Selecting User Queries in Interactive Job Scheduling[1]

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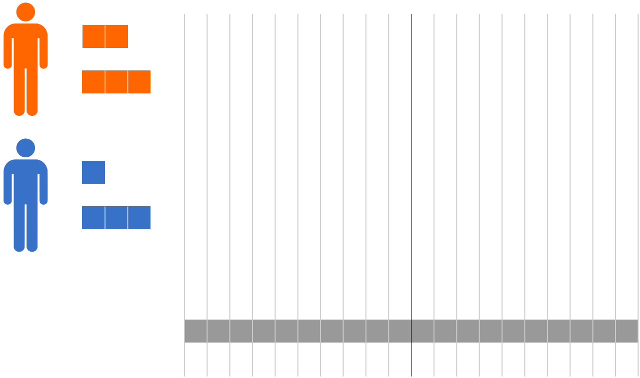
Problem Setting



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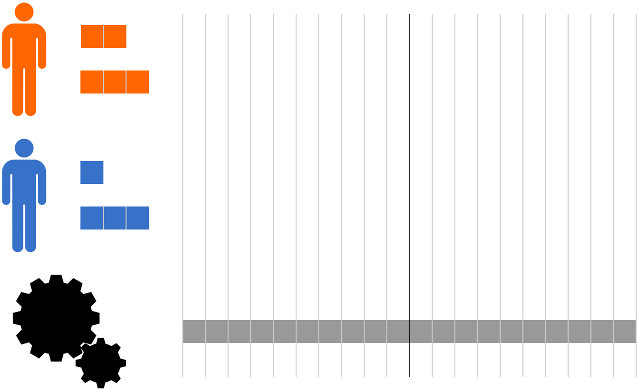

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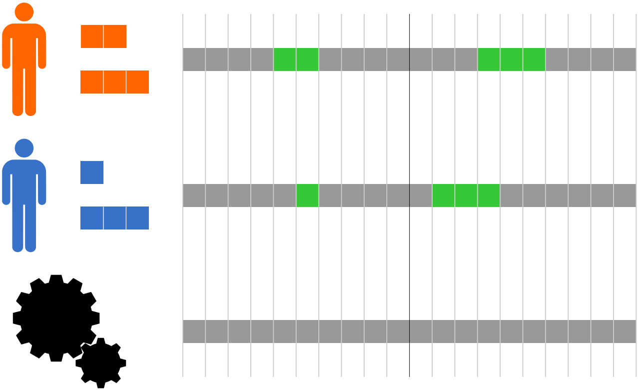

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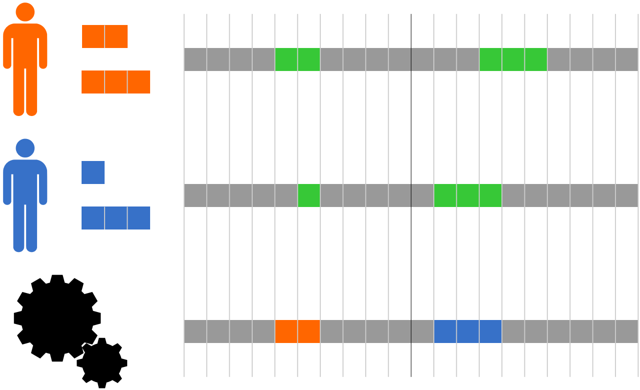

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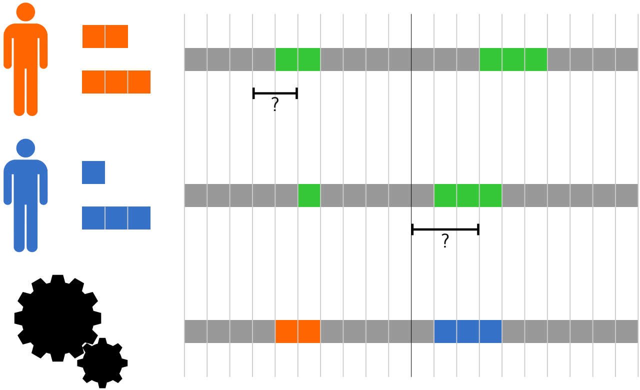

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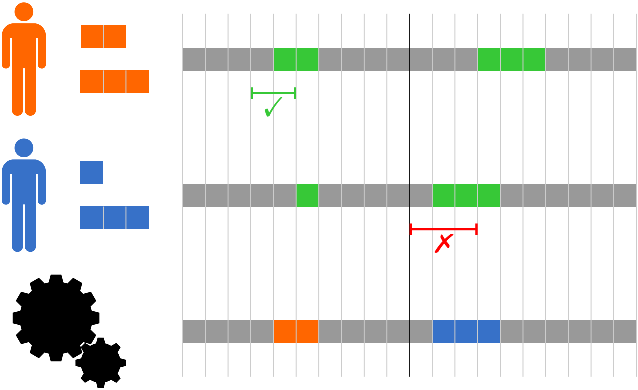

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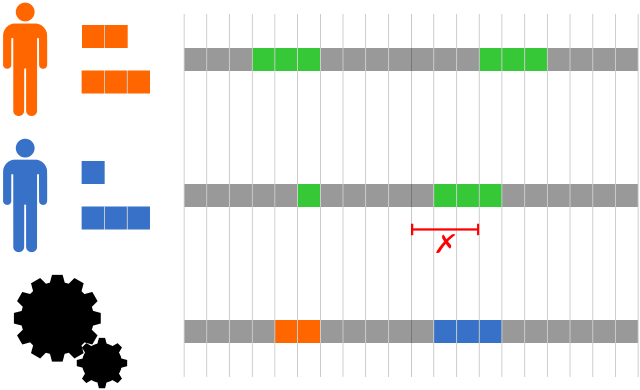

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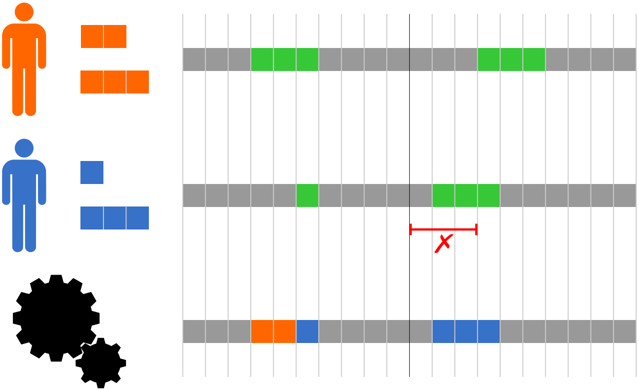

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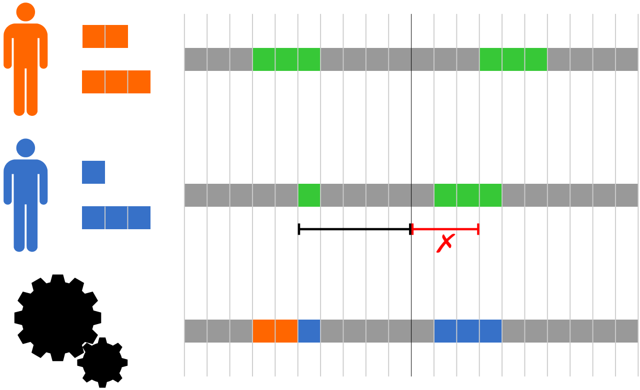

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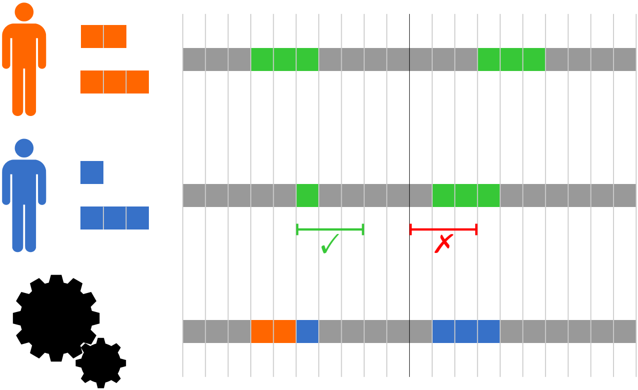

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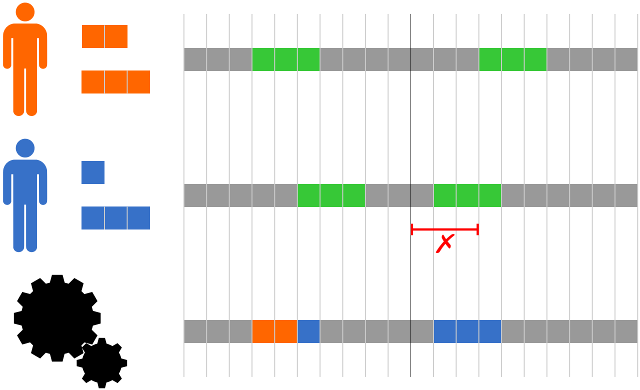

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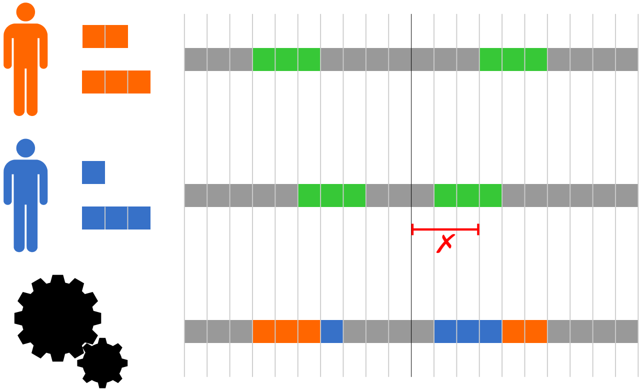


Problem

Core problem:

- Discrete time planning horizon of multiple days
- Multiple users
- Multiple jobs per user
- one machine
- Schedule jobs non-preemptively on machine

Objective:

- time dependent costs c_t for using the machine at timestep t
- penalty q_j for not scheduling a job j
- not scheduling a job is more expensive than scheduling it

Problem

User availabilities:

- Limit job running times
- Only partially known
- Complement knowledge with interaction

Interaction:

- B rounds of interaction
- each with up to b queries
- Query types: Yes/No and Timeframe

Application examples:

- Human resource planning (e.g. scheduling of lectures)
- EV Charging

Literature

Considered problem setting in previous work[2]

Neglect users: Job Scheduling Problem $Pm||TEC$

- MILP and various heuristics (greedy, genetic algorithm, local search) for $Pm||C_{\max}, TEC$[3]
- MILP and Dantzig-Wolfe decomposition for $Rm||TEC$[4]
- Improved MILP[5]

[2] Varga et al. 2023; Varga et al. 2024.
[3] Wang et al. 2018; Anghinolfi, Paolucci, and Ronco 2021.
[4] Ding et al. 2016.
[5] Cheng, Chu, and Zhou 2018; Saberi-Aliabad, Reisi-Nafchi, and Moslehi 2020.

Probabilistic User Models

Criteria for queries:

1. Good response likely $\longrightarrow$ Model users in probabilistic way
2. Improve the schedule $\longrightarrow$ Optimize

Given:

- Known availabilities T^{avail}
- Rejected time intervals I^{rej}

Compute:

- Acceptance probability of queries
- Reasonable user availabilities

Single user, single day

Markov-Model[6]

Model availabilites with Markov process

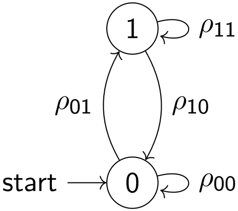


Figure: Two-state Markov Chain

[6] Varga et al. 2023.

Advanced model[7]

Assumptions:

- User available in ≤ 2 intervals
- Morning interval: start 9am$\pm$1h, duration 4h$\pm$1h, probability 90%
- Afternoon interval: start 1pm$\pm$1h, duration 5h$\pm$1h, probability 90%

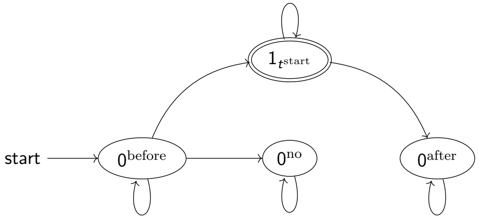
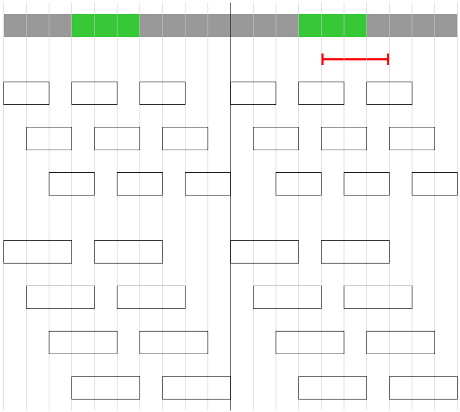


Figure: State diagram for single interval.

[7]Varga et al. 2024.

Probability Threshold[8]



Query candidates

Figure: Procedure in each round

[8]Varga et al. 2023.

Probability Threshold[8]

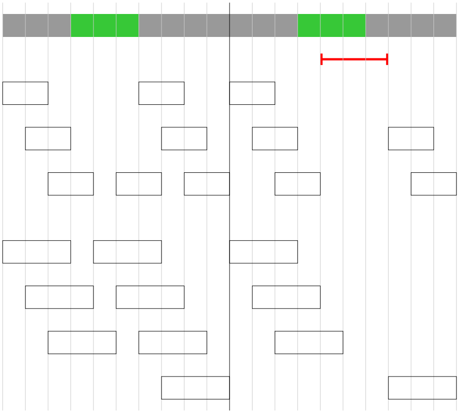
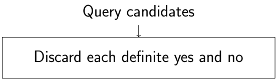


Figure: Procedure in each round



[8] Varga et al. 2023.

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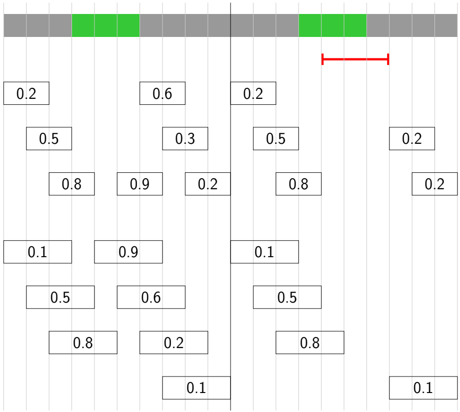

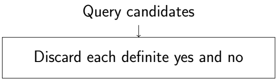

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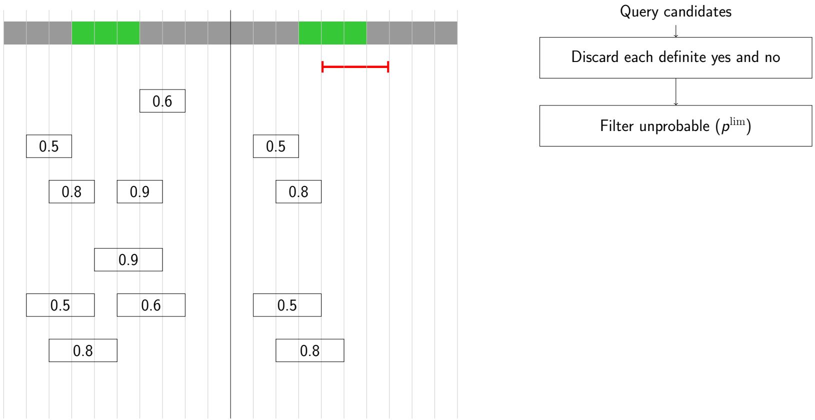

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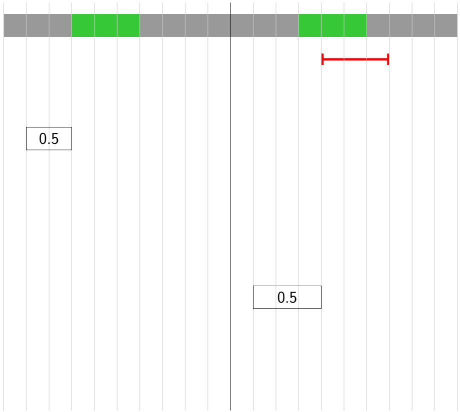

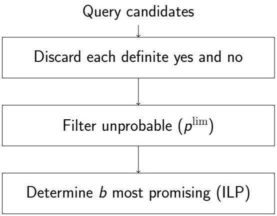

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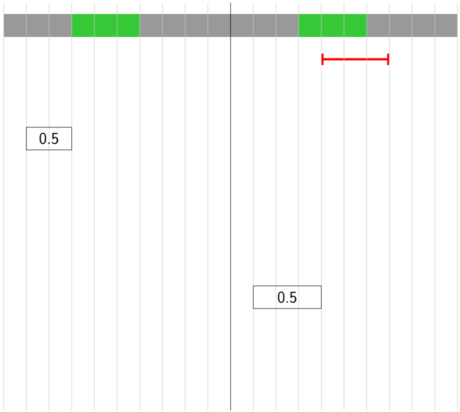

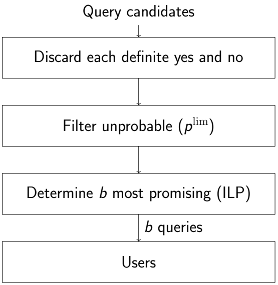

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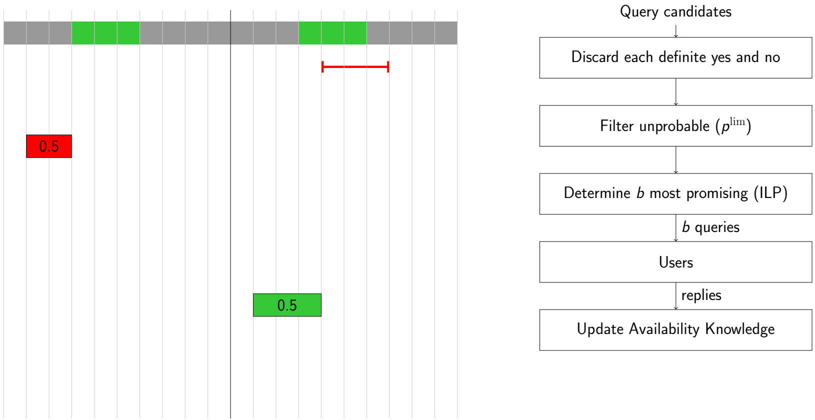

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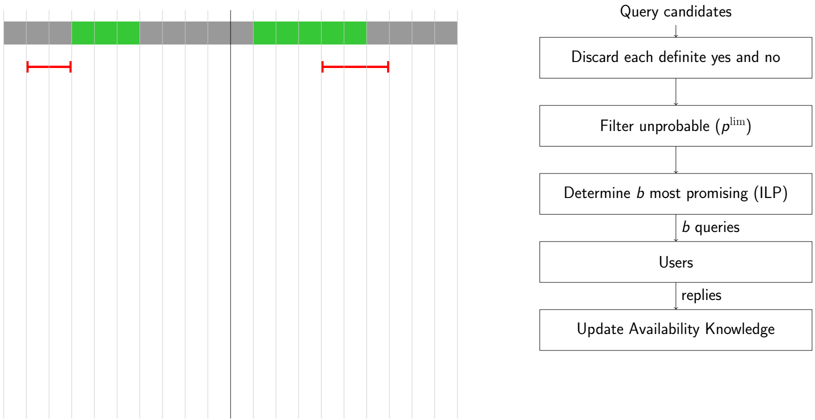

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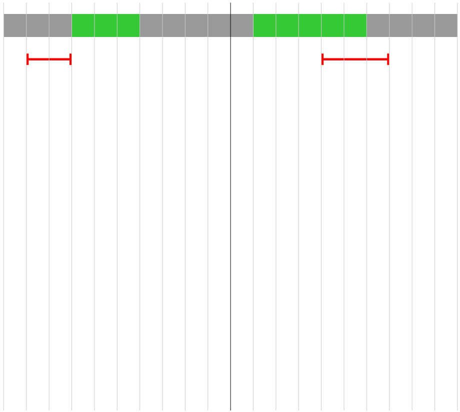


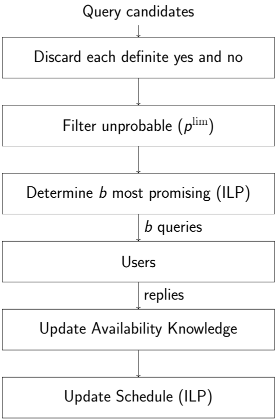


Figure: Procedure in each round

[8]Varga et al. 2023.

Stochastic Programming

Possible queries for each job:

- New starting time
- Half-day timeframe (6am-2pm, 2pm-10pm)

Two stages:

1. Select queries
2. Expected costs

$$
\begin{aligned}
\text{min} \quad & \mathbb{E}_{T^{\text{avail}*}}(\text{ILP}(\mathcal{T}(T^{\text{avail}*}, s^{\text{time}}, s^{\text{frame}}))) \\
\text{s.t.} \quad & \sum_{j \in J} \left(\sum_{t \in T} s_{jt}^{\text{time}} + \sum_{f \in F} s_{jf}^{\text{frame}} \right) \leq b \\
& s_{jt}^{\text{time}} \in \{0,1\} && j \in J, t \in T \\
& s_{jf}^{\text{frame}} \in \{0,1\} && j \in J, f \in F
\end{aligned}
$$

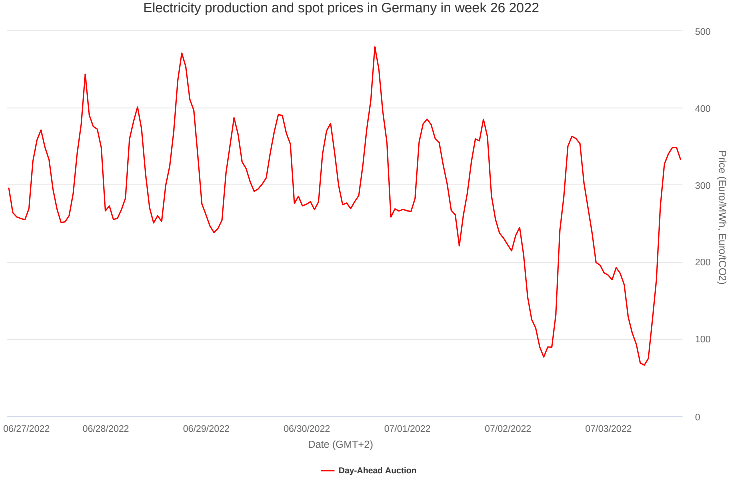
Solve: ILP for sample average approximation (70 samples)

Instance Generation

- one machine, 24 jobs, 6 users
- 30 instances
- five rounds, each with 6 user queries
- five days (6am to 10pm), 4 timesteps per hour
- Job duration: uniformly random from [0.5h,4h]
- Users are simulated and available
  - from 9am$\pm$1h for 4h$\pm$1h with probability 0.9 and
  - from 1pm$\pm$1h for 5h$\pm$1h with probability 0.9
- Known availabilities: one random starting time chosen for each job

Cost Function: Energy Prices in Germany

Job penalty: 40 Euro per timestep



Energy-Charts.info; Data Source: 50 Hertz, Amprion, Tennet, TransnetBW, EEX, EPEX SPOT; Last Update: 01/04/2023, 2:08 PM GMT+1

Results 1

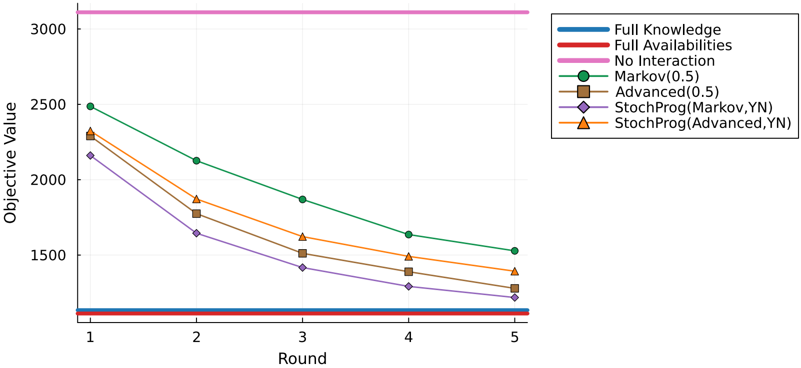
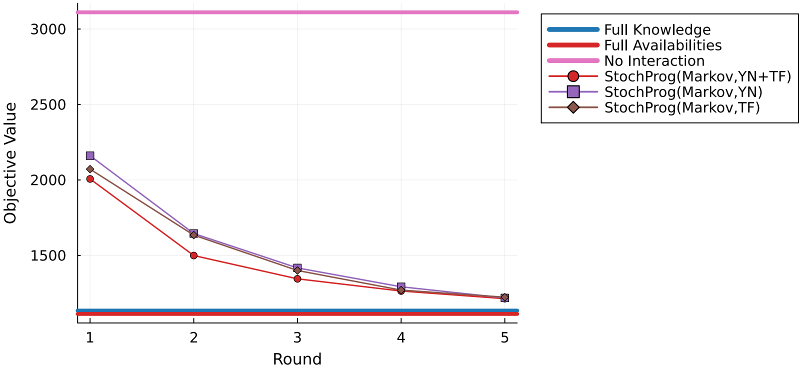


Figure: Mean objective values, 24 jobs, 6 users

Results 2



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Results 3

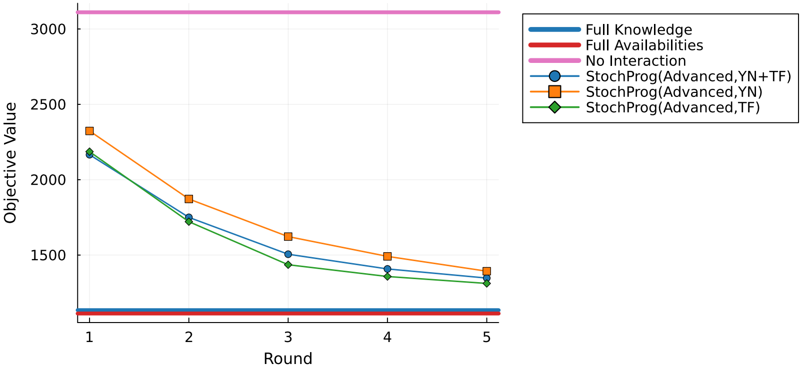


Figure: Mean objective values, 24 jobs, 6 users

Conclusion and Future Work

Conclusions:

- Stochastic programming significantly better than probability threshold approach
- But: harder to solve
- Query type: small influence
- Markov model better for stochastic programming

Future Work:

- Learn user model from historic availability data
- Heuristic and/or Benders decomposition → solve larger instances

Thank you!

ILP (Interactive Job Scheduling)

$$
\begin{aligned}
\mathrm{ILP}(\mathcal{T}) \quad \min \quad & \sum_{j\in J}\sum_{t\in\mathcal{T}_j}\sum_{t'\in T_j[t]} c_{t'} x_{jt} + \sum_{j\in J} q_j \left(1 - \sum_{t\in\mathcal{T}_j} x_{jt}\right) \\
\text{s.t.} \quad & \sum_{t\in\mathcal{T}_j} x_{jt} \le 1 && j \in J \\
& \sum_{j\in J}\ \sum_{t\in\mathcal{T}_j \mid t'\in T_j[t]} x_{jt} \le 1 && t' \in T \\
& \sum_{j\in J_u}\ \sum_{t\in\mathcal{T}_j \mid t'\in T_j[t]} x_{jt} \le 1 && u \in U,\ t' \in T \\
& x_{jt} \in \{0,1\} && j \in J,\ t \in \mathcal{T}_j
\end{aligned}
$$

J ... Jobs $\quad$ T ... Time horizon

$\mathcal{T}_j$ ... allowed starting times for job j

x_{jt} ... 1, iff job j starts at timestep t

$T_j[t]$ ... timesteps job j runs in when started at timestep t

Second Stage of Probabilistic Program

n^{samples} instances of ILP(T^{job}) with variables $x_{jt}^{(k)}$ and additional constraints

$$x_{jt}^{(k)} = 0 \qquad j \in J, t \in T \setminus T_j^{\mathrm{pos,(k)}}$$

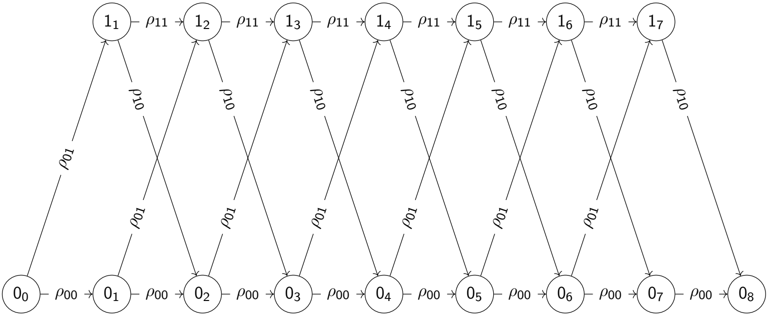
$$s_{jt}^{\mathrm{time}} + \sum_{f \in F_j^{\mathrm{pos,(k)}} \mid t_{jf}^{\mathrm{reply,(k)}} = t} s_{jf}^{\mathrm{frame}} \geq x_{jt}^{(k)} \qquad u \in U, j \in J_u, t \in T, T_j[t] \not\subseteq T_u^{\mathrm{avail}}$$

Computing Environment

- Julia 1.9.3
- Gurobi 10.0.3 (single-threaded) via JuMP
- Single core of Intel Xeon E5-2640 v4
- 60min timelimit for Gurobi

Probability Calculation: Graph

E.g. day with 7 timesteps, $T^{\text{avail}} = \{5, 6\}$, $I^{\text{rej}} = \{[1, 5], [3, 7]\}$



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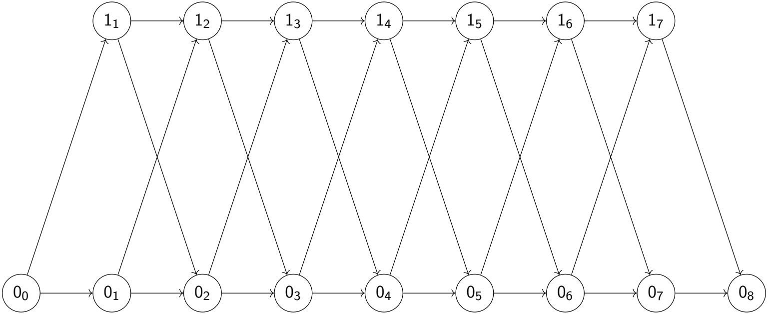

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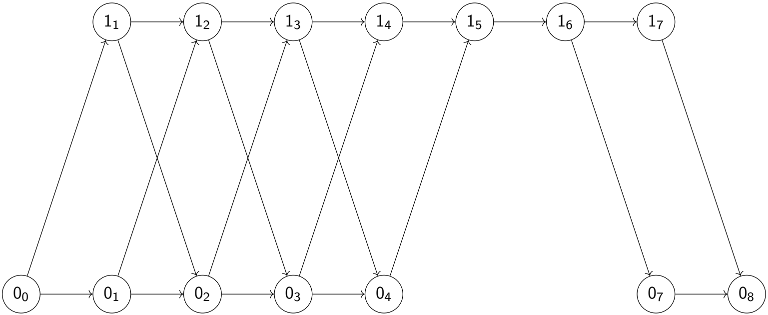

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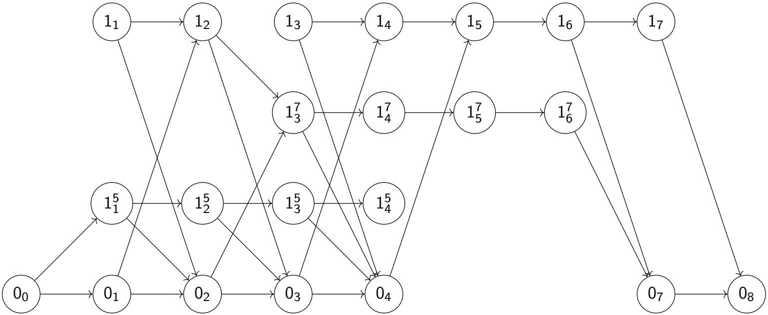

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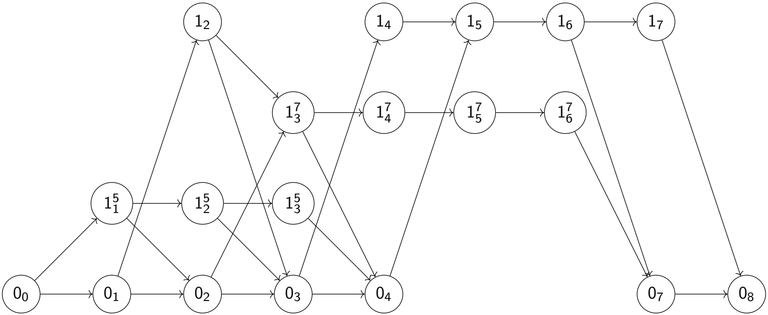


Probability Calculation

$$p^{\text{path}}_{0_0,v} = \sum_{P \in \text{Paths}(0_0,v)} \prod_{(w,w') \in P} \rho(w,w')$$

$$= \sum_{u \in N^-(v)} \sum_{P \in \text{Paths}(0_0,u)} \left(\prod_{(w,w') \in P} \rho(w,w') \right) \cdot \rho(u,v)$$

$$= \sum_{u \in N^-(v)} p^{\text{path}}_{0_0,u} \rho(u,v)$$

$$p^{\text{path}}_{v,0_{t^{\max}+1}} = \sum_{w \in N^+(v)} p^{\text{path}}_{w,0_{t^{\max}+1}} \rho(v,w)$$

Probability Calculation

Probability that $[\tau, \tau']$ will be accepted:

$$p^{\mathrm{avail}}([\tau, \tau'] \mid T^{\mathrm{avail}}, I^{\mathrm{rej}}, 0_{t^{\max}+1}) = \frac{\sum_{P \in \text{1-Paths}(\tau,\tau')} p^{\mathrm{path}}_{0_0, P_\tau} \cdot \rho_{11}^{\tau'-\tau} \cdot p^{\mathrm{path}}_{P_{\tau'}, 0_{t^{\max}+1}}}{p^{\mathrm{path}}_{0_0, 0_{t^{\max}+1}}}$$

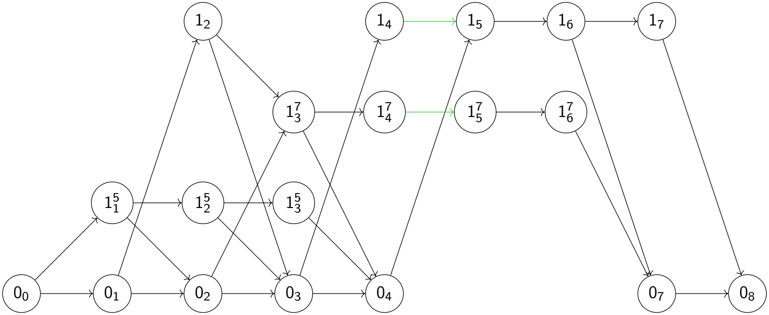


Figure: 1-Paths(4,5) for the example in green

Results 4

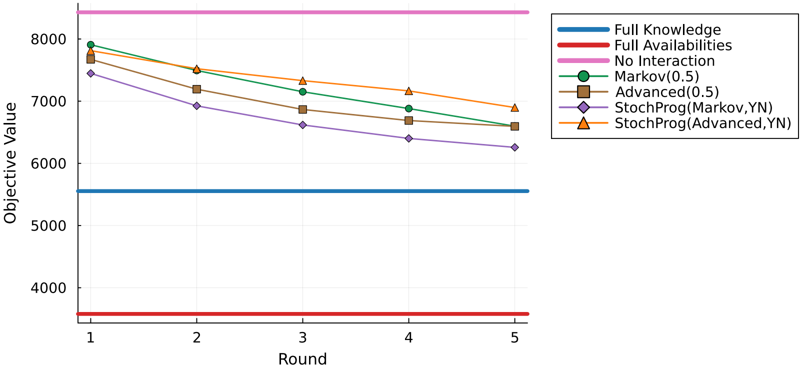
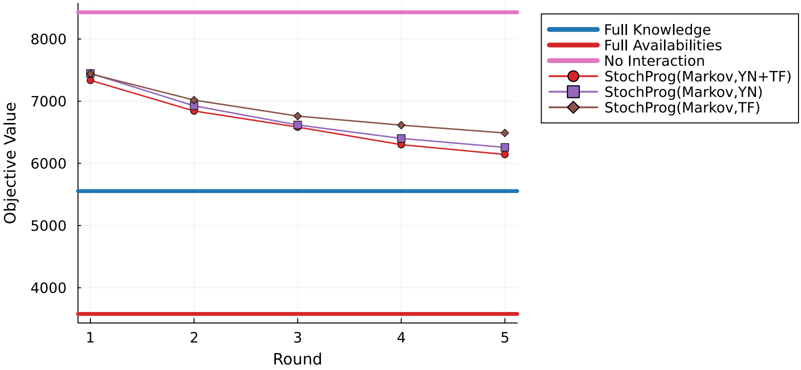


Figure: Mean objective values, 48 jobs, 12 users

Results 5



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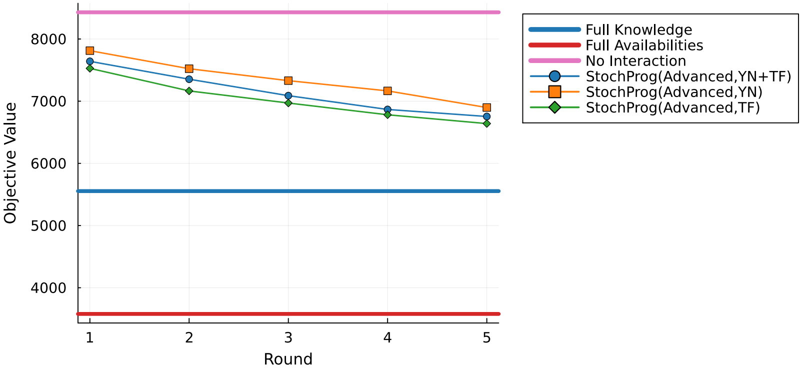

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