Boosting Power System Operation Economics via Closed-Loop Predict-and-Optimize (C-PO)

Xianbang Chen, Stevens Institute of Technology
Yikui Liu, Sichuan University
Lei Wu, Stevens Institute of Technology

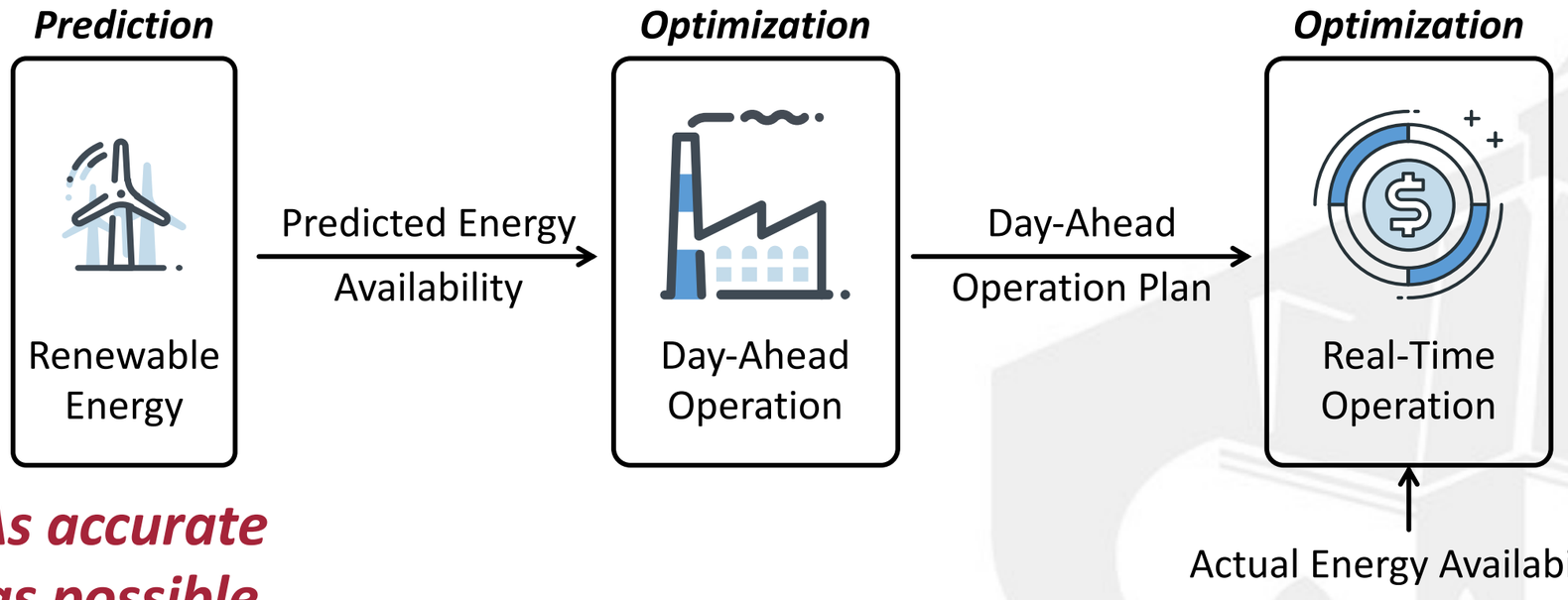
June 5, 2024

Content

Boosting Power System Operation Economics via Closed-Loop Predict-and-Optimize (C-PO)

Background: Power System Operations

- ***Operations in Open-Loop Predict-then-Optimize (O-PO)***



As accurate as possible

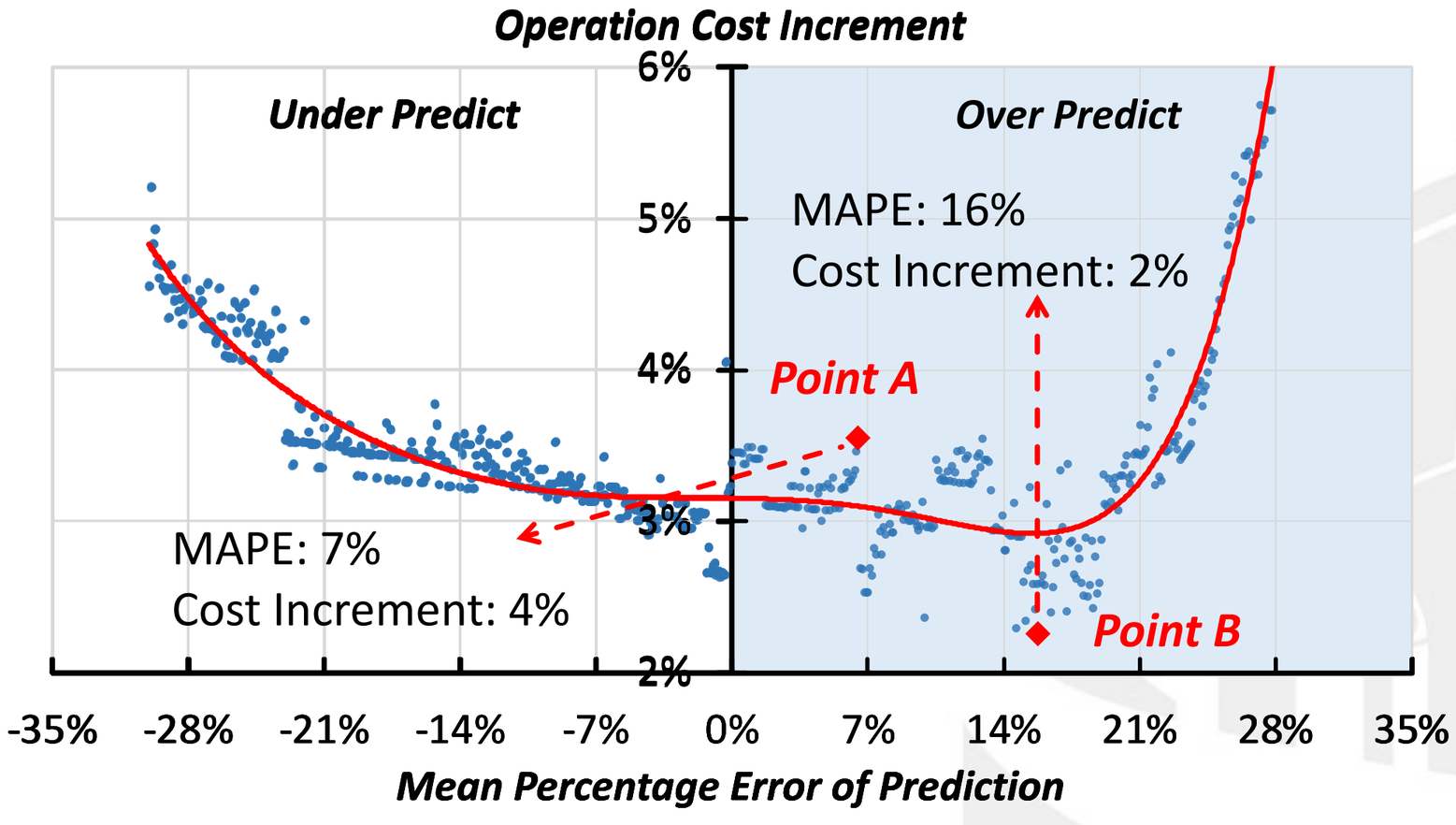
⇨ ***Minimum Operation Cost***

- ***Lower Operation Cost ⇔ Better Operation Economics***

Motivation: Flaw in Open-Loop Process

- ***More Accurate Prediction ⇏ Lower Operation Cost***

MAPE: Mean absolute percentage error



Point A vs Point B

Worse error enables better operation economics.

Why?

Systems are complex.

The accuracy-economics relationship is nonlinear.

O-PO ignores this.

*“In many real-world applications, the **ultimate goal** is not to make good predictions, but rather to use the often noisy predictions to **make good decisions**.”*

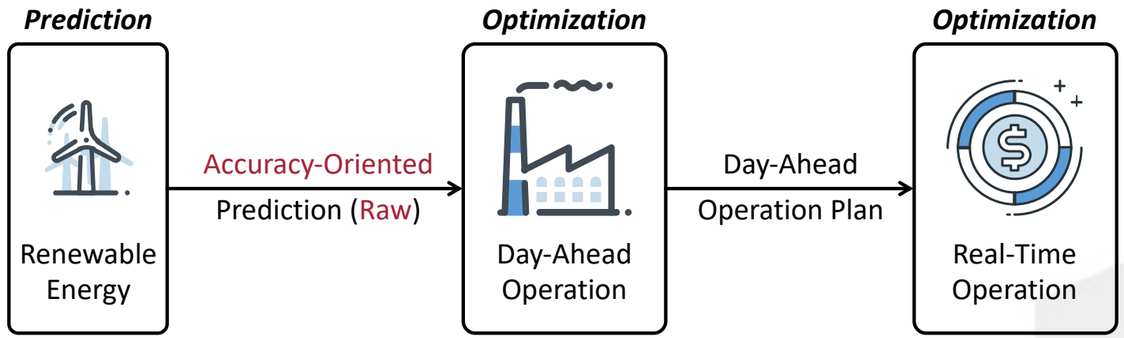
---- Yoshua Bengio

in *Using a Financial Training Criterion Rather than a Prediction Criterion*, 1997

Our Idea: Closed-Loop Predict-and-Optimize

Open-Loop

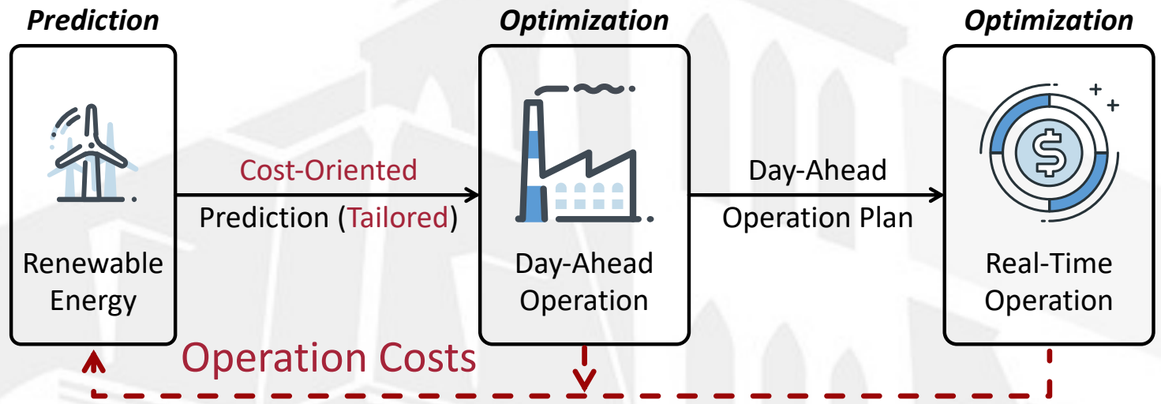
Predict-then-Optimize (O-PO)



- Train predictor with accuracy criterion
- Open-loop and accuracy-oriented

Closed-Loop

Predict-and-Optimize (C-PO)



- Train predictor with cost criterion
- Closed-loop and cost-oriented

C-PO.v1: Train Cost-Oriented Predictor $\boldsymbol{H}$

$$\min_{\boldsymbol{H}} \frac{1}{k} \sum_{k=1}^{K} SPO\ \ell oss_k$$

- $SPO\ \ell oss = \left| Operation\ Cost(\boldsymbol{H}) - Operation\ Cost^{\text{Perfect}} \right|$
  $Operation\ Cost^{\text{Perfect}}$ is resulted by error-free prediction.
- Measure operation cost increment caused by predictor $\boldsymbol{H}$.
- Predictor $\boldsymbol{H}$ learns to generate cost-oriented predictions that can make the operation cost lower.

C-PO.v2: Bilevel Training for Predictor $\boldsymbol{H}$

Upper Level (Predictor Training)

$$\min_{\boldsymbol{H}} \frac{1}{K}\sum_{k=1}^{K}(\boldsymbol{a}^\top \boldsymbol{x}_k + \boldsymbol{b}^\top \boldsymbol{y}_k)$$

$$\widehat{\boldsymbol{w}}_k = \boldsymbol{H}\boldsymbol{f}_k;\ \forall k$$

Total Operation Cost

Prediction $\widehat{\boldsymbol{w}}_k$

Lower Level 1 (Day-Ahead Operation)

$$\boldsymbol{x}_k \in \underset{\boldsymbol{x}_k \in \mathcal{X}(\widehat{\boldsymbol{w}}_k)}{\operatorname{argmin}}\ \boldsymbol{c}^\top \boldsymbol{x}_k;\ \forall k$$

Day-Ahead Operation Plan $\boldsymbol{x}_k$

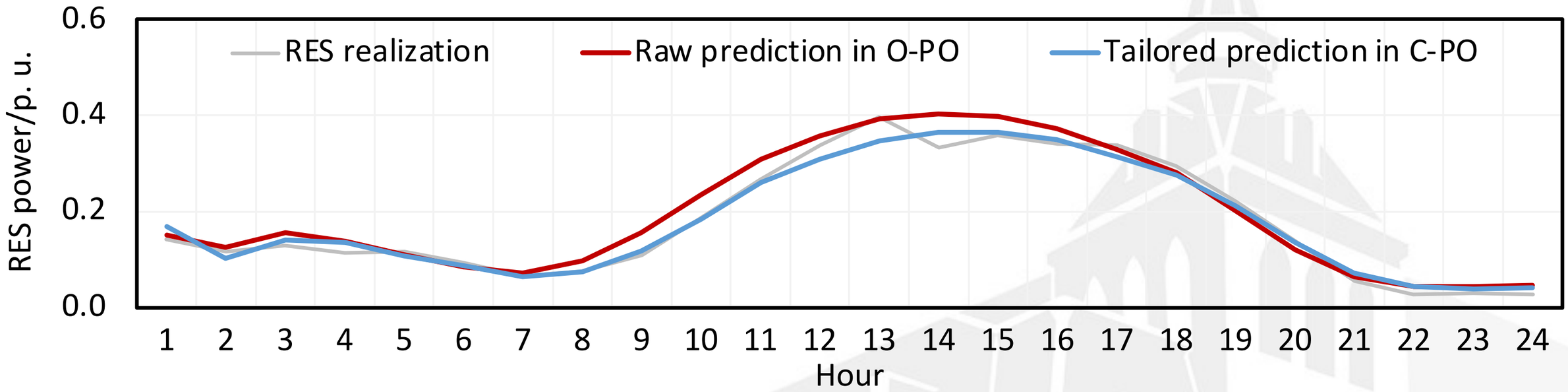
Lower Level 2 (Real-Time Operation)

$$\boldsymbol{y}_k \in \underset{\boldsymbol{y}_k \in \mathcal{Y}(\boldsymbol{x}_k, \tilde{\boldsymbol{w}}_k)}{\operatorname{argmin}}\ \boldsymbol{d}^\top \boldsymbol{y}_k;\ \forall k$$

Day-Ahead Operation Cost $\boldsymbol{a}^\top \boldsymbol{x}_k$

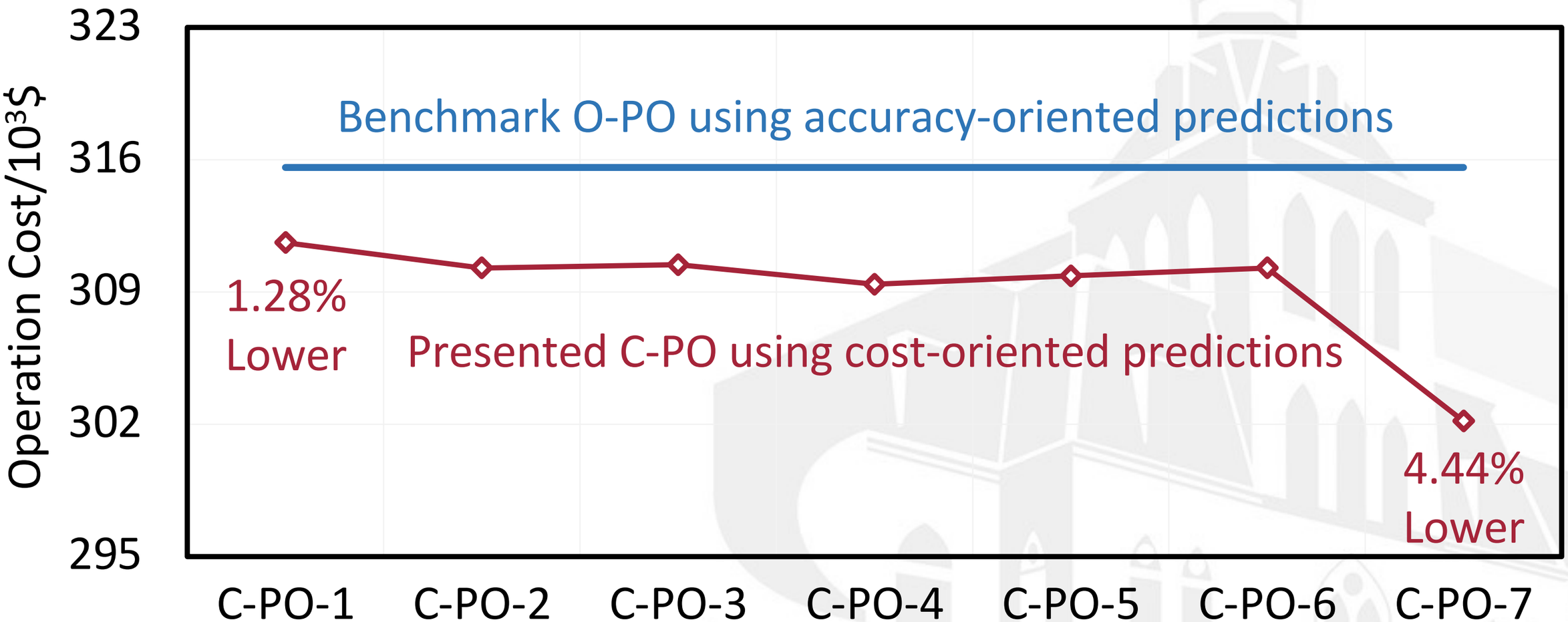
Real-Time Operation Cost $\boldsymbol{b}^\top \boldsymbol{y}_k$

C-PO vs O-PO on Real-World Dataset



Type of Prediction	Mean Absolute Percentage Error (MAPE)	Root Mean Square Error (RMSE)
Accuracy-Oriented	39%	130MW
Cost-Oriented	34% (Better)	149MW (Worse)

C-PO vs O-PO on Real-World Dataset



Takeaways

- ***Key Points***
  - Prediction is to improve the operation performance instead of accuracy.
- ***Thinking***
  - Use reinforcement/deep learning to do closed-Loop predict-and-optimize?
  - Reliability-oriented prediction?
- ***References and Codes***

"Feature-Driven Economic Improvement for Network-Constrained Unit Commitment: A Closed-Loop Predict-and-Optimize Framework," *IEEE Transactions on Power Systems*, 2022.

"Towards Improving Operation Economics: A Bilevel MIP-Based Closed-Loop Predict-and-Optimize Framework for Prescribing Unit Commitment," *Third-Round Review under IEEE Transactions on Sustainable Energy*.