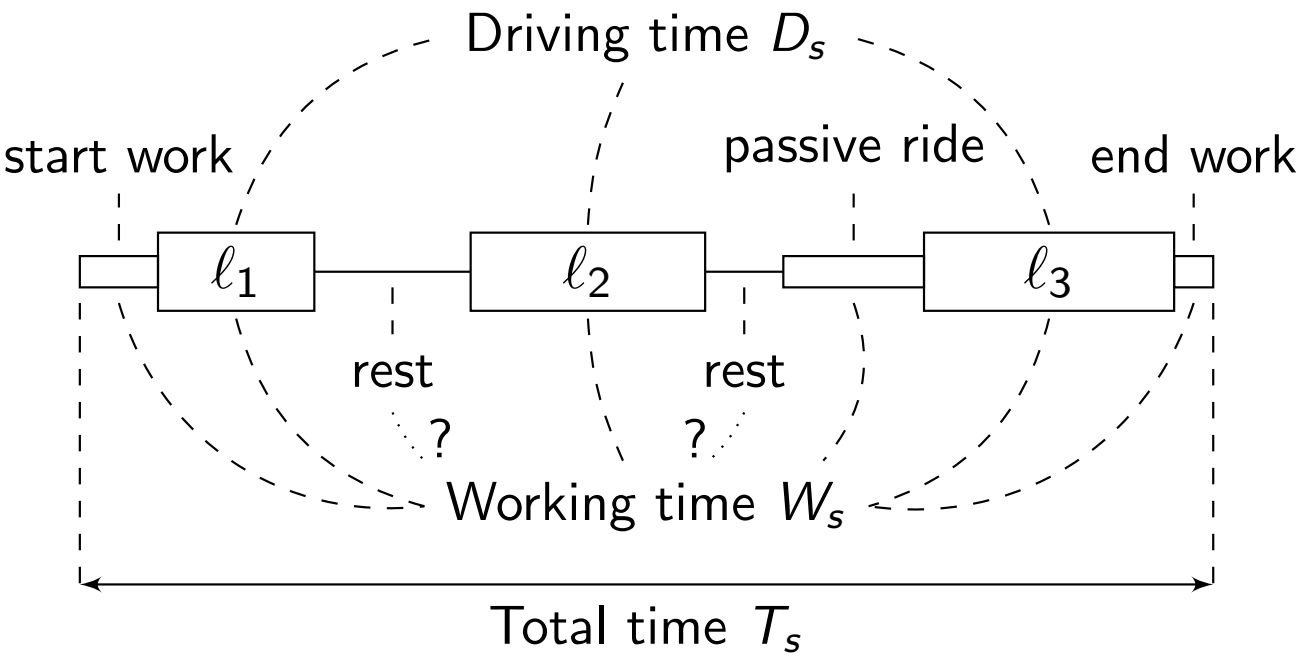
- $D_s \leq D_{max} = 9$ hours
- Regular driving breaks after at most 4 hours:



Working Time Constraints



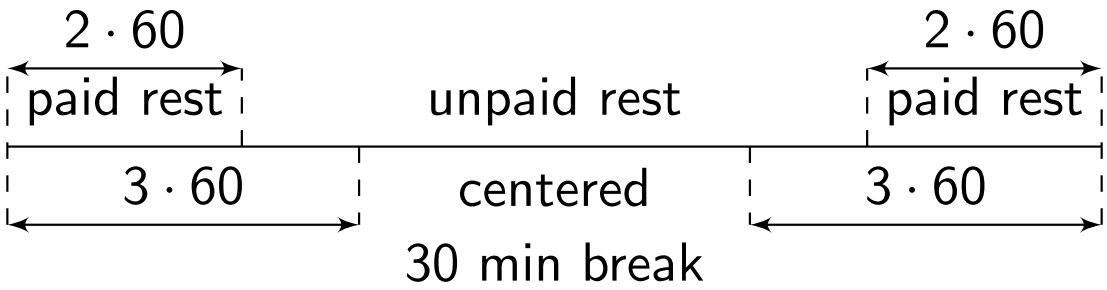
Working Time Constraints



- Break ≥ 3 hours: shift split

Working Time Constraints

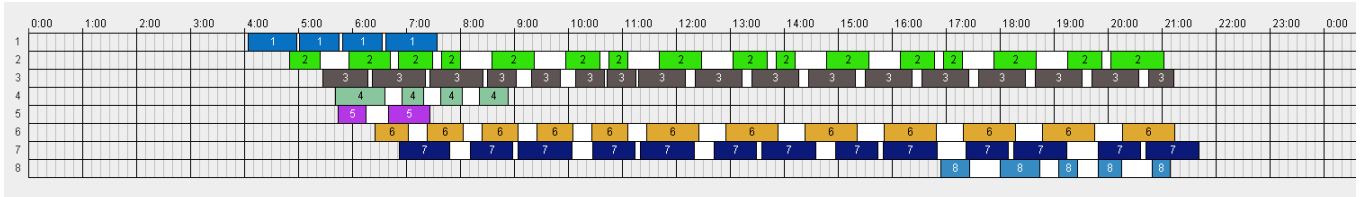
- $W_s \leq W_{max} = 10$ hours
- At least $W_{min} = 6.5$ hours is paid
- Required rest break:
  - $W_s < 6$ hours: no rest break
  - 6 hours $\leq W_s \leq 9$ hours: at least 30 minutes
  - $W_s > 9$ hours: at least 45 minutes
- 1 part ≥ 30 minutes $+$ parts ≥ 15 minutes
- First part no later than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



