Rollout-Based Charging Strategy for Electric Trucks with Hours-of-Service Regulations

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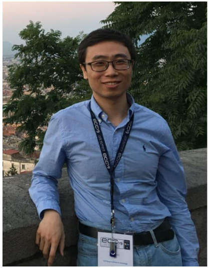
Collaborators



Dr. Yuchao Li

Prof. Karl Henrik Johansson

Prof. Jonas Mårtensson

Road Freight Electrification

Charging of heavy, electric truck

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Positive impacts:

1) Reduce air and noise pollution
2) Mitigate climate change
3) Cope with energy shortages
4) Save operational cost
5) Lead to sustainable transport
6) ...

Truck electrification is lagging far behind...

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	USA	EU	China
Continuous driving time (max.)	8 h	4.5 h	4 h
Mandatory rest time (min.)	30 min	45 min	20 min
Daily driving time (max.)	11 h	9 h	10 h

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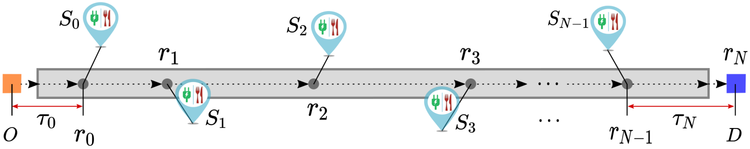
Hours-of-service (HoS) regulations

Problem: How to design reliable and efficient **charging strategies** for electric trucks to complete delivery missions on time while aligning with the HoS regulations?

Route Model



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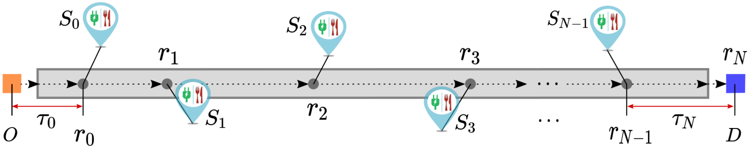


- Decision variables:

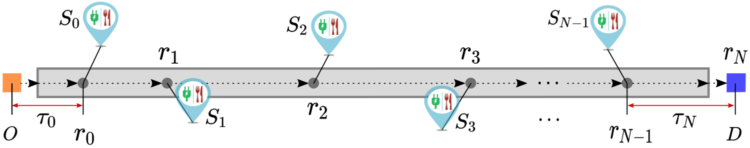
$$b_k, \tilde{b}_k \in \{0, 1\}, \quad t_k \in \Re_+$$

b_k: whether to charge at the station S_k

$\tilde{b}_k$: whether to rest at S_k

t_k: how long to charge the truck at S_k if $b_k = 1$

Dynamics



- The **remaining battery** upon arriving at r_{k+1}:

$$e_{k+1} = e_k + b_k \Delta e_k - \bar{P}\Big(2(b_k \vee \tilde{b}_k) d_k + \tau_{k+1}\Big)$$

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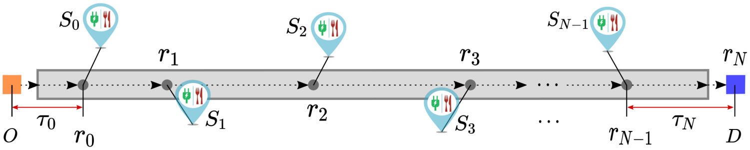

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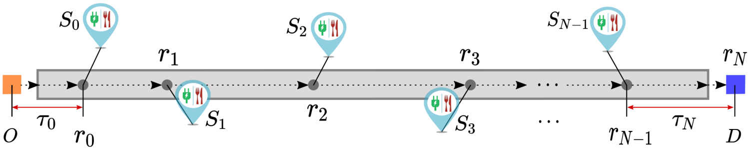

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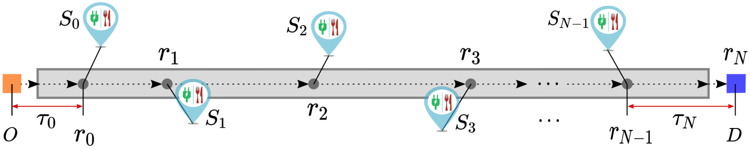
- The **consecutive driving time** at r_{k+1}:

$$c_{k+1} = \tau_{k+1} + (b_k \vee \tilde{b}_k) d_k + \big(1 - \tilde{b}_k\big)\big(c_k + b_k d_k\big)$$

Constraints



- Sufficient energy to reach S_k: $e_k \geq$ battery for safe operation$+\bar{P}d_k$

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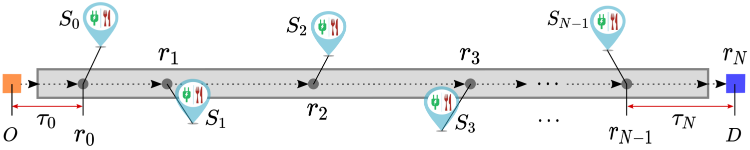

