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Value of Modelling Constraints in Generation Scheduling

Towards Computationally Efficient Scheduling Proxies

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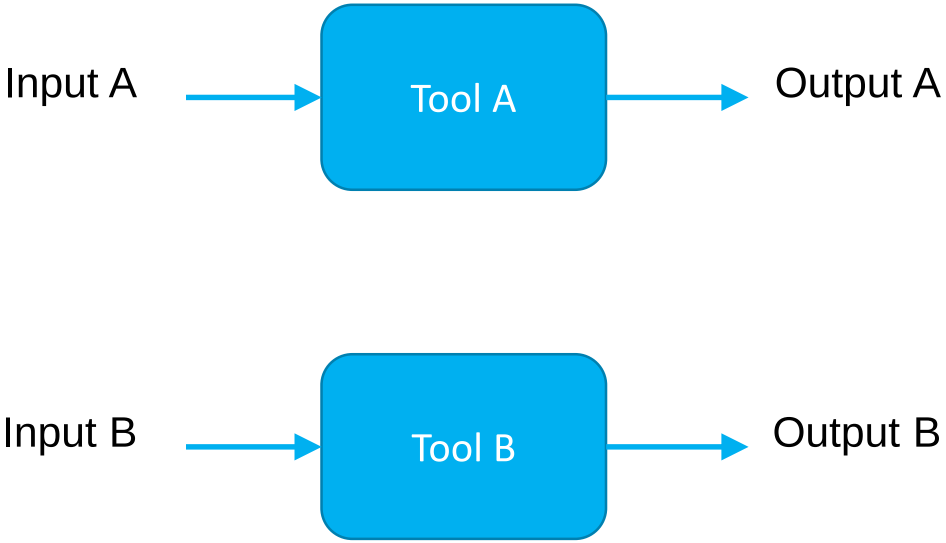
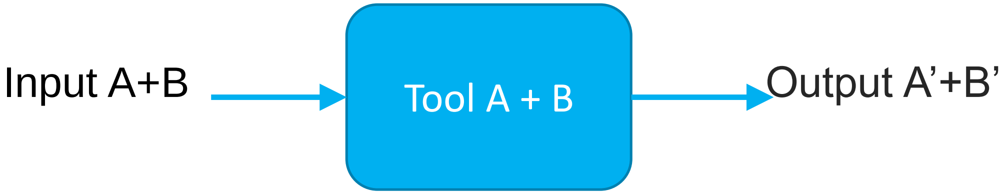
Background: Link Power System Tools

- Problem:

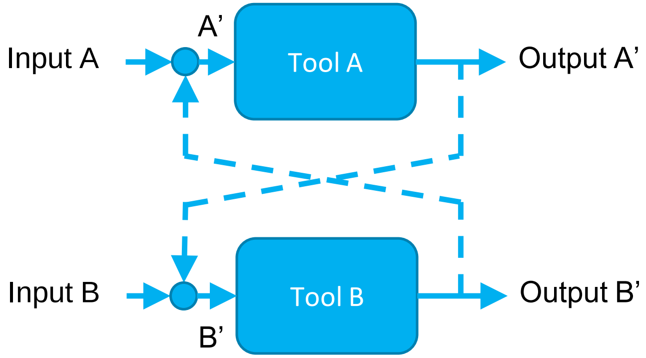
  Two tools → two different domains:



- Single shot solution (Big computer!)



- Co-simulation



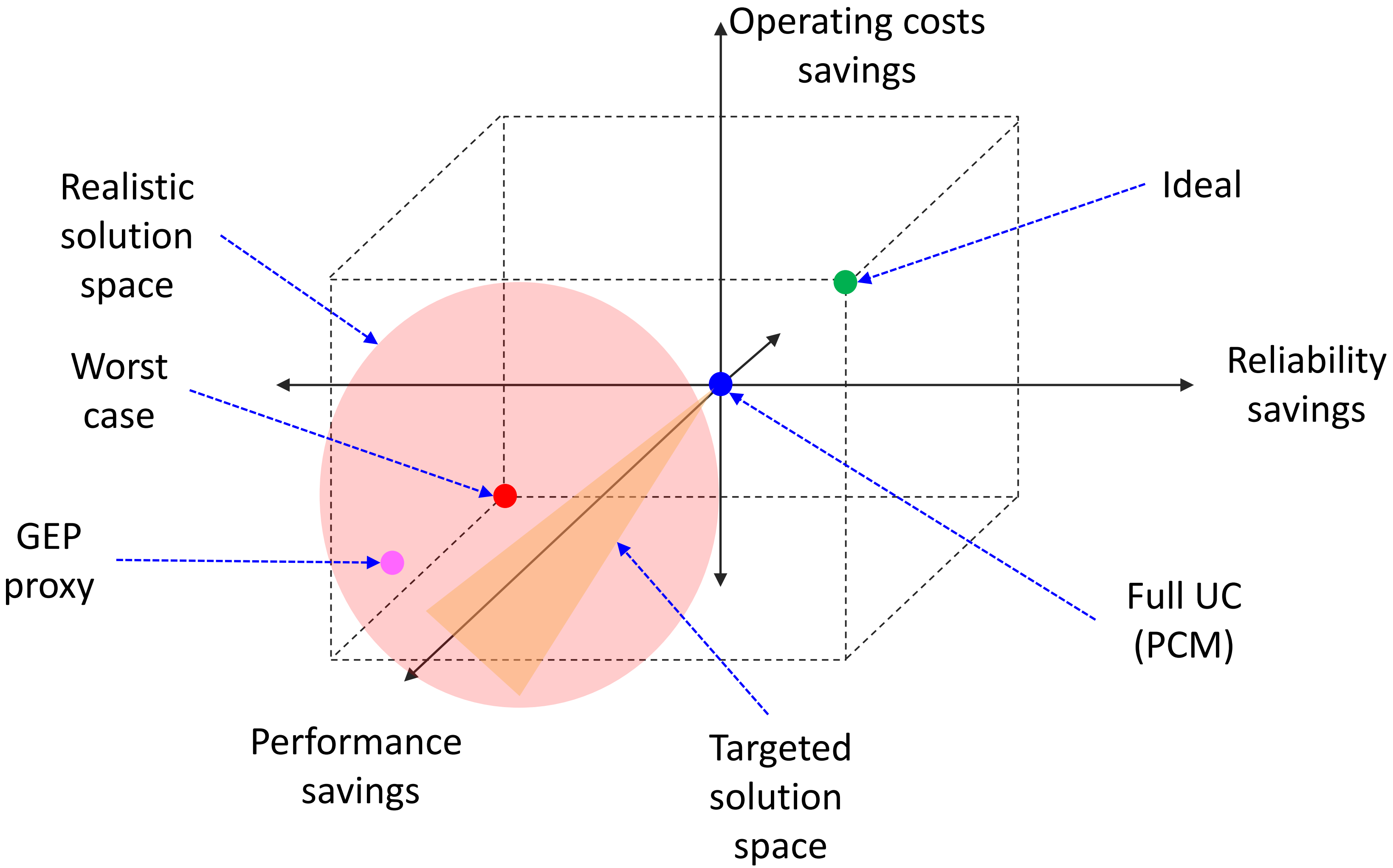
- Simplify the problem: Proxy

Introduction

- Modeling accuracy in UC formulation increases computational burden
- Expansion tools need to explore long time horizons (20 years or more) and over multiple scenarios
- Expansion tools resort to simplified versions of UC (convolved LDCs, ignore binaries and constraints, temporal aggregation, cluster generation sets, among others)
  - Gain computational speed
  - Sacrifice solution accuracy
- Worked fairly well in the past, with “well-behaved” and predictable load patterns
- As the penetration of RES increases in the system, variability and uncertainty require greater degrees of flexibility
- The introduction of emerging technologies such as storage require modelling inter-temporal couplings

Problem

- Find the tradeoffs between model accuracy and computational tractability



Proposed Method

Step 1:
Simplified UC

Speed up calculations

Modelling assumptions

Enforce desired constraint:

a) Min. up & down times
b) Reserves requirements
c) Start-up costs
d) Minimum stable generation (P_{min})
e) Ramp rates

Step 2:
Full UC formulation

Fixed schedule from Step 1

Enforce all UC constraints

Determine UC violations

Step 3:
Cost and violations

Accommodate RT deviations

Determine dispatch and reserve violations

Formulation

Full UC formulation:

$$\min_{u,p}\left\{\sum_{i\in I} c_i(u_{i,t},p_{i,t})\right\}$$

$$L_t - p_t^{\text{RES}} - \sum_{i\in I} p_{i,t} = 0 \quad \forall t\in T$$

$$u_i\cdot P_i^{\min} \le p_{i,t} \le u_i\cdot P_i^{\max} \quad \forall t\in T$$

$$\mathbf{h}(\mathbf{u},\mathbf{p}) \le 0$$

$$u\in\{0,1\}$$

$$p\in\mathbb{R}^{0+}$$

Simplified UC Variants

{Enforce some constraint(s)}

Most simplified generation "scheduling":

$$\min_{p}\left\{\sum_{i\in I} c_i(p_{i,t})\right\}$$

$$L_t - p_t^{\text{RES}} - \sum_{i\in I} p_{i,t} = 0 \quad \forall t\in T$$

$$0 \le p_{i,t} \le P_i^{\max} \quad \forall t\in T$$

$$p\in\mathbb{R}^{0+}$$

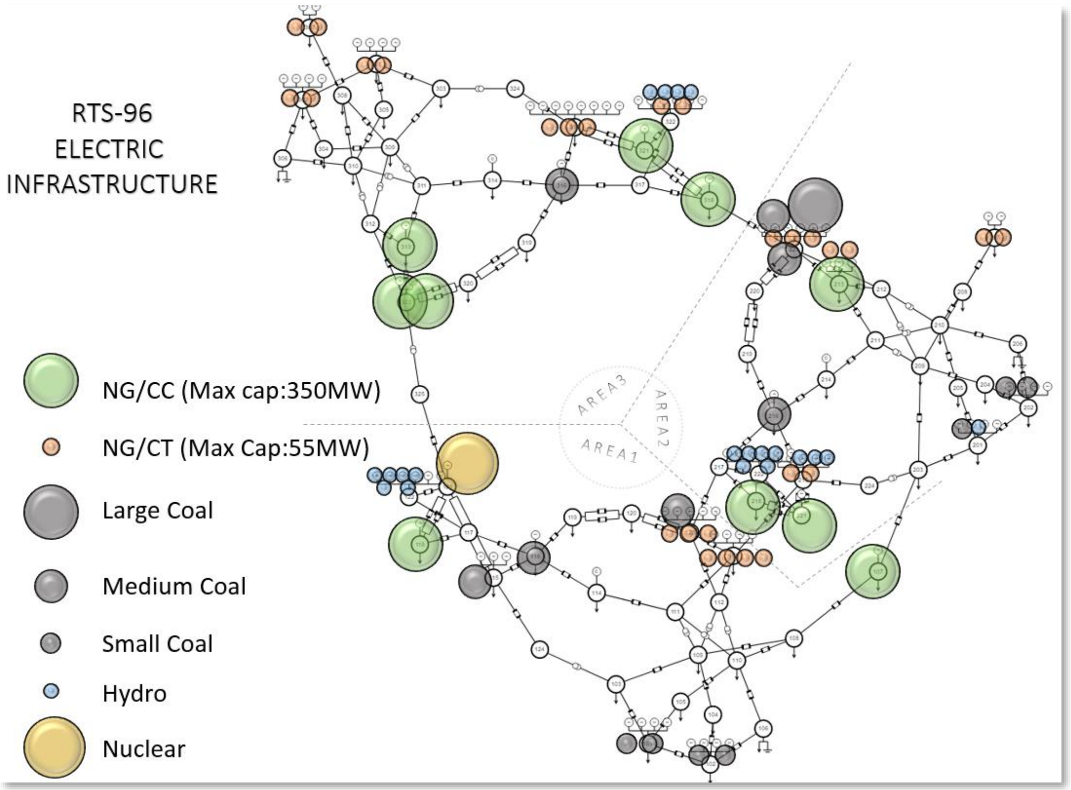
A. J. Wood and B. F. Wollenberg, *Power Generation, Operation and Control*, 2nd ed. New York; Chichester: Wiley, 1996.
R. Baldick, "The generalized unit commitment problem," *IEEE Trans. Power Syst.*, vol. 10, no. 1, pp. 465-475, Feb. 1995

Test Cases

1. Full UC model
2. Simplified UC: No min up&dn times; no reserves; no start-up; np Pmin; no ramps
3. UC enforcing units’ minimum up and down times
4. UC enforcing system-wide reserve constraints
5. UC considering units’ start-ups
6. UC enforcing generators’ Pmin
7. UC enforcing generators’ ramp rates

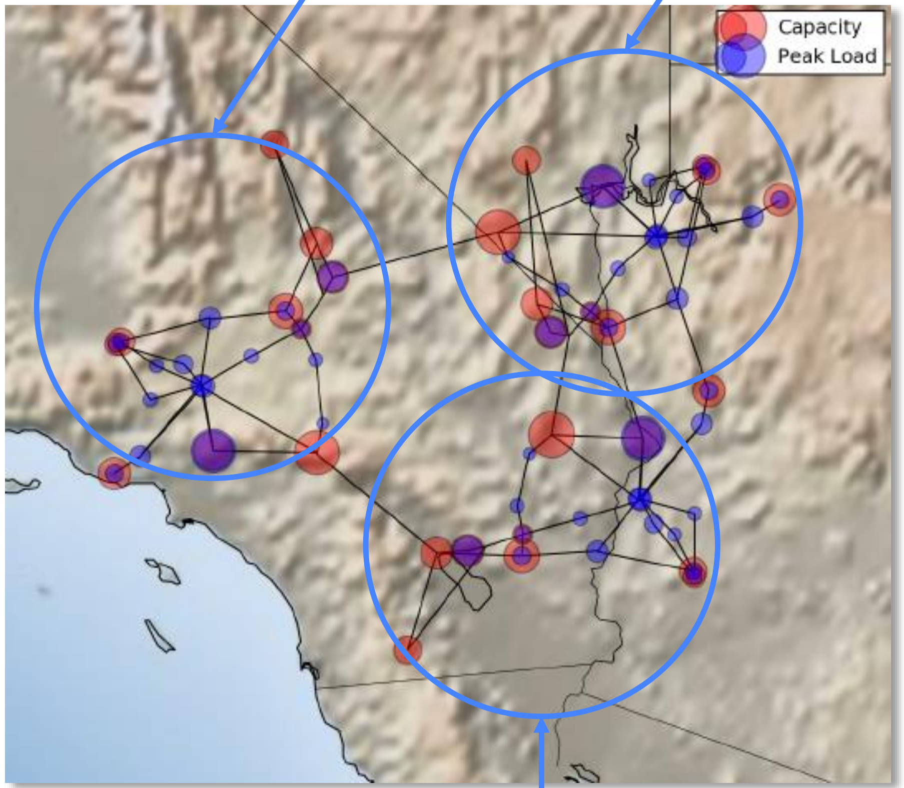
Test System – RTS GMLC

- Adapted to represent three realistic area
- https://github.com/GridMod/RTS-GMLC



LA Division of Water and Power

Nevada Energy



Arizona Power Service

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Test System – RTS GMLC

Generation type	Number of units	Fuel	P_{min} (MW)	P_{max} (MW)	Total (MW)	Ramp up (MW/min)	Ramp down (MW/min)
Steam Turbine (ST)	7	Oil	5	12	84.0	1	1
Combustion Turbine (CT)	12	Oli	8	20	240.0	3	3
Combustion Turbine (CT)	27	Natural Gas	22	55	1458.0	3.7	3.7
Steam Turbine (ST)	7	Coal	30	76	532.0	2	2
Steam Turbine (ST)	7	Coal	62	155	1085.0	3	3
Steam Turbine (ST)	2	Coal	140	350	700.0	4	4
Combined cycle (CC)	10	Natural Gas	170	355	3550.0	4.14	4.14
Nuclear	1	Nuclear	396	400	400.0	20	20
Hydro*	20	K water	0	50	400.0	0*	0*
Wind**	4	K wind	--	--	2507.9	--	--
Utility PV	25	SI	--	--	1554.5	--	--
Rooftop PV	25	SI	--	--	1161.4	--	--

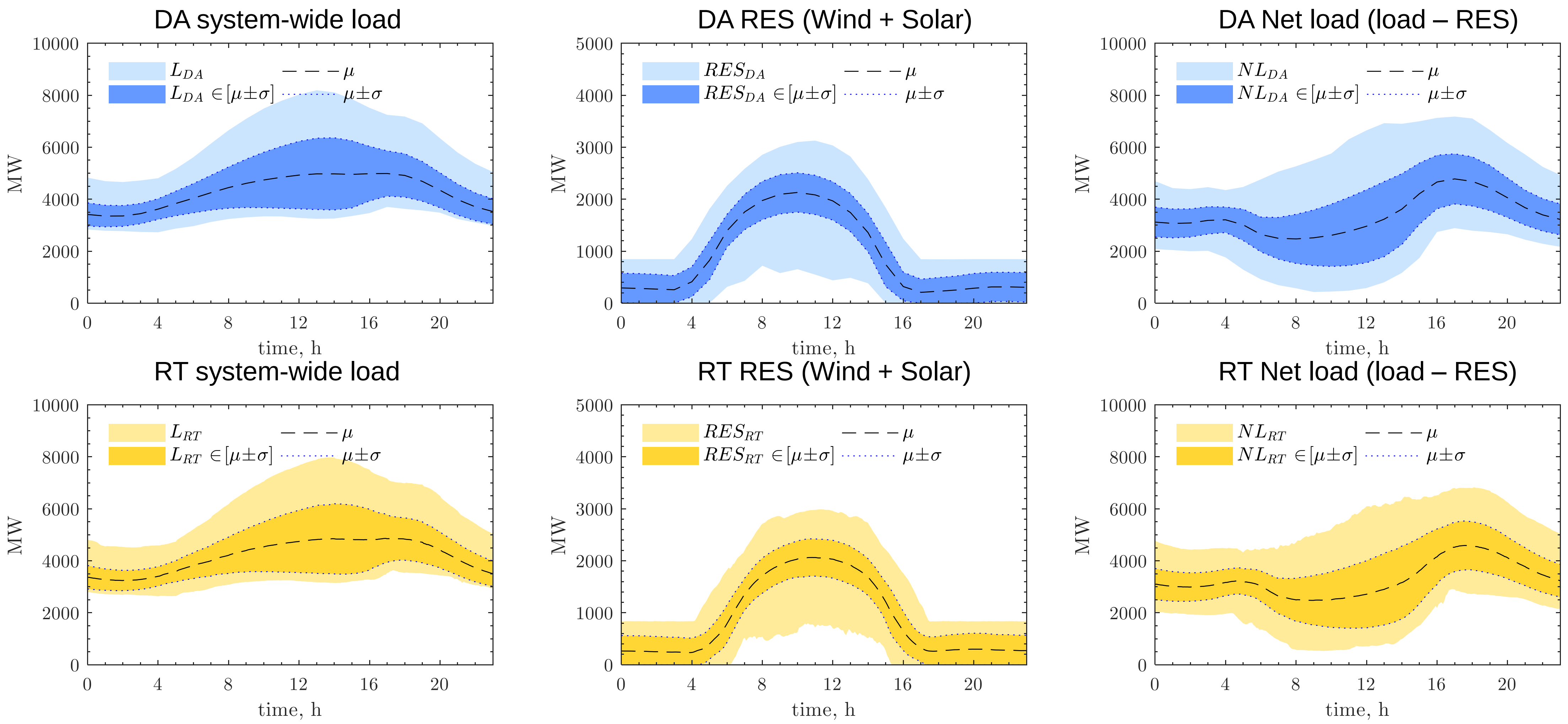
Total = 13,672.8 MW

* Schedule determined by a hydro-thermal coordination and deemed as known for scheduling and dispatch purposes. This hydro profile data was obtained from [ref WECC TEPPC 2024]

** Only one wind plan was modelled, 303_WIND_1

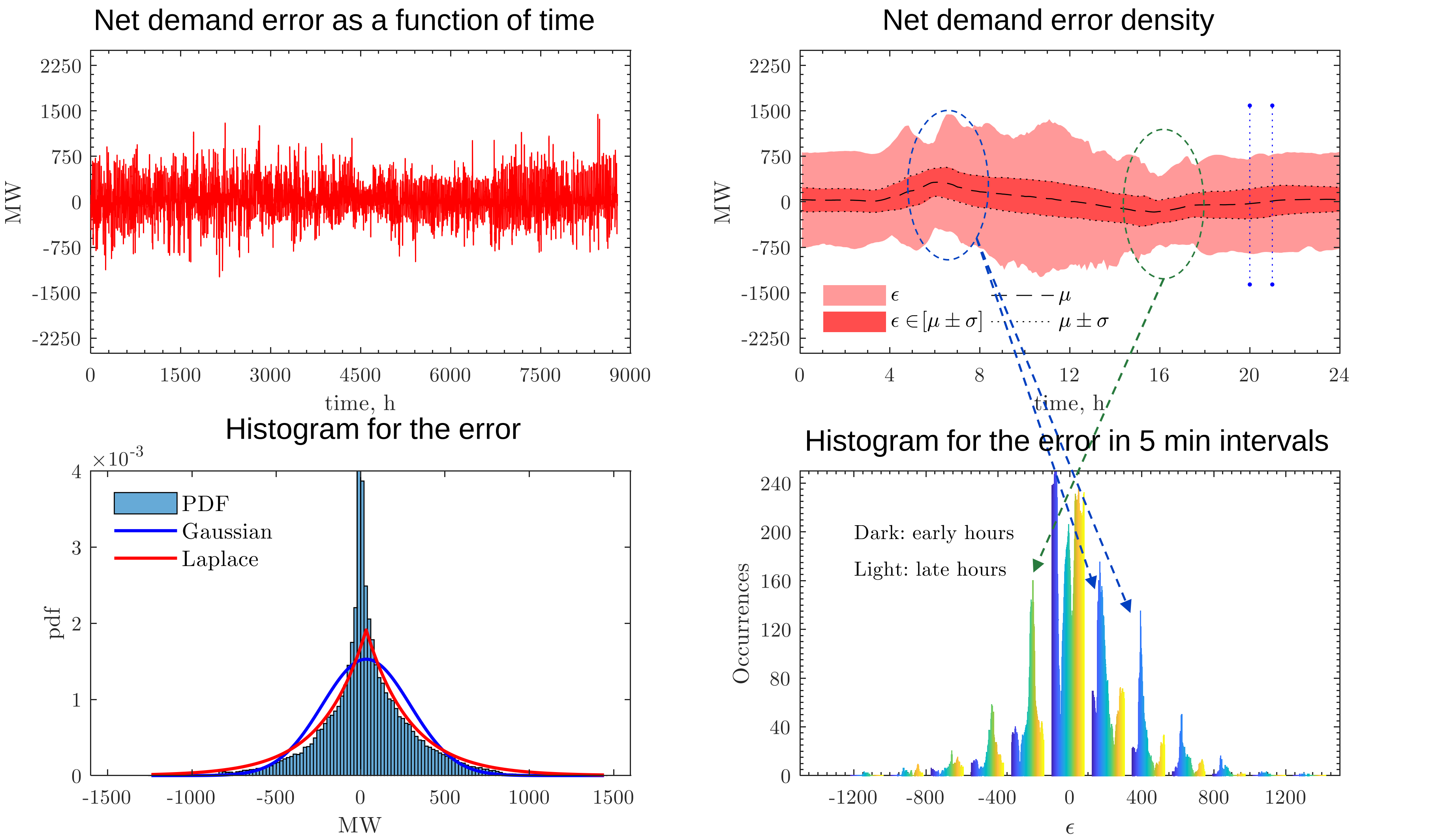
Test System – RTS GMLC

- DA and RT time series (TS) for year 2020



Test System – RTS GMLC's Net Demand Error

- Unavoidably, deviations from DA materialize in RT → System flexibility

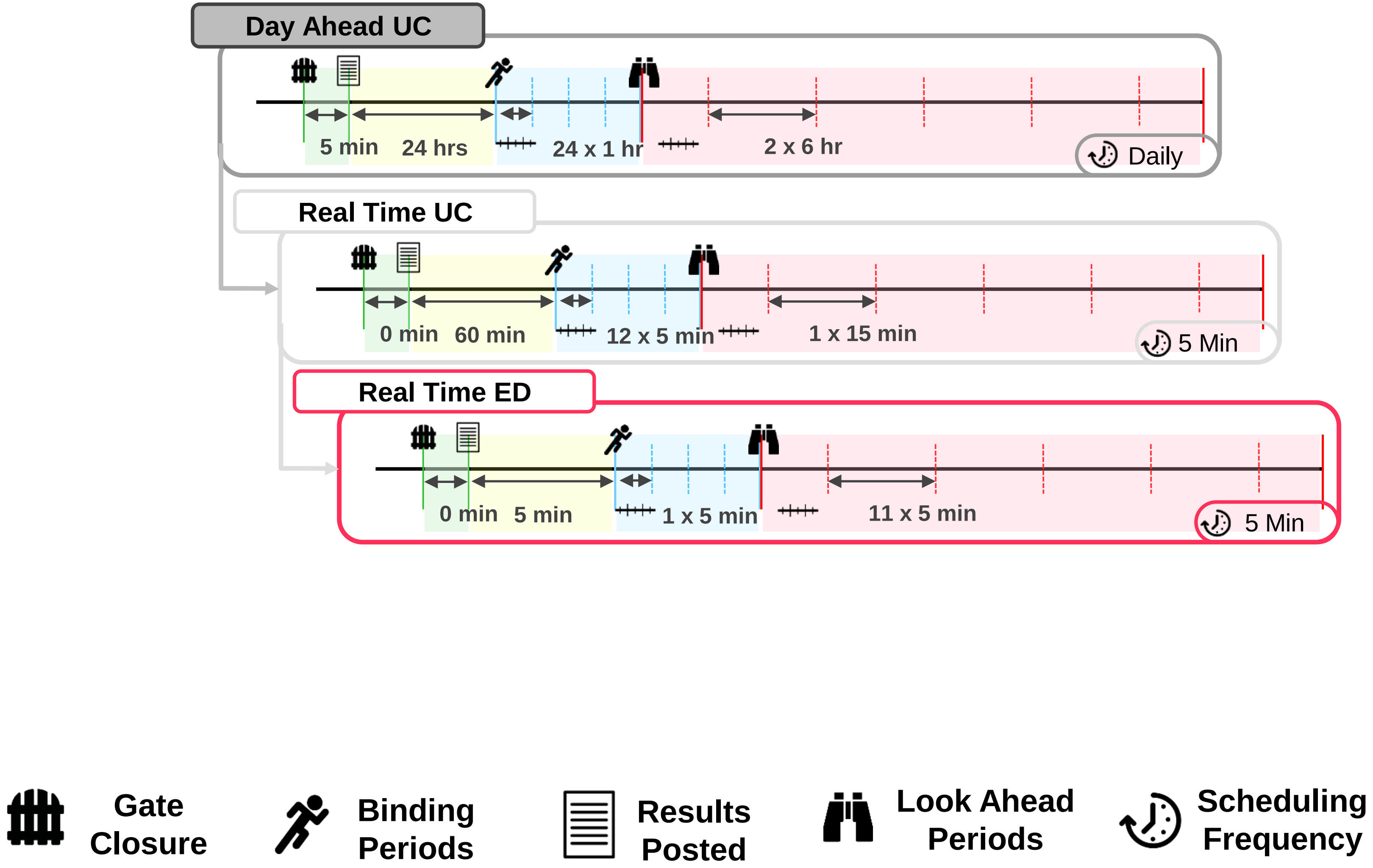


Simulation Parameters

- Power System Optimizer (PSO) based on AIMMS
  - DA cycle: 24 h horizon with 1 h resolution. Nuclear unit is a must run
  - RT cycle: 1 h horizon with 5 min resolution. No additional synchronizations → dispatch only
- Reserve products from the RTS-GMLC (regulation, flexibility and spinning)
- Generator physical and operating limits, power balance, reserve requirements
- Penalty factors
  - Load balance violations: $5000/MWh
  - Reserve violations: Regulation ($1500/MWh); spinning ($1250/MWh)
- Solution tolerances
  - MIP gap tolerance: 0.1% (DA and RT)
  - Time limit: 15 min. for DA and 5 min. for RT

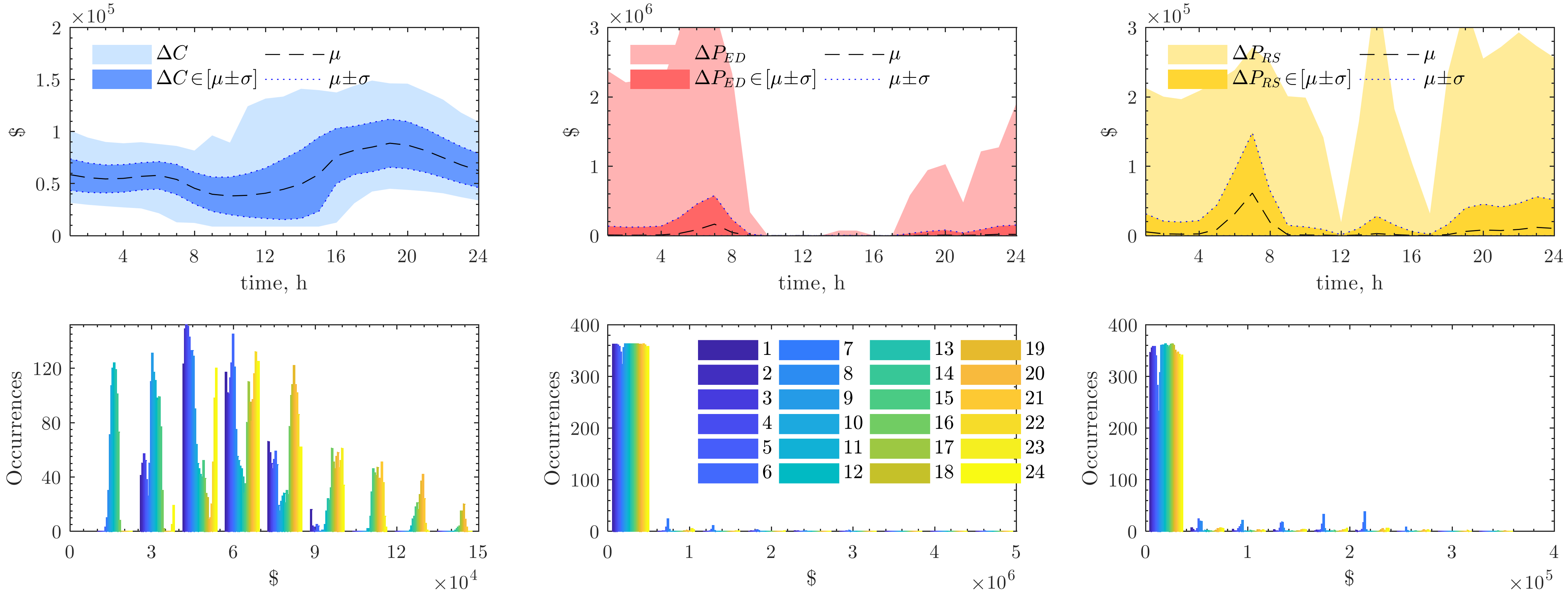
http://psopt.com/
https://github.com/GridMod/RTS-GMLC

Scheduling Process



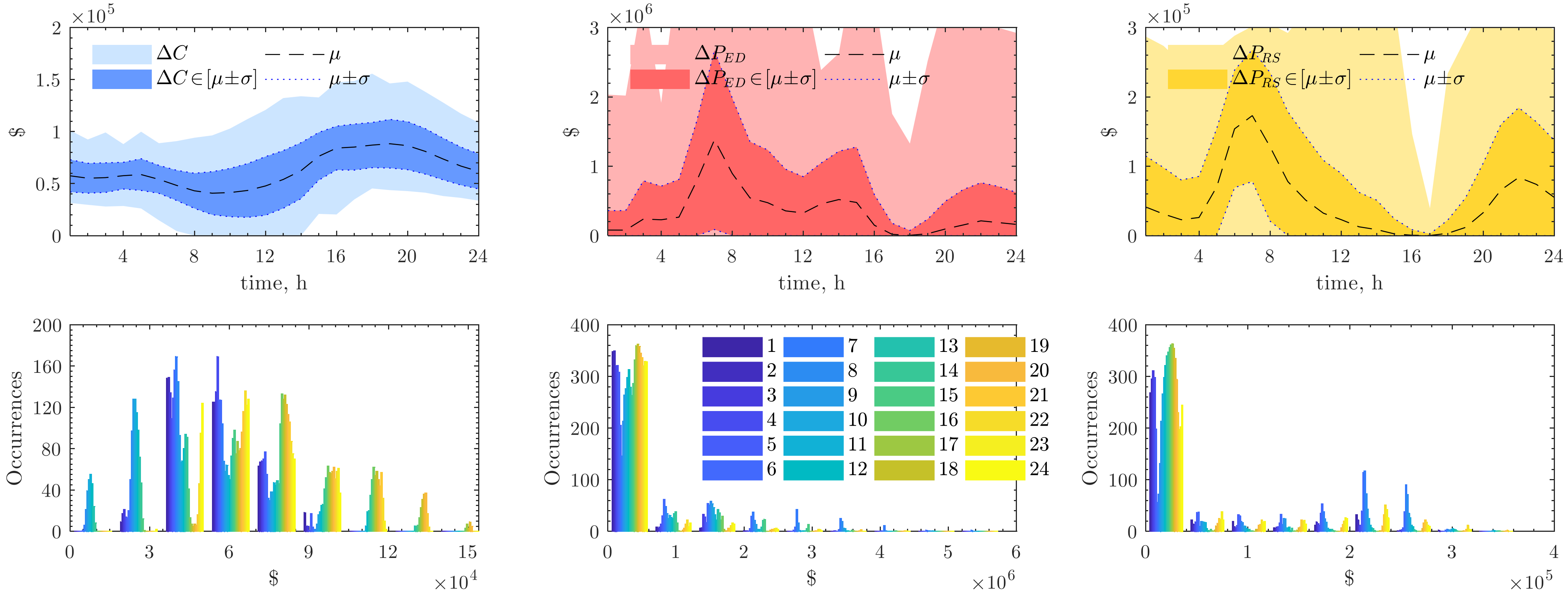
Results

- Full UC formulation: operating costs; ED violations; and RS violations



Results

- Simplified UC formulation: operating costs; ED violations; and RS violations

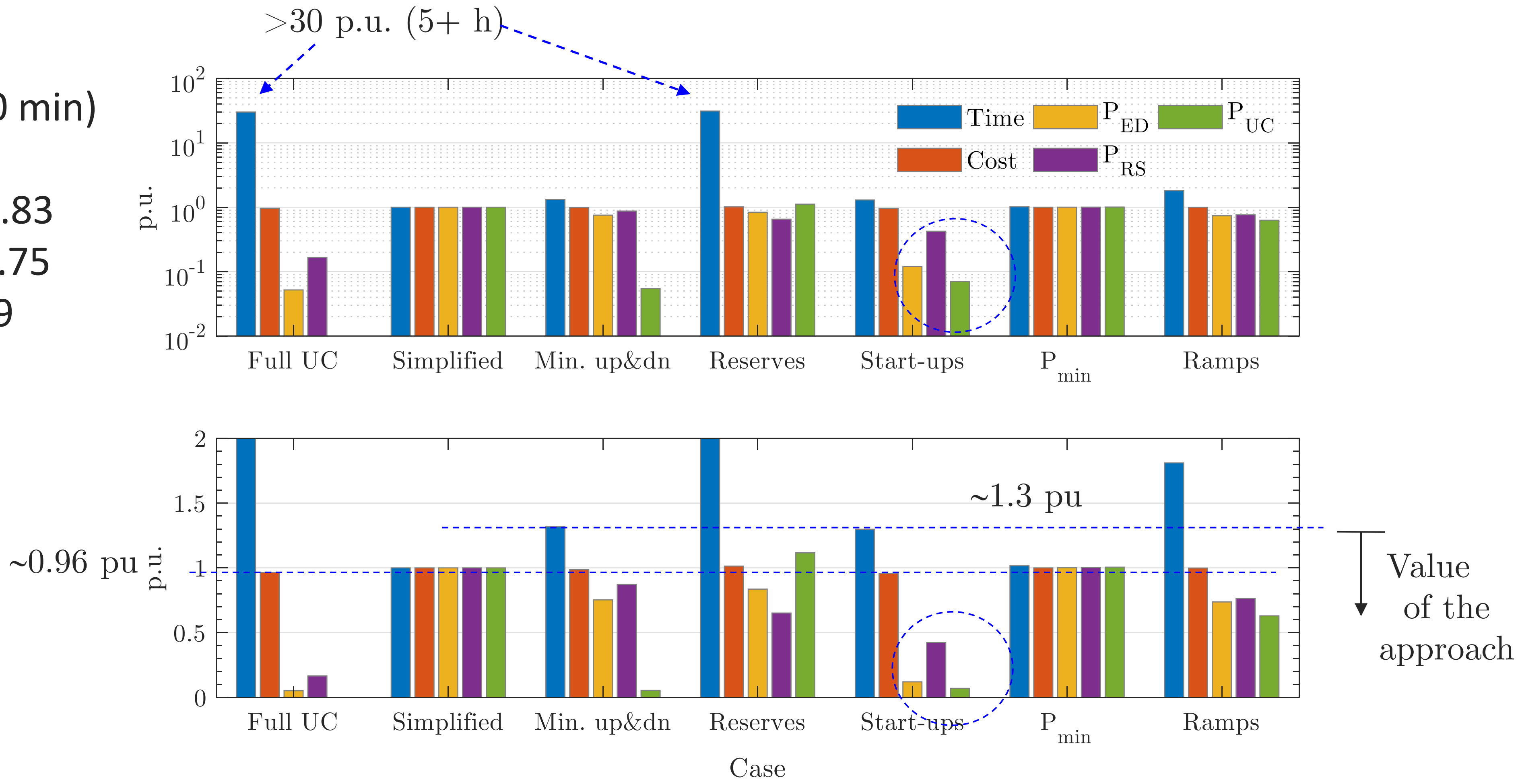


Results

- Results are normalized with respect to the simplified UC

Simplified UC:
Solve time: 613.4 s (>10 min)
Cost: M$ 548.22
UC penalties: M$ 6,371.83
ED penalties: M$ 2,949.75
RS penalties: M$ 429.39

Gap: 1×10^{-3}

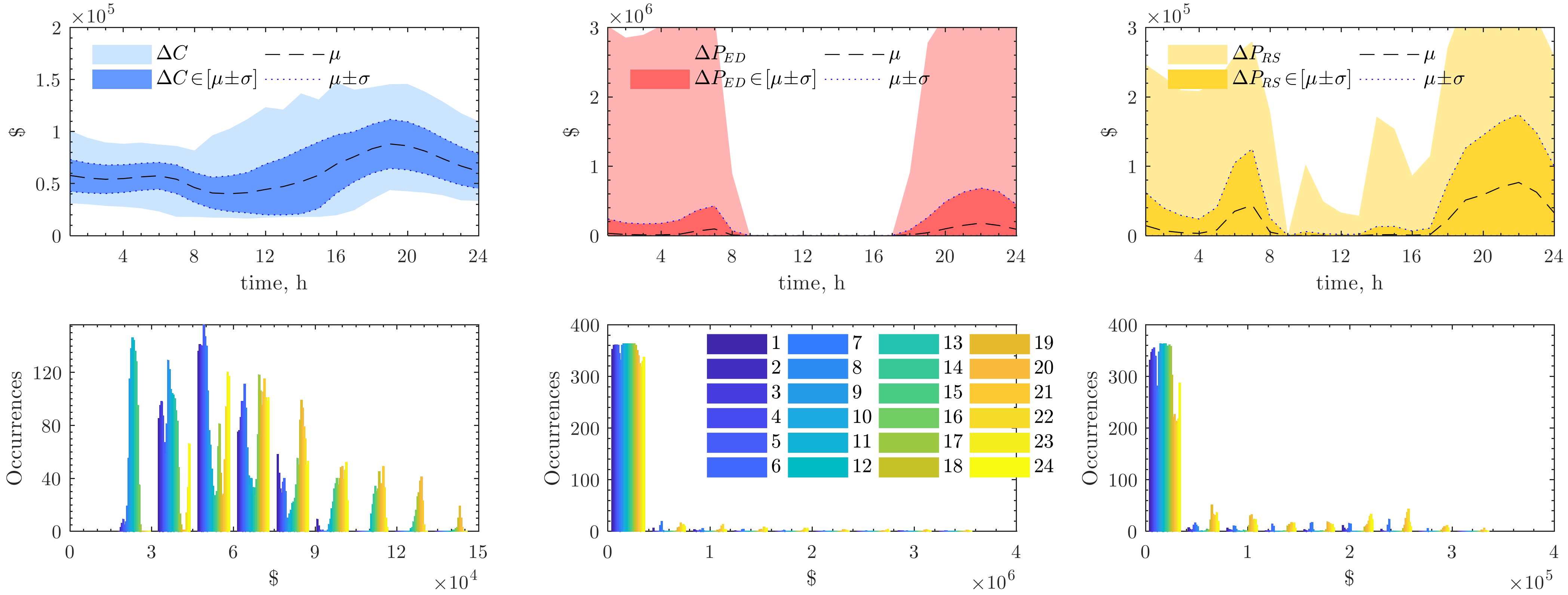


Intel Xeon CPU E5-2643
3.40 GHz (2 processors)

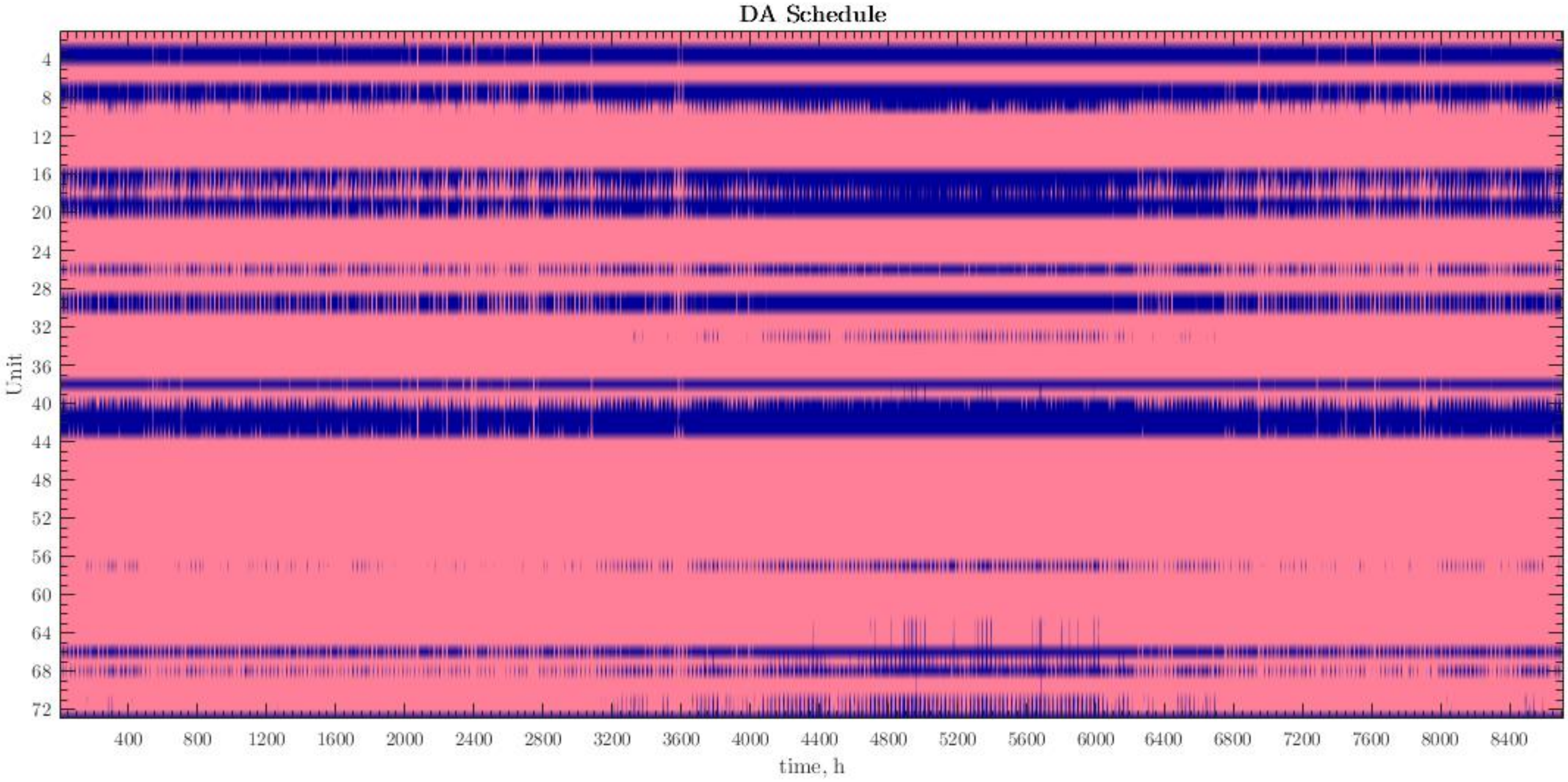
96 GB RAM

Results

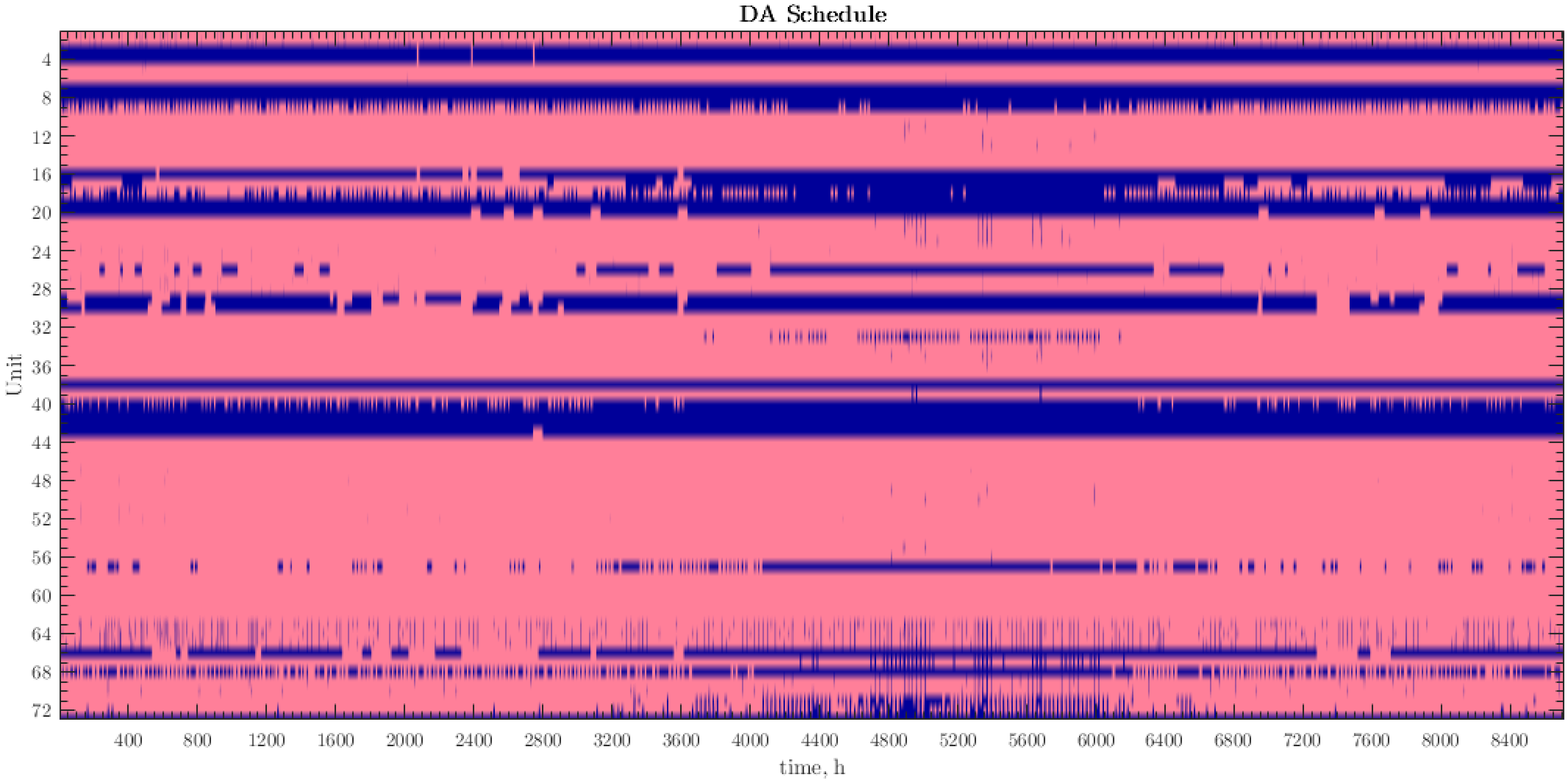
- Modeling start-up costs only



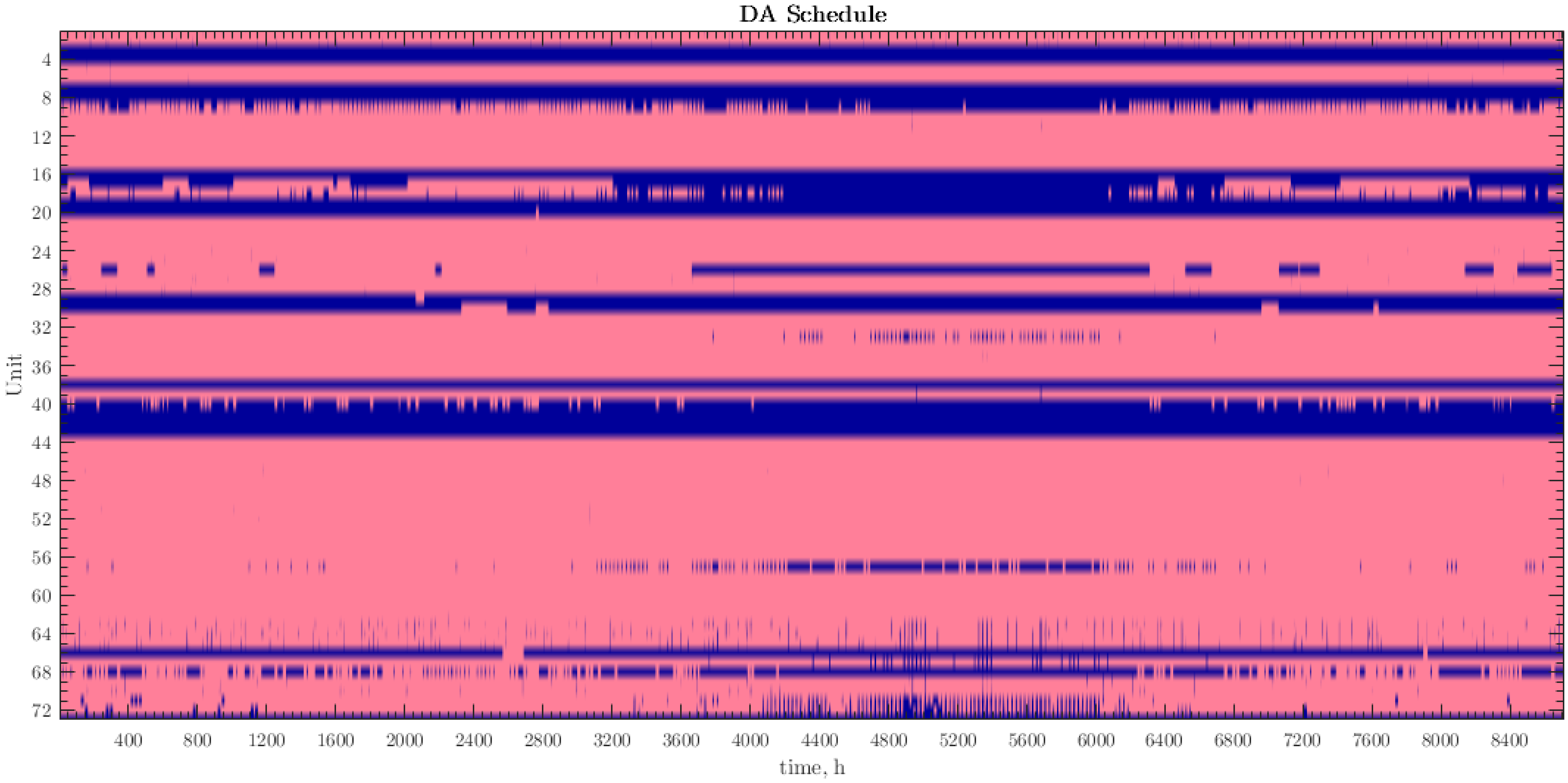
Unit Commitment – Simplified UC



Unit Commitment – Full UC

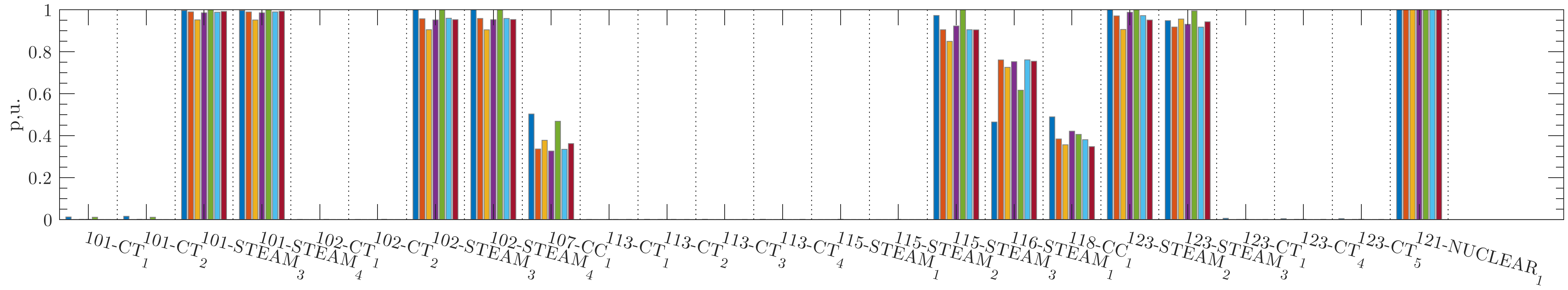


Unit Commitment – Start-ups Only



Units’ Utilization – Normalized Hours Committed

[1:23 73]



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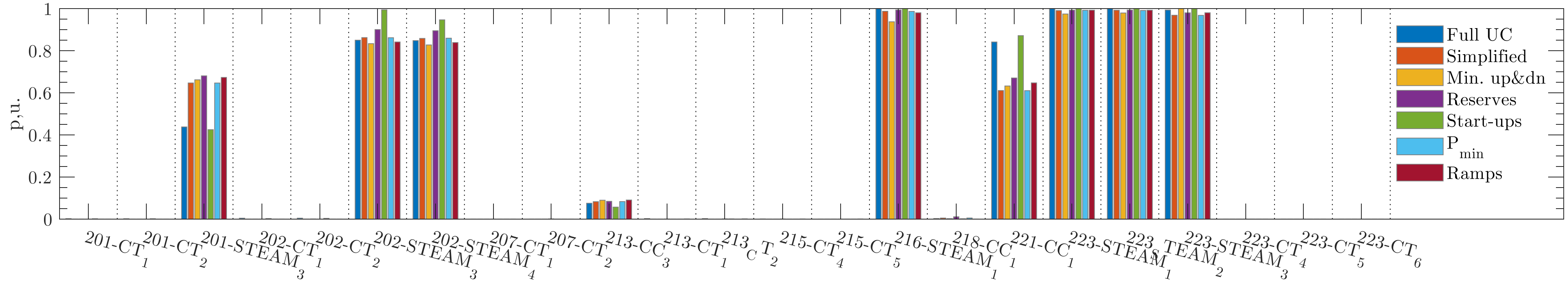

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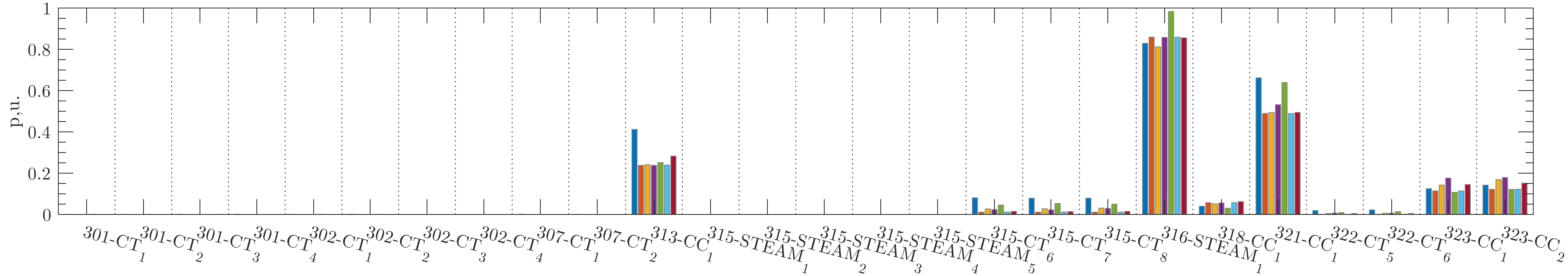

Units’ Utilization – Normalized Units’ Mileage

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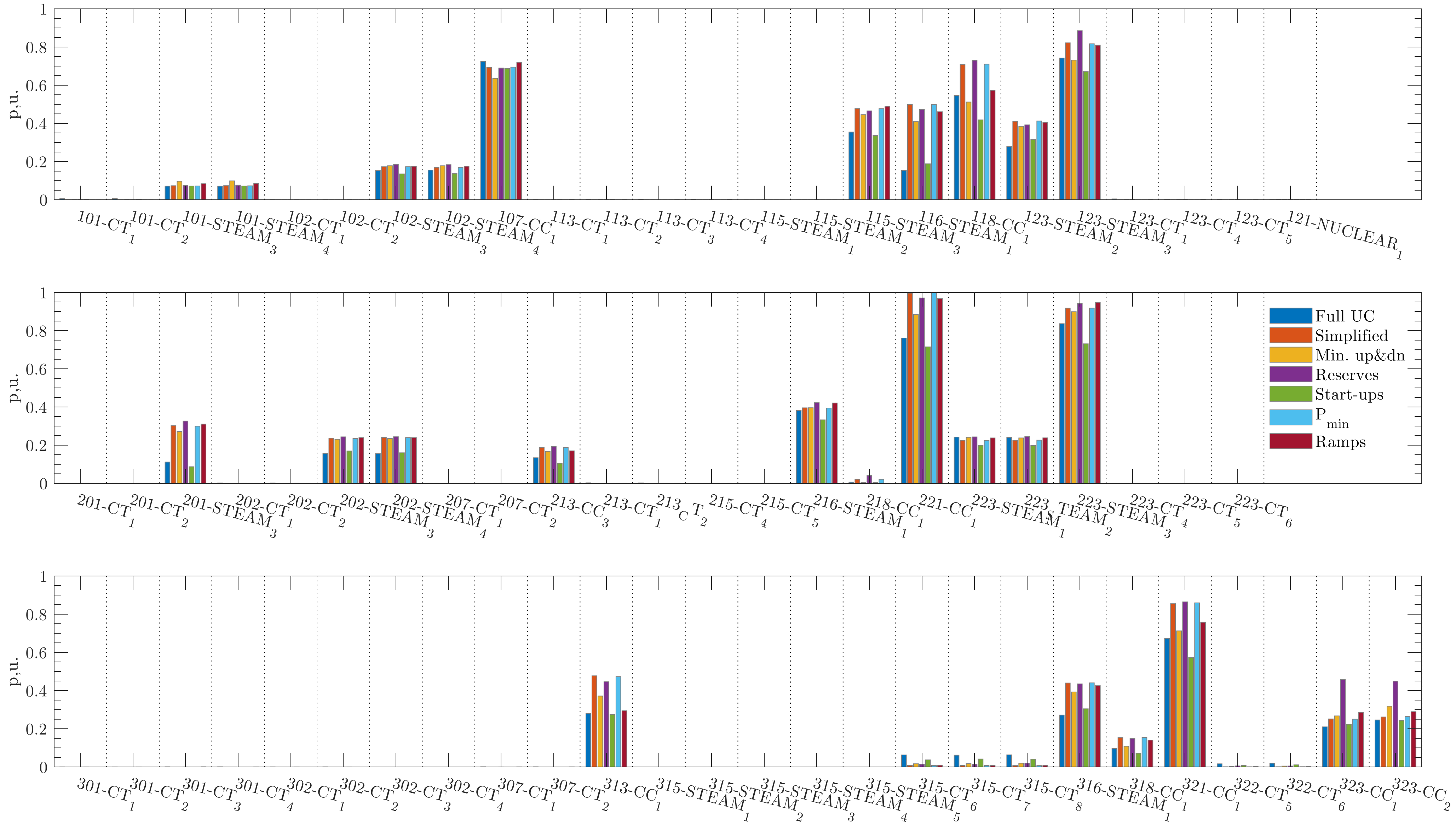

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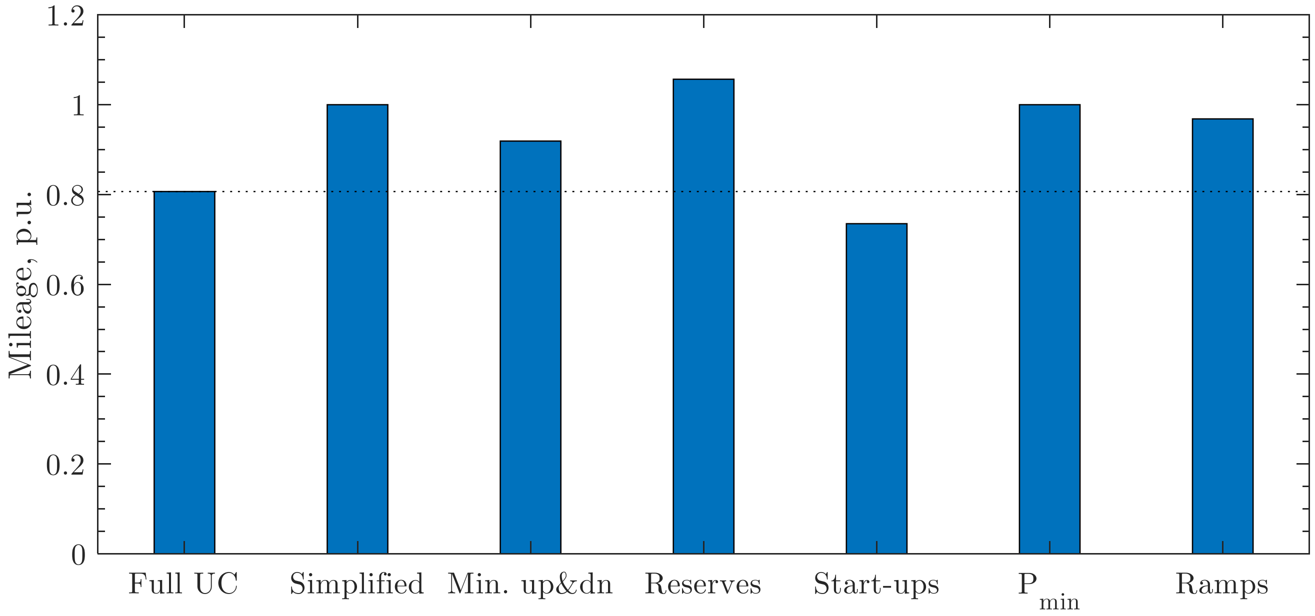
Aggregated Mileage

- Net demand mileage is the same regardless of the generation schedule
- Each approach results in different aggregated system mileage and cycling



Aggregated Mileage

- Net demand mileage is the same regardless of the generation schedule
- Each approach results in different aggregated system mileage and cycling
- Example: Assume 2 units with start-ups cost costs of $ 25, and the data on the tables below:

Generators

	P_{min} MW	P_{max} MW	π $/MWh
Unit 1	10	100	1
Unit 2	10	100	2

Load

Load	t_1	t_2	t_3
Forecast	110	100	110
Actual	100	100	100

Scheduling cases:

a) Ignore start-up costs

b) Consider start-up costs

UC&ED "a"

	t_1	t_2	t_3
Unit 1	90	100	90
Unit 2	10	-	10

Cycling "a"

	$\lvert\Delta t_{21}\rvert$	$\lvert\Delta t_{32}\rvert$
Unit 1	10	10
Unit 2	10	10

UC&ED "b"

	t_1	t_2	t_3
Unit 1	90	90	90
Unit 2	10	10	10

Cycling "b"

	$\lvert\Delta t_{21}\rvert$	$\lvert\Delta t_{32}\rvert$
Unit 1	0	0
Unit 2	0	0

Units' Utilization – Units' Utilization Factor

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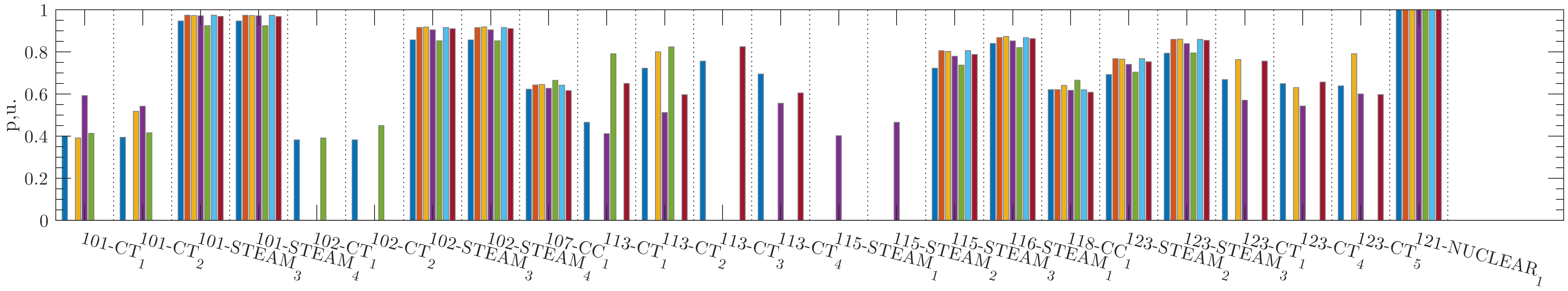

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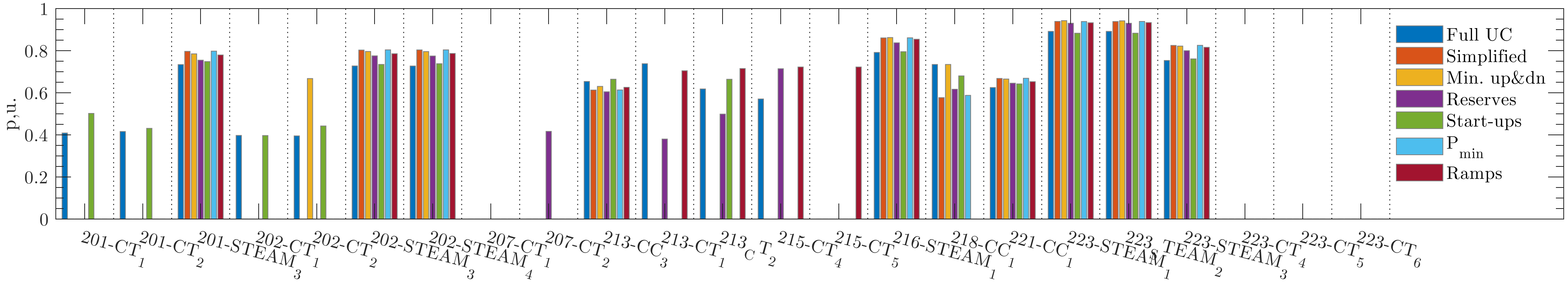

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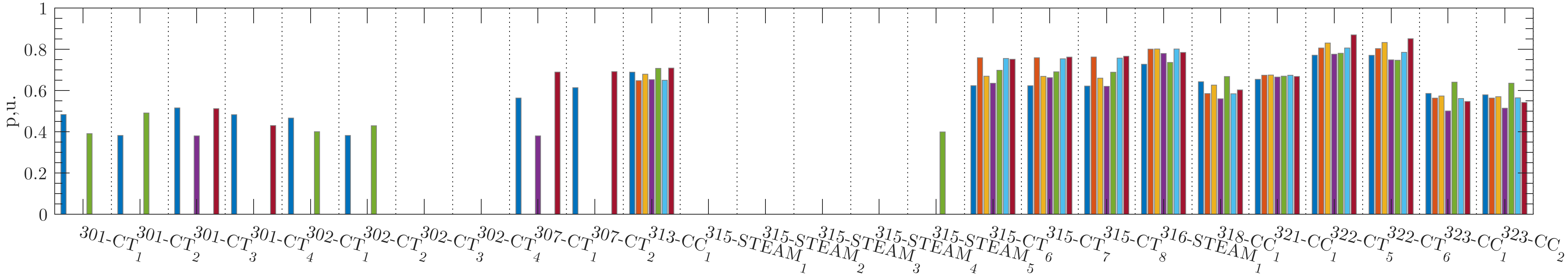

Units’ Profits

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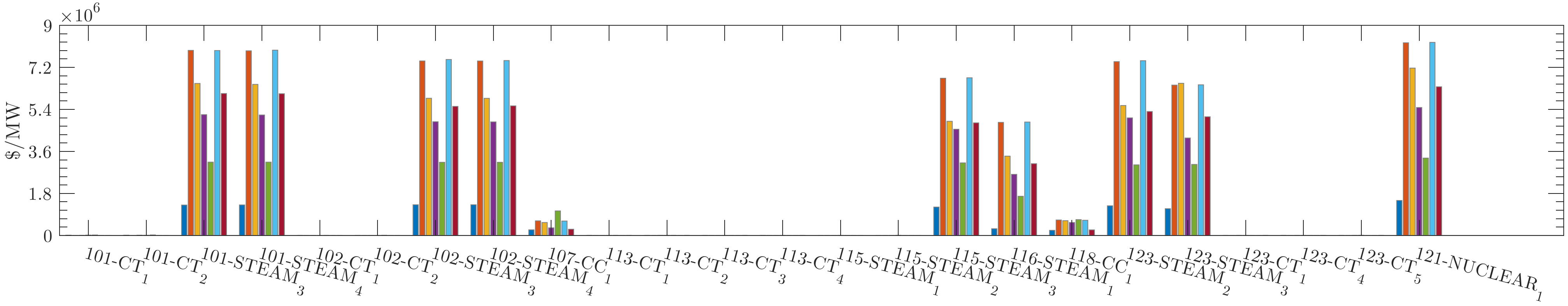

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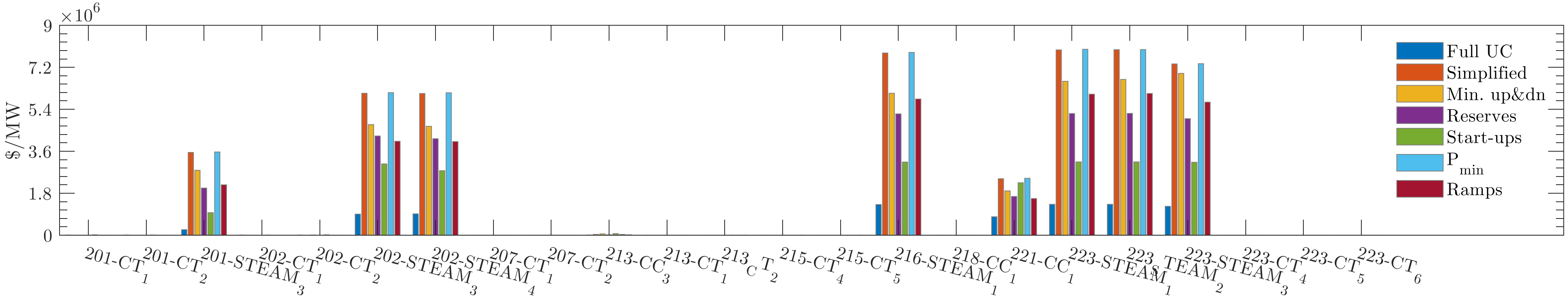

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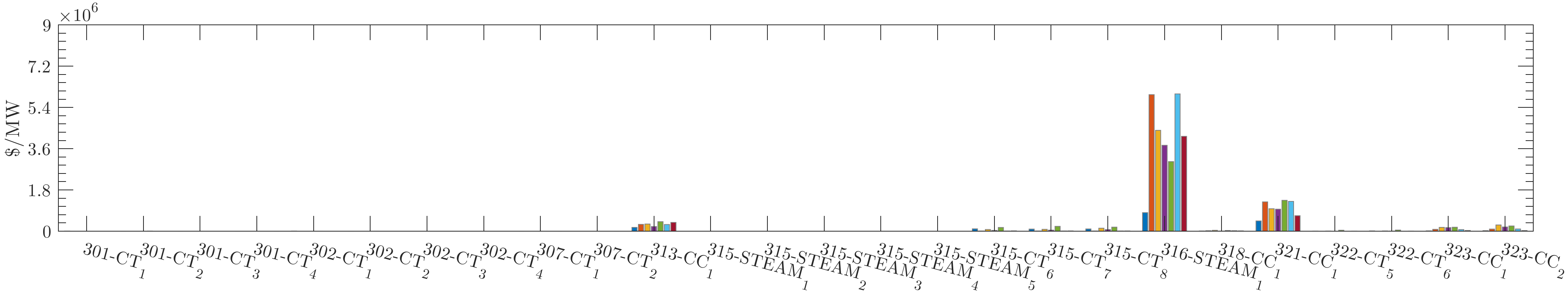

Conclusions

- Enforcing start-ups serves as an **indirect umbrella** for other constraints:
  - Min. up & down times:
    - Once a unit is synchronized/shut-down, it will remain as "long" as possible to avoid additional start-up costs
    - These on/off periods exceed the minimum up and down times
  - Ramps:
    - Optimization is performed over a time horizon. Keeping sufficient generation synchronized/offline considering the implicit look-ahead periods avoids unnecessary ramping
  - Minimum stable generation (P_{min}):
    - Synchronized generation is used to meet demand considering look-ahead periods, and since its synchronization comes at a cost, unnecessary generation is not synchronized and online generation is dispatched above P^{min}.
  - Reserves:
    - Optimization is performed over long horizons where net demand varies. In order to keep costs at a minimum, sufficient capacity is kept to meet expected peak periods. During lower net demand periods there is an implicit generation margin, i.e. reserve.

Conclusions

- Important to avoid over-generalizations
- Determine sensitivity of start-ups to different parameters
  - Fuel and carbon costs
  - Different penetrations of RES

- Pave the way to new array of tools at EPRI
  - Able to simulate and solve multiple scenarios → contingency screening and risk planning
  - New family of expansion tools that account for operating needs

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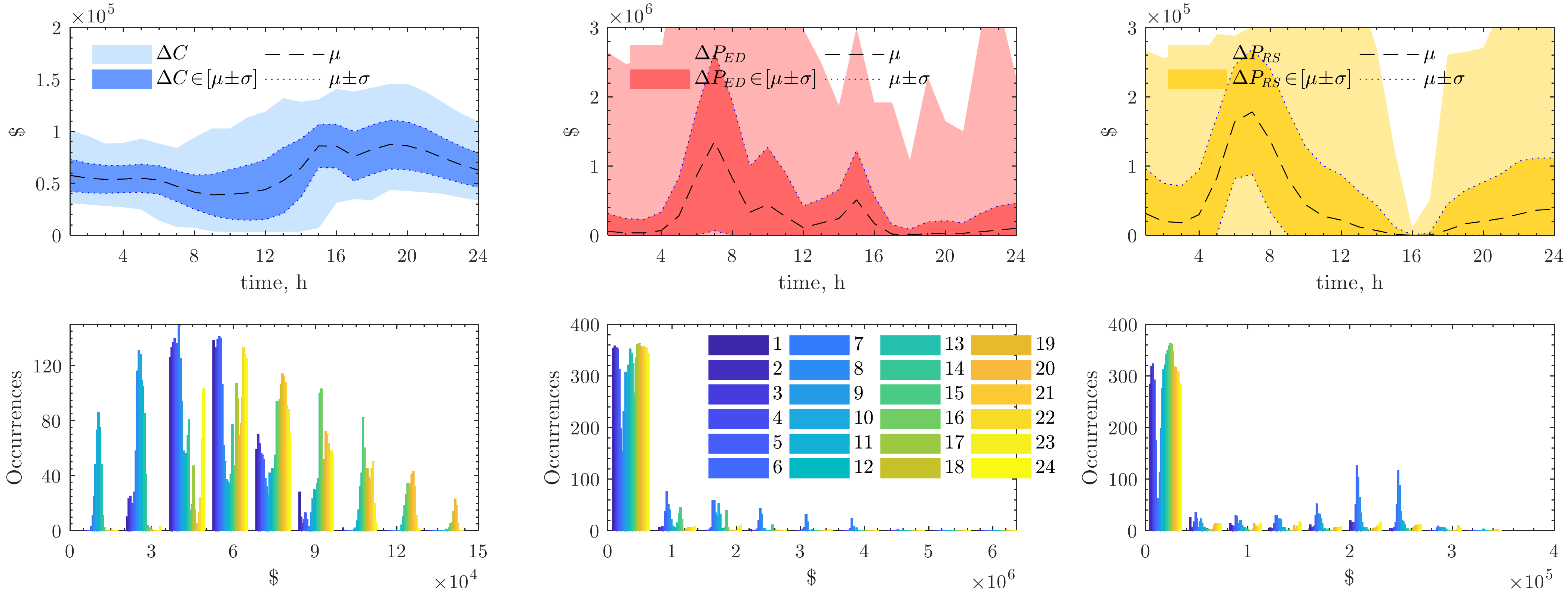
Support material

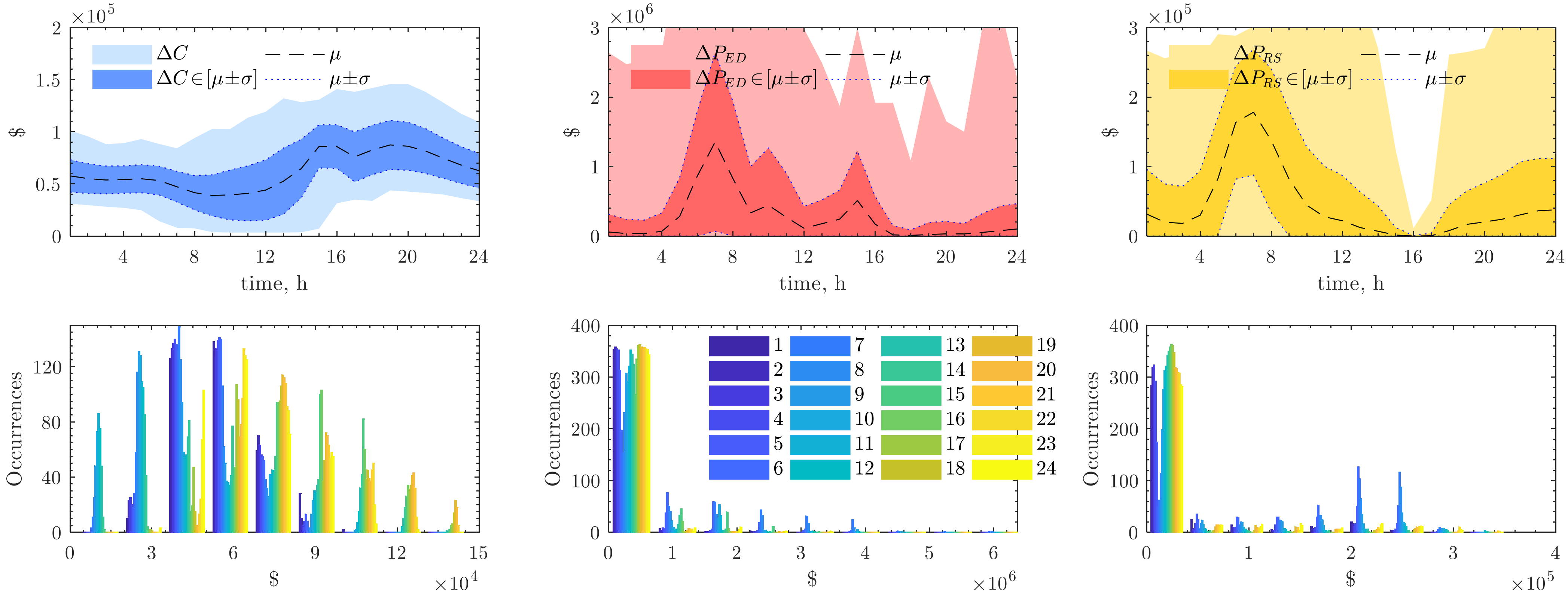
Results

- Modeling minimum up and down times



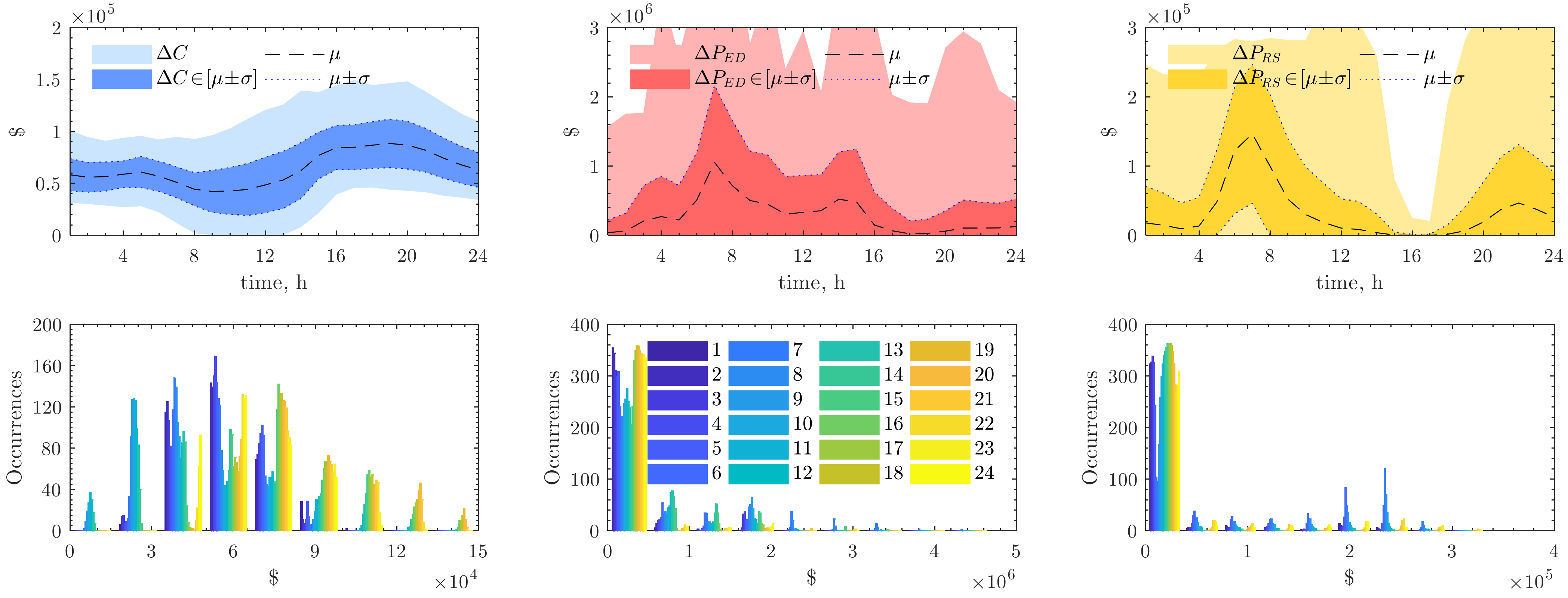
Results

- Modeling minimum up and down times only



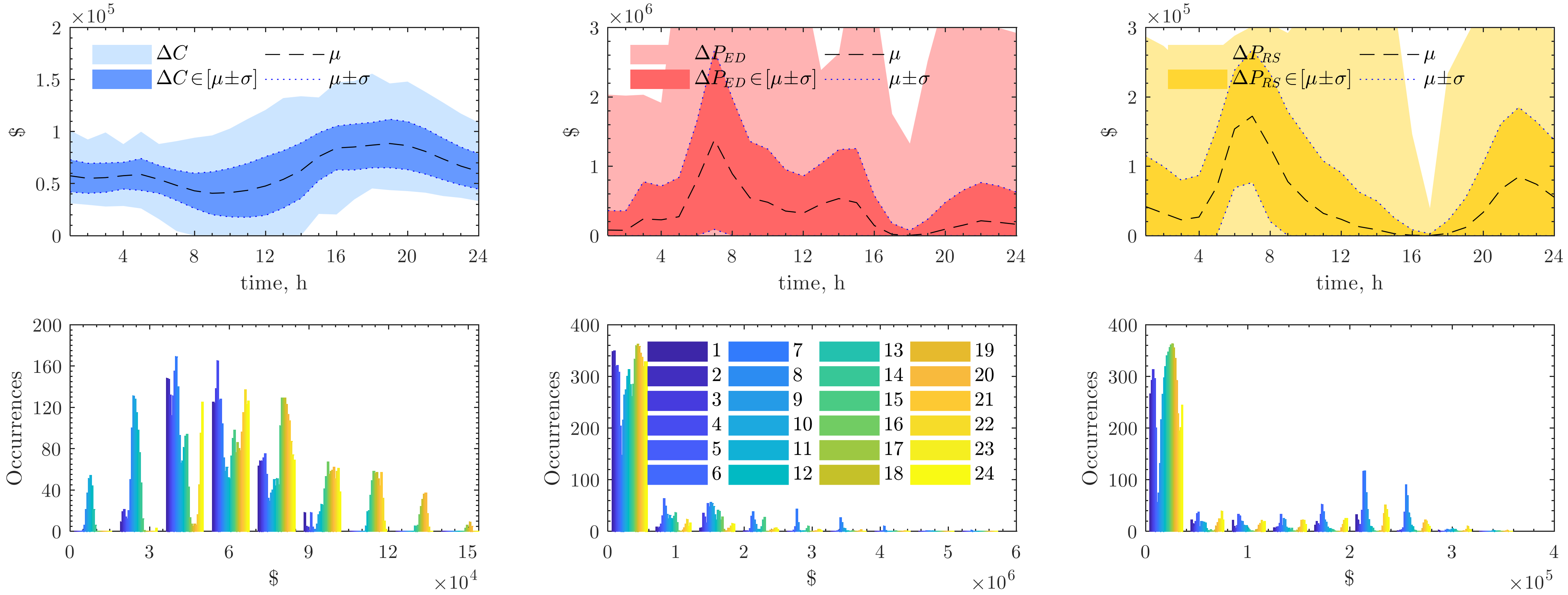
Results

- Modeling reserves only



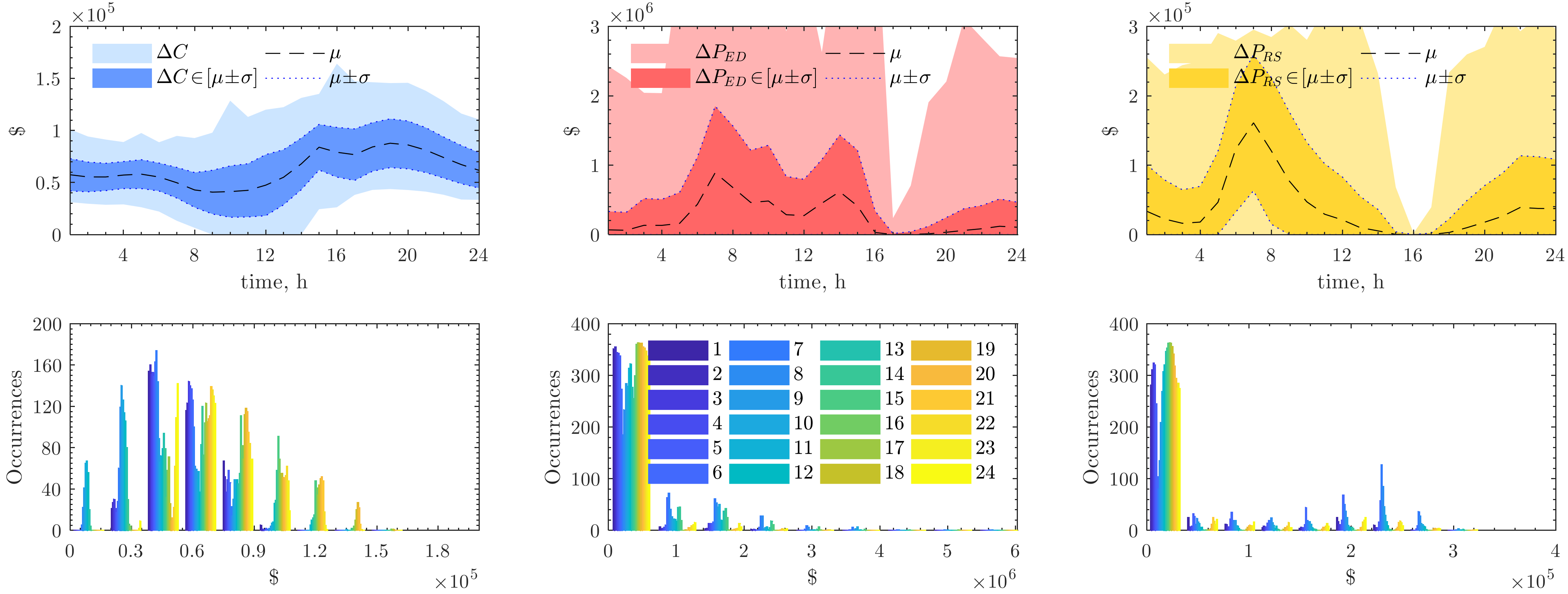
Results

- Modeling P_{min} only

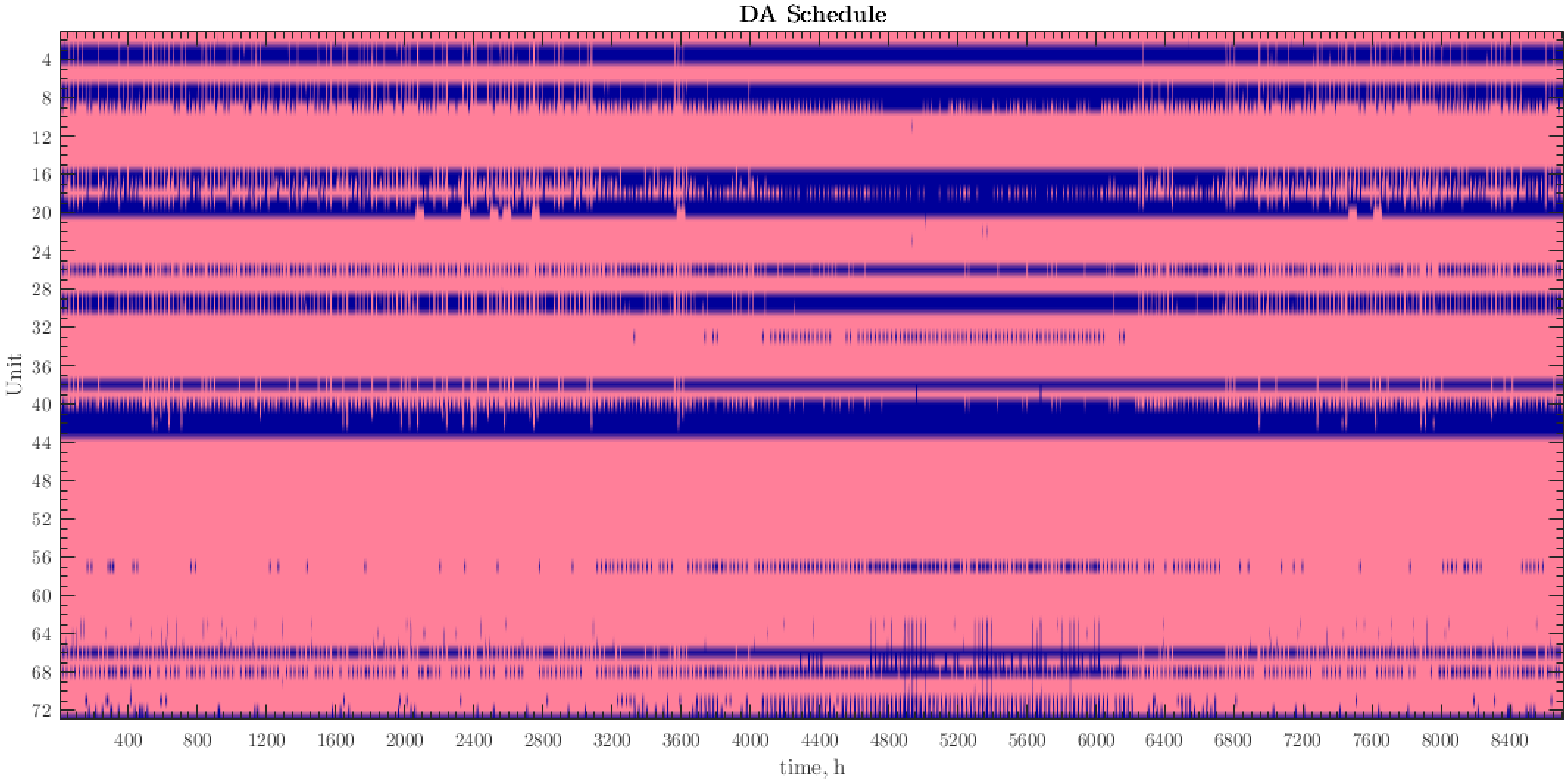


Results

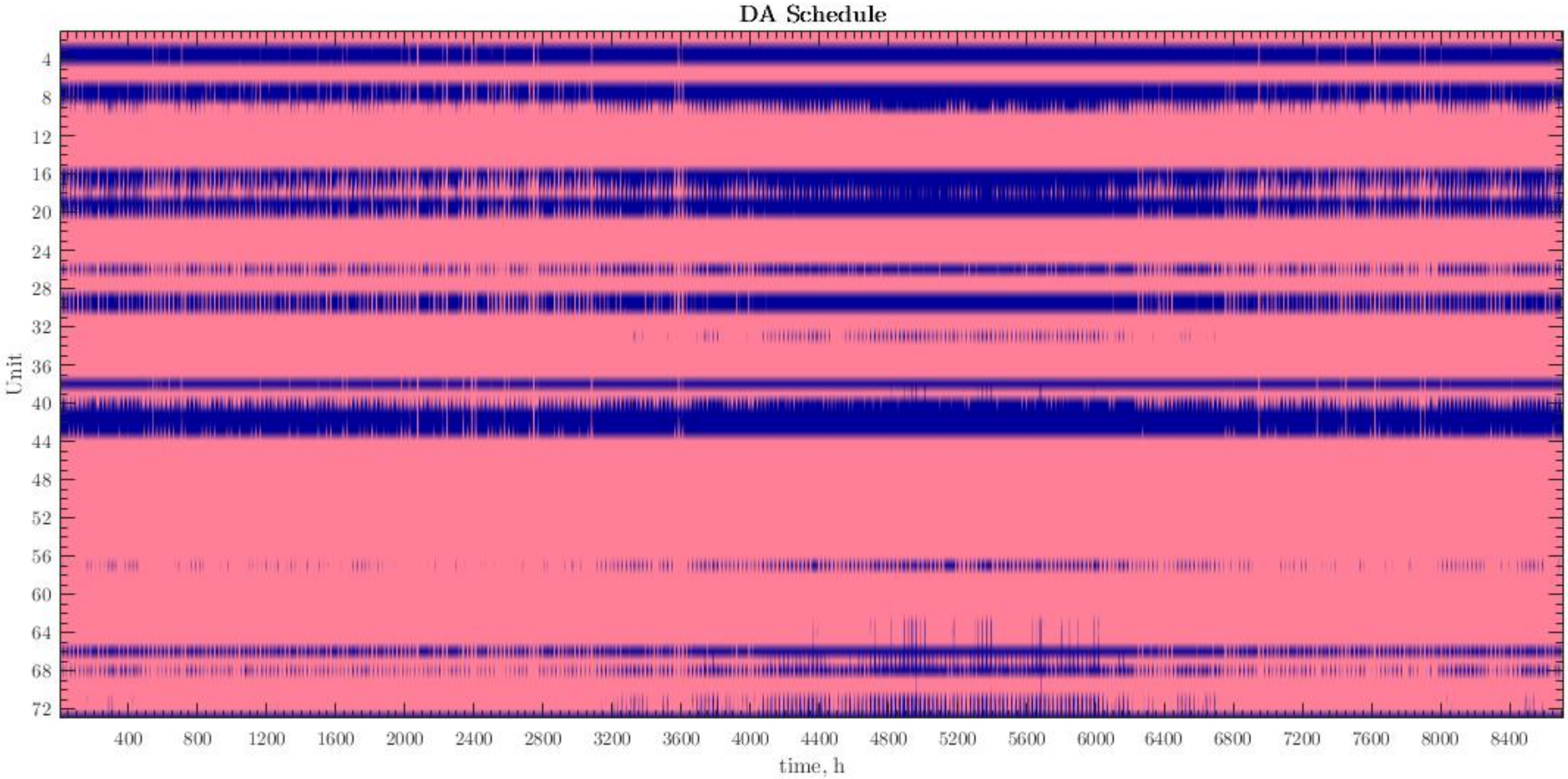
- Modeling Ramps only



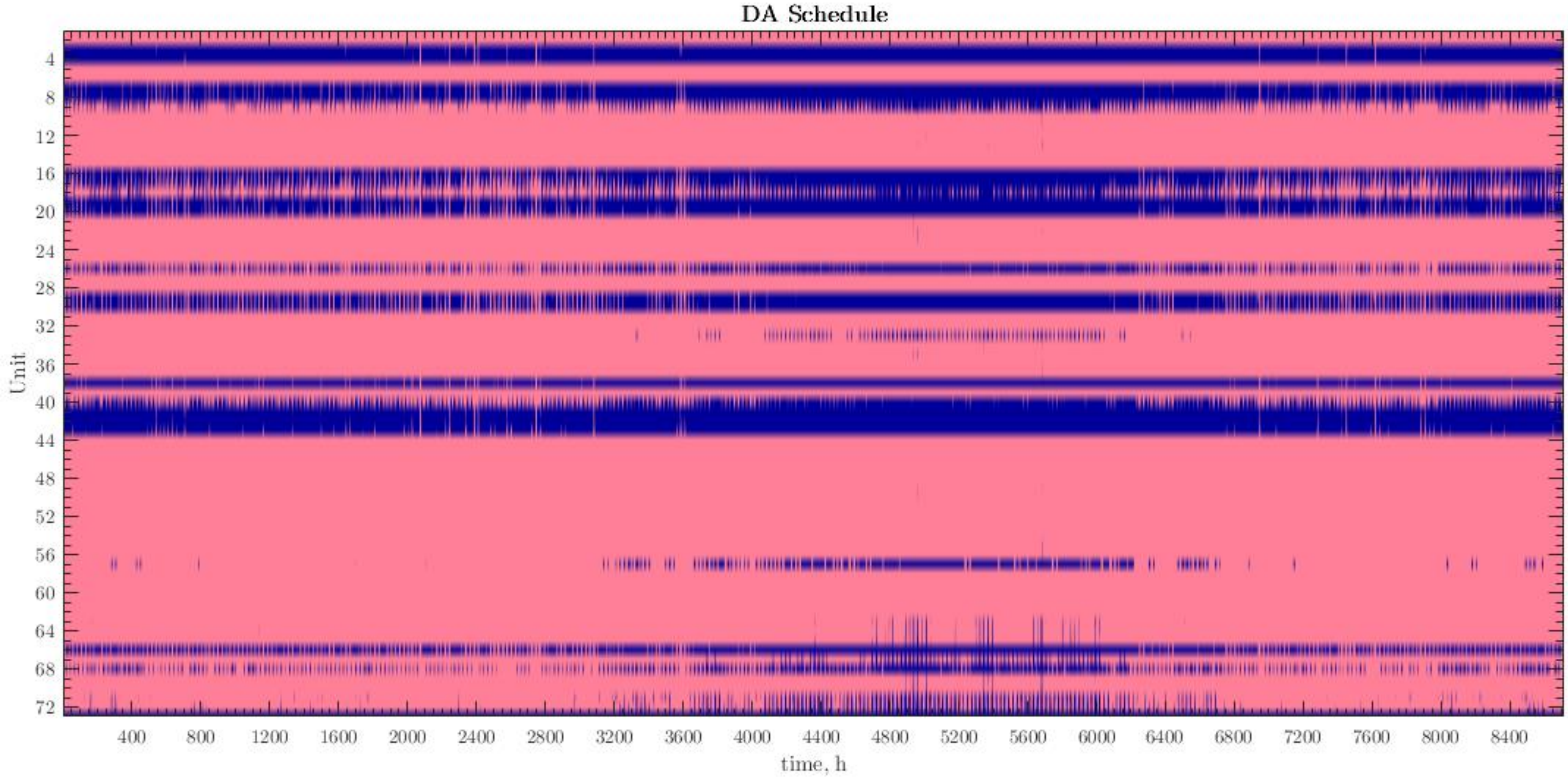
Unit Commitment – min up & down times



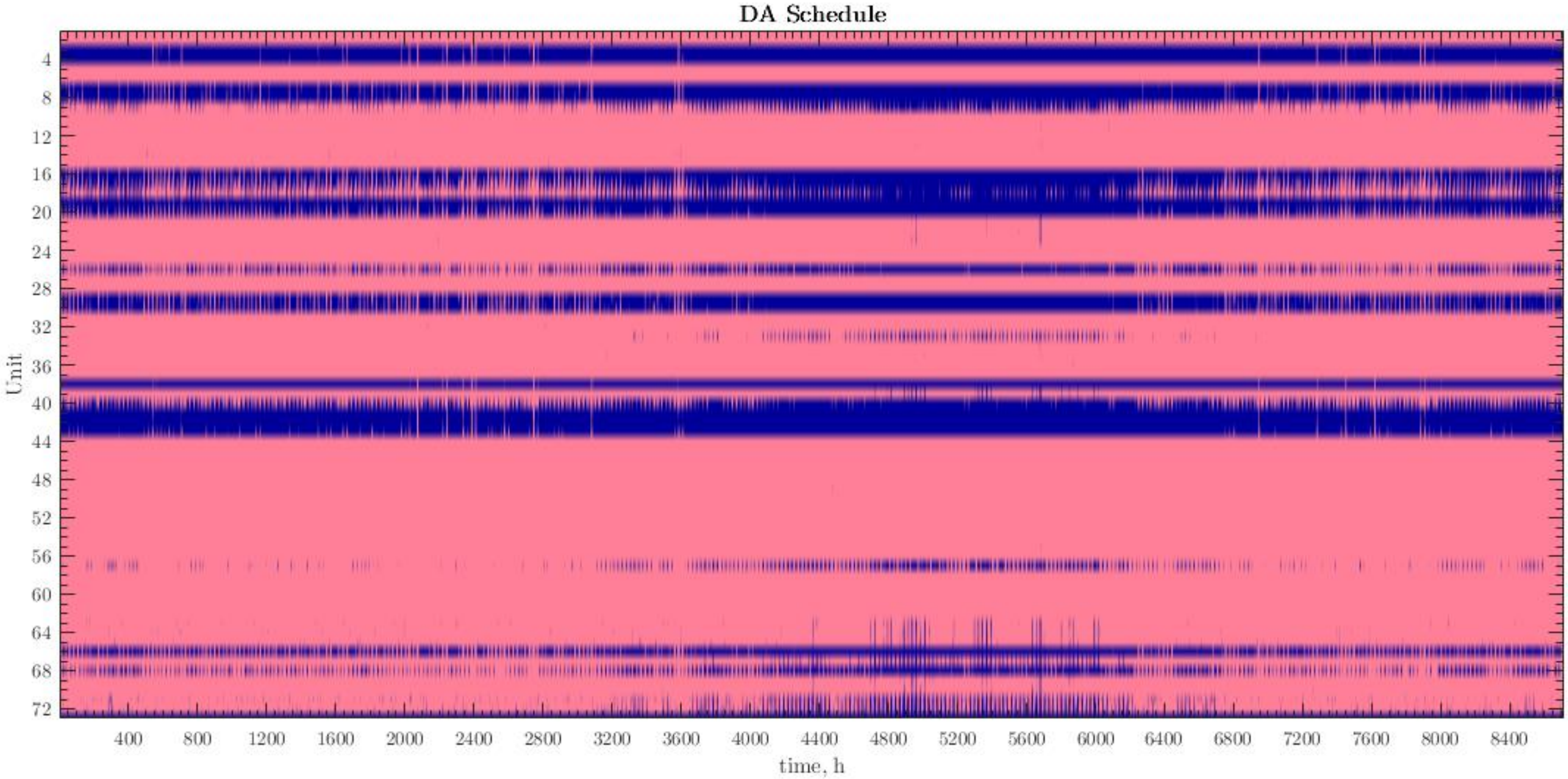
Unit Commitment – P_{min} only



Unit Commitment – Ramps only



Unit Commitment – Reserves only



Units’ Revenues

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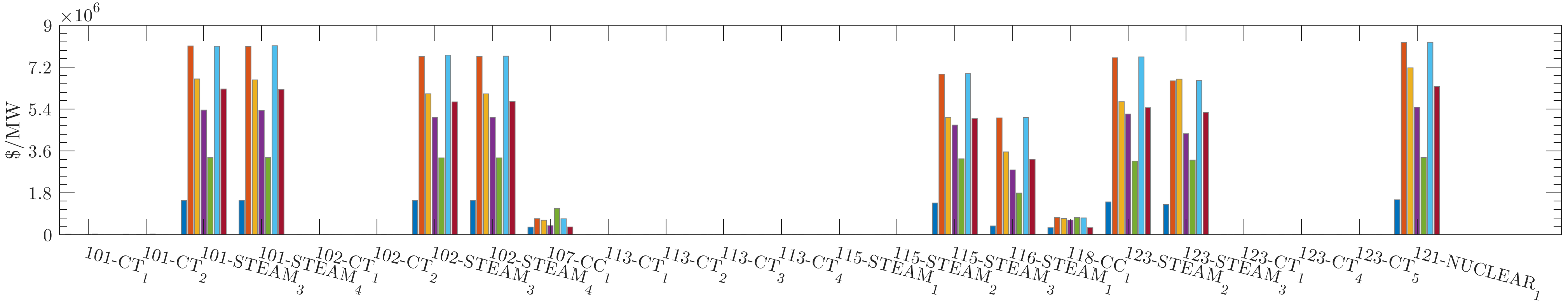

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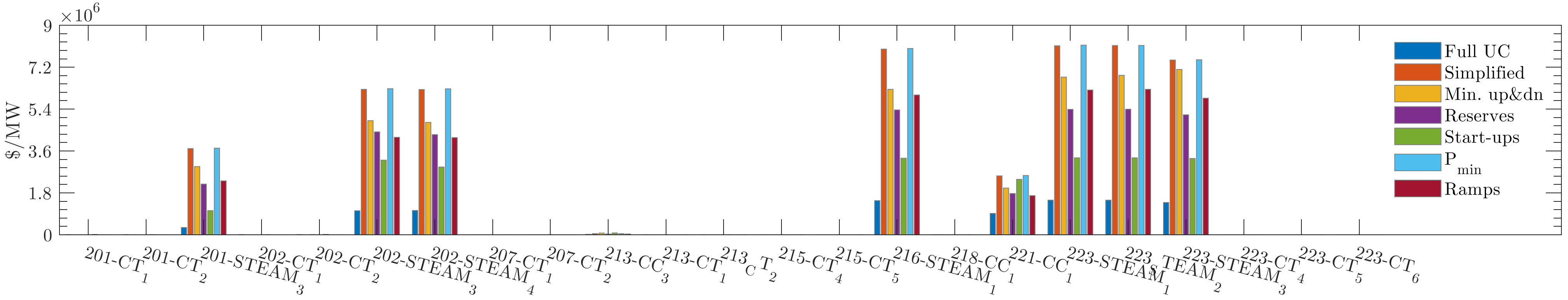

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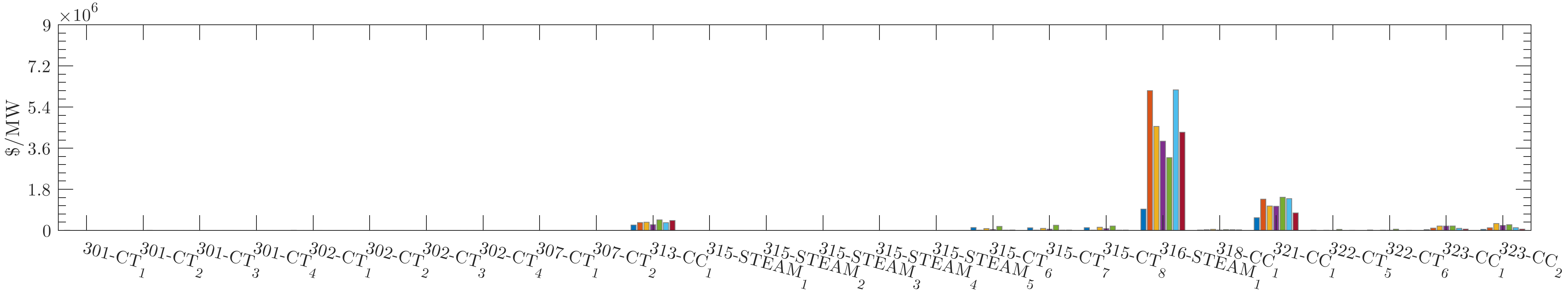

Units' Costs

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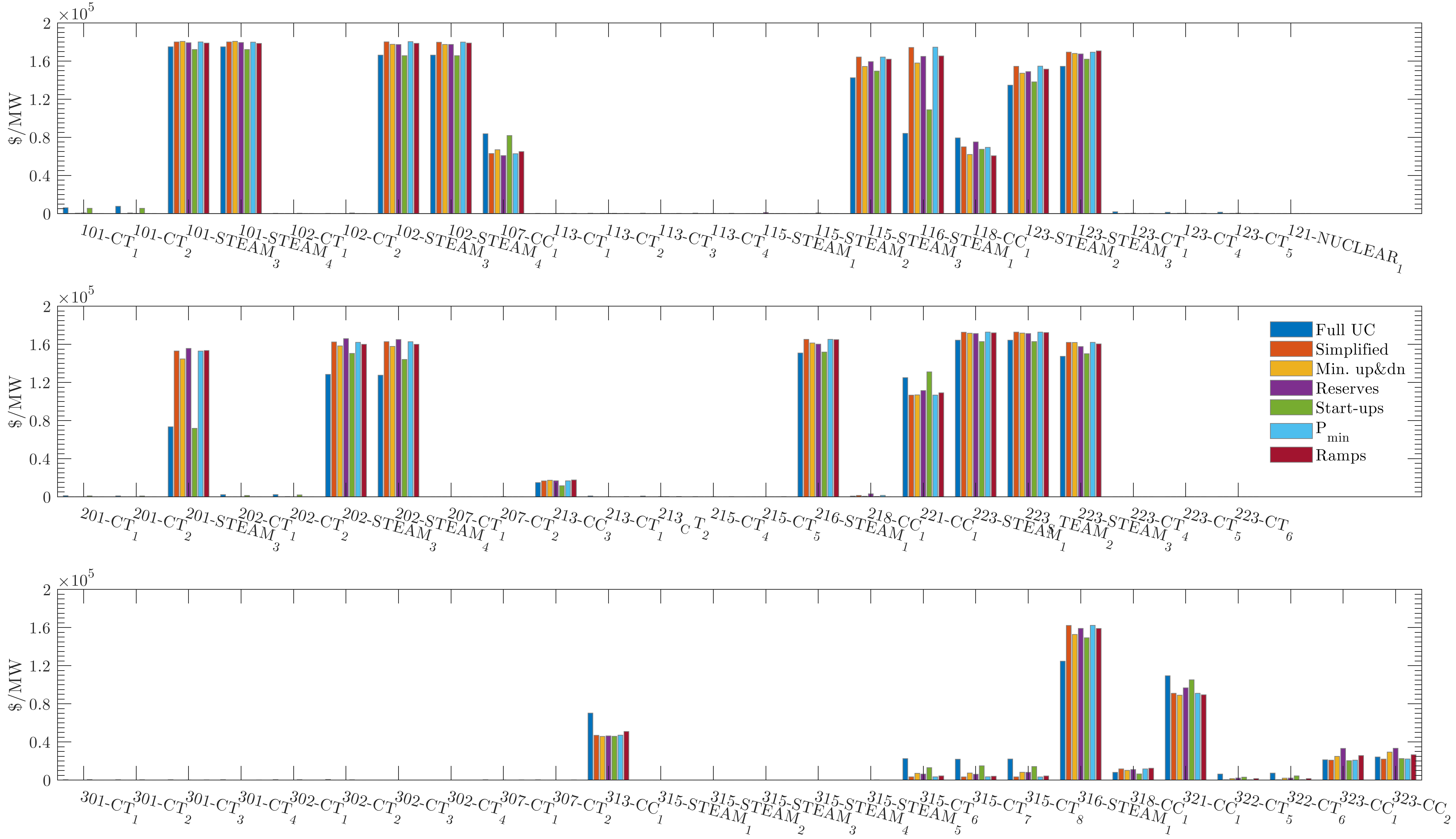

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