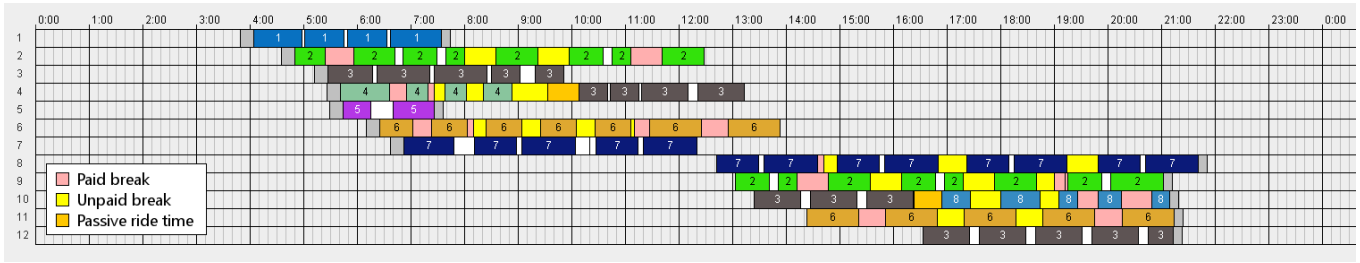
Solution

$$objective = \sum_s 2 \cdot W'_s + T_s + ride_s + 30 \cdot change_s + 180 \cdot split_s$$

Tours



Shifts



Contributions

- Analysis of problem characteristics
- New benchmark data set
- Solution method based on construction heuristic and simulated annealing
- Evaluation of employee satisfaction criteria

Demand Distribution

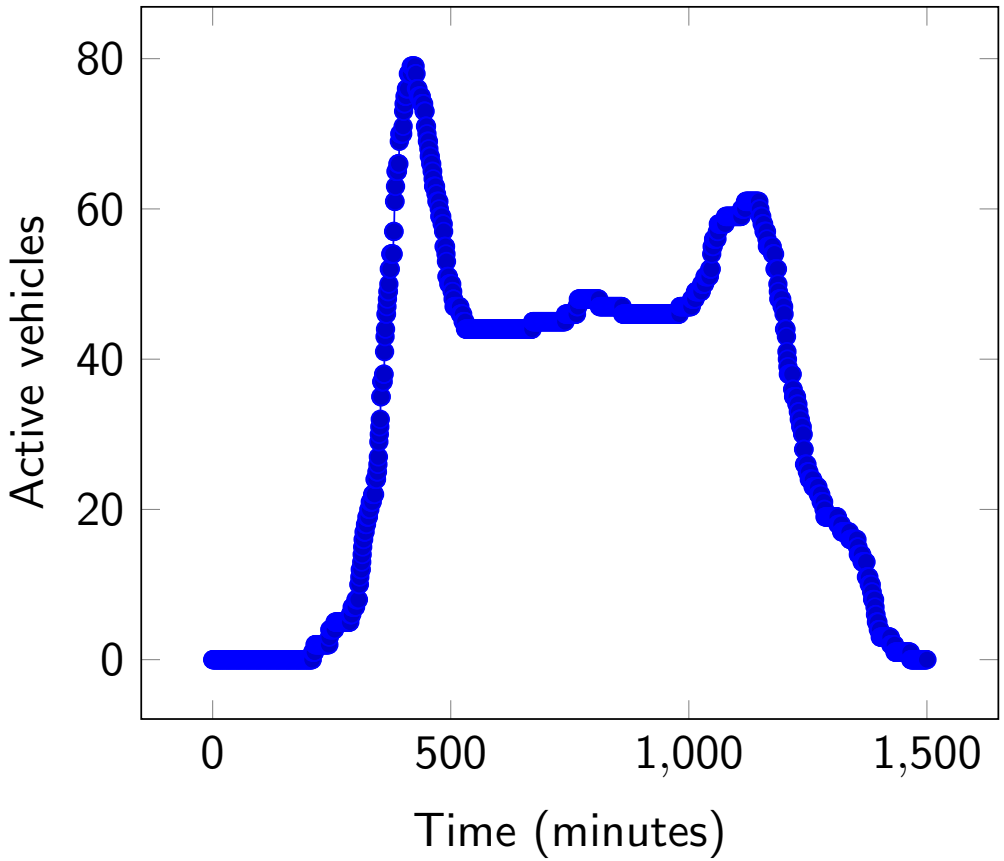
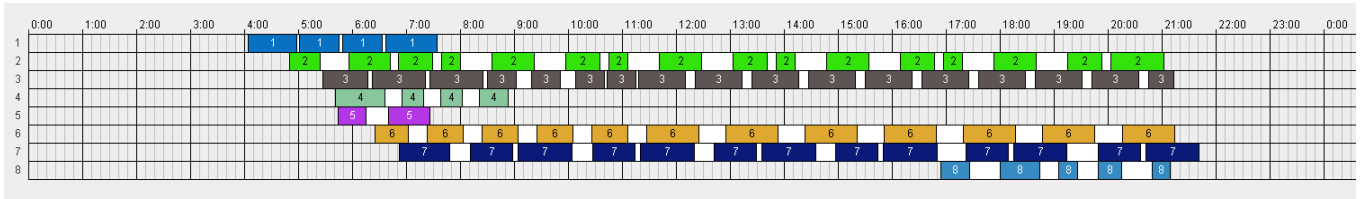


Figure: Demand distribution for instance 100_50.

Waiting Times

- Many options to distribute split breaks

Tours



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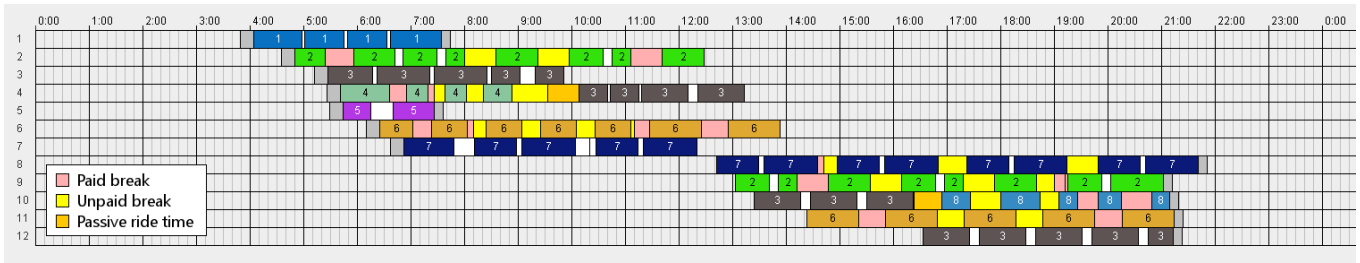


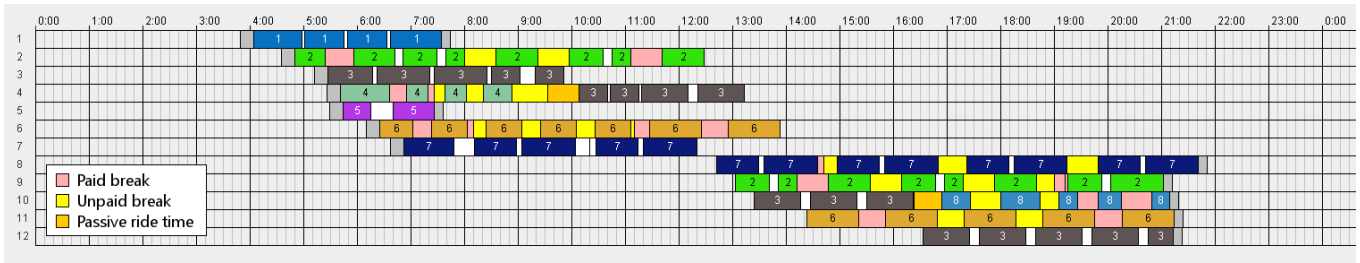
Benchmark Instances

- 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

Shifts



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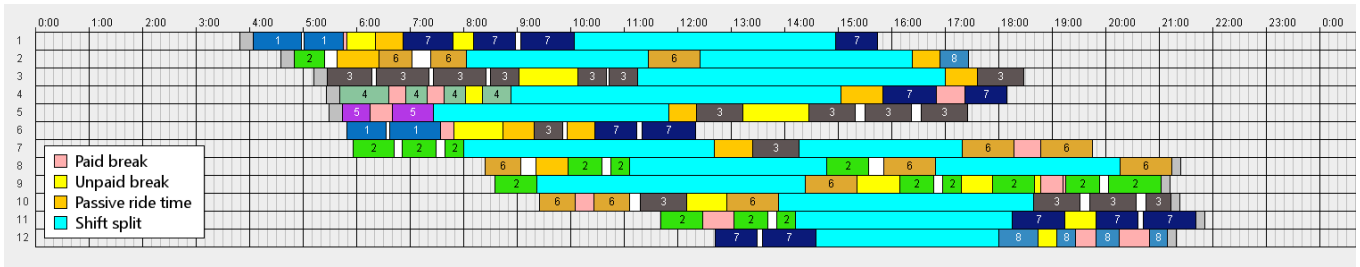

	Working time	Span	Passive ride	Tour changes	Shift splits
Combined	4840	4611	66	2	0
Working time	4680	8470	375	19	13
Change	−3.3%	+83.7%	+468.2%	+850%	+∞%

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

	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
- 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?