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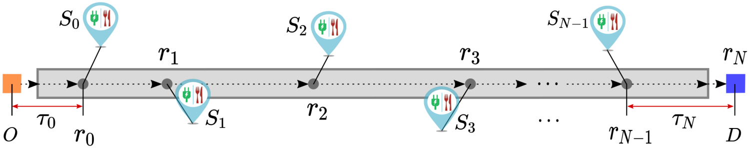

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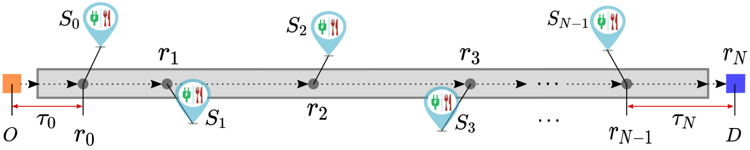

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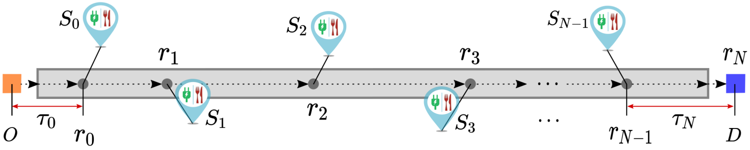

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- Delivery deadline:

$$\sum_{k=0}^{N-1} \max \left\{ b_k \left(2d_k + p_k + t_k\right), \tilde{b}_k \left(2d_k + T_r\right) \right\} \leq \Delta T$$

The Optimal Charging Problem

$$\min_{\{(b_k, \tilde{b}_k, t_k)\}_{k=0}^{N-1}} \quad F\left(b_0, \tilde{b}_0, t_0, \ldots, b_{N-1}, \tilde{b}_{N-1}, t_{N-1}\right)$$

$$= \sum_{k=0}^{N-1} \xi_k b_k t_k + \sum_{k=0}^{N-1} \max\left\{ b_k(2d_k + p_k + t_k), \tilde{b}_k(2d_k + T_r) \right\} \epsilon$$

$$\mathrm{s.t.} \quad \text{dynamics and constraints introduced earlier}$$

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  - It cannot be directly solved by many standard solvers
  - Exact solutions: iterate over all possible combinations of integer variables
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  - Linear transformation: it may still require an exponential number of iterations [see, p.480][1]

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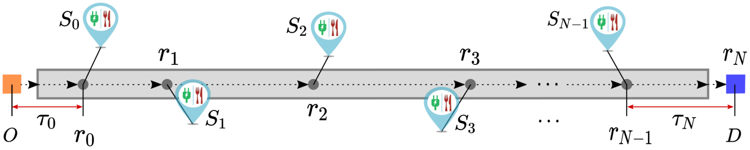
Rollout-Based Approximate Solution



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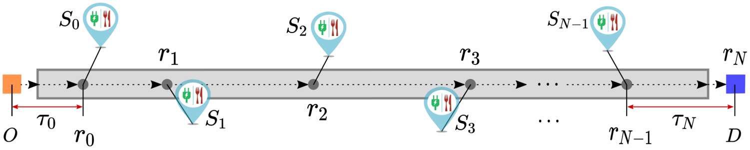

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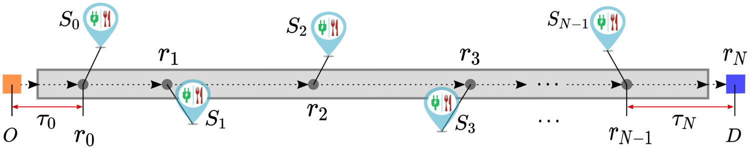

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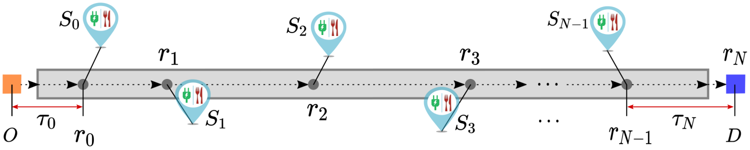

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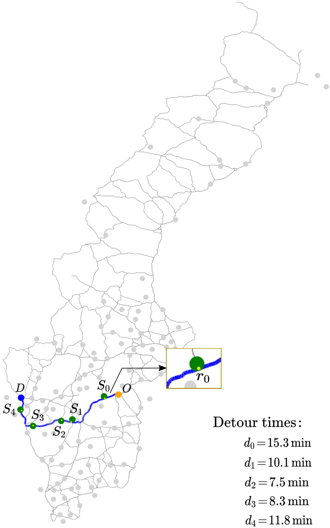
- Complexity: it requires solving at most $4N$ continuous optimization problems

Simulation Studies



The route of one truck.

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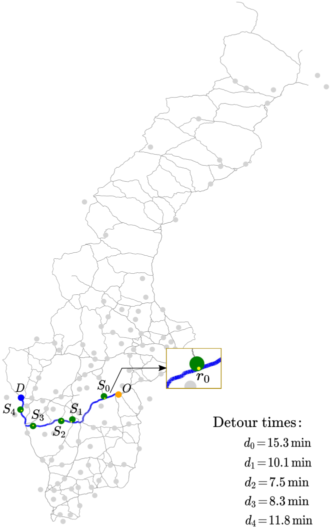

The route of one truck.

- Routes are obtained via *OpenStreetMap*
- Data for electric trucks manufactured by Scania
  - $P_k = 300$ kW
  - $P_{\text{max}} = 375$ kW
  - $e_f = 468$ kWh
  - $\bar{P} = 1.83$ kWh/min
  - $p_k = 6$ min
  - $\xi_k = 0.36$ €/kWh, $\epsilon_k = 0.4$ €/min
- EU's HoS regulations

Simulation Studies

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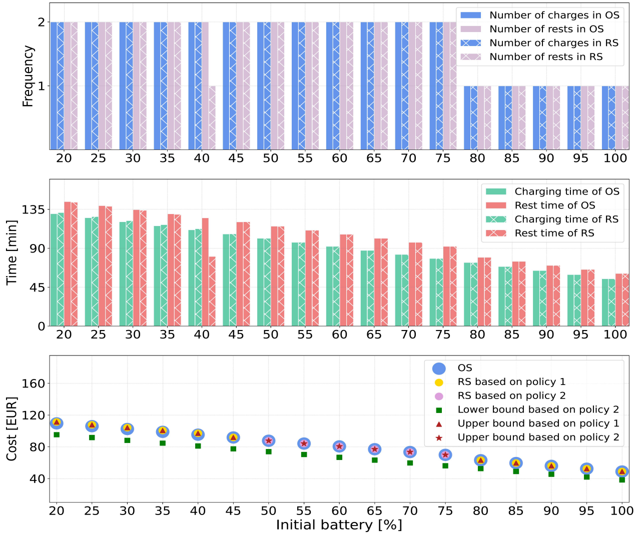
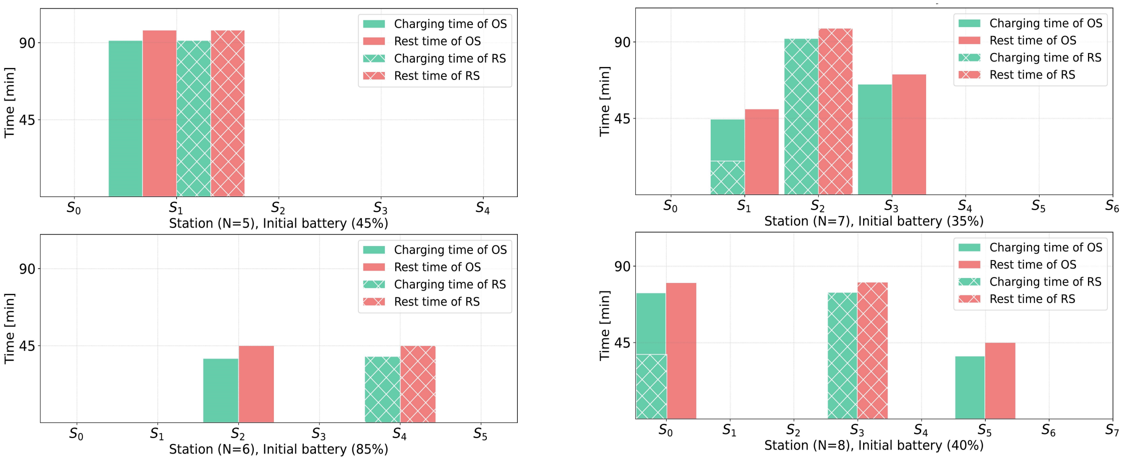


N=8

Simulation Studies

- Comparison between the optimal solution (OS) and rollout solution (RS).



Simulation Studies

Table: Comparison between the OS and RS

N	5	6	7	8	9	10
Average optimality gap-RS [%]	0	0.55	0.72	0.49	0.03	0.42
Average optimality gap-UB [%]	1.04	5.46	2.23	0.48	4.28	1.72
Average computation time of RS [s]	0.34	0.42	0.57	0.65	0.84	1.43
Average computation time of OS [min]	0.32	1.34	5.45	24.02	98.50	413.68

- The optimality gap between the RS and OS:

$$\frac{(F(RS) - F(OS)) \times 100}{F(OS)}$$

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Future work:

- Developing optimal charging strategies with limited charging resources at stations