# *Toward Integrating Mathematical Programming and Machine Learning: Boosting Power System Operation Economics via Closed-Loop Predict-then-Optimize*

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# Agenda

**Closed-Loop Predict-then-Optimize (C-PO)**

I. Preliminaries and Motivations

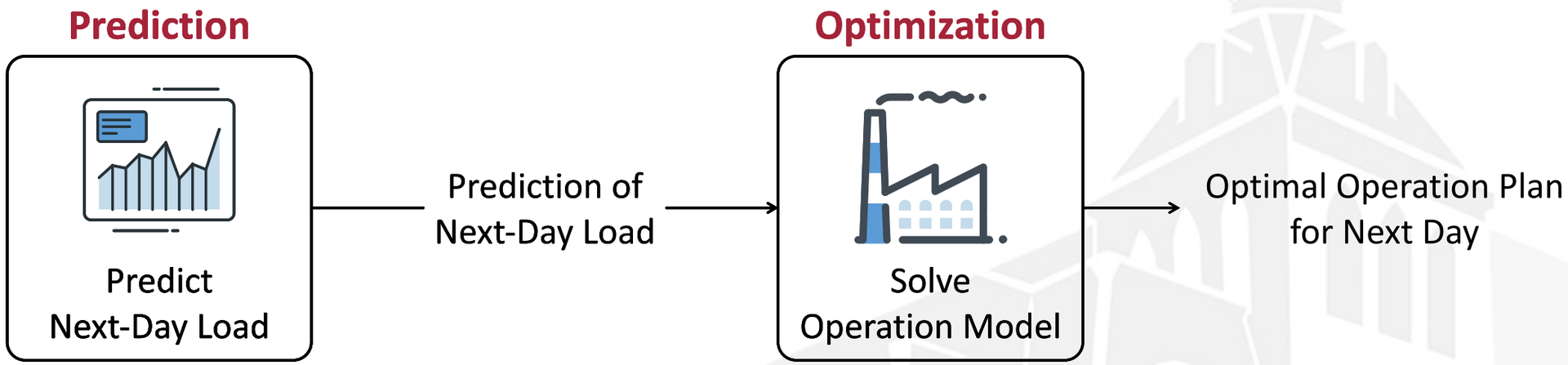
II. Closed-Loop Predict-then-Optimize Idea

III. Case Studies

IV. Summary

# Preliminaries

- ***Operations in Open-Loop Predict-then-Optimize (e.g., PSE&G around Hoboken):***

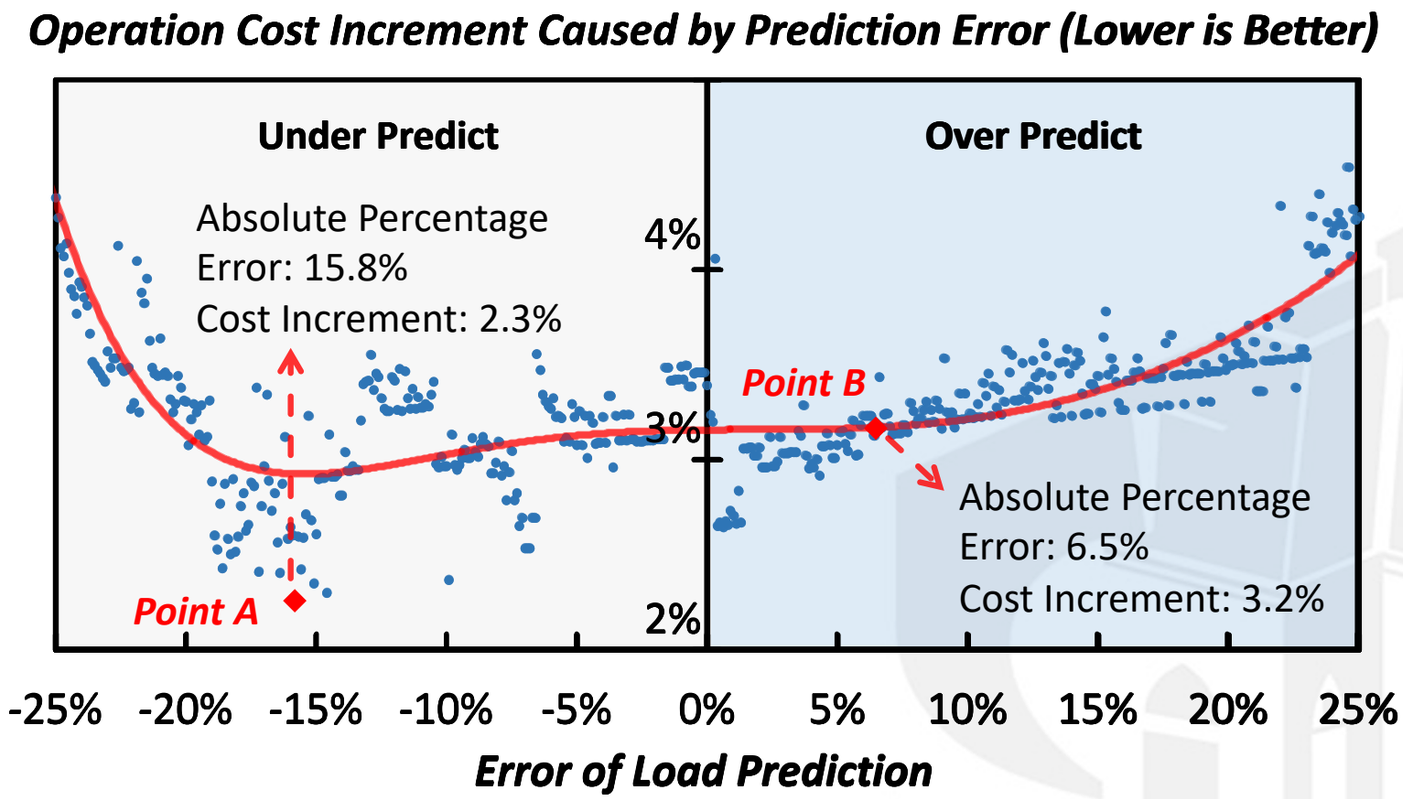



  - ***Step 1: Machine learning predicts load demand as accurately as possible***
  - ***Step 2: Operation plans are optimized by solving mathematical models***

- ***Operator's Goal: Minimum Operation Cost (Lower Cost Means Better Economics)***

# Motivations: Flaw in Open-Loop Predict-then-Optimize (O-PO)

- *More Accurate Prediction ⇏ Lower Operation Cost*




**Point A vs Point B**

Worse prediction error enables lower operation cost

**Why?**

Real-world operation problems are nonlinear

Accuracy-cost relationship is nonlinear

O-PO ignores this

# *Motivations: Flaws in Open-Loop Predict-then-Optimize (O-PO)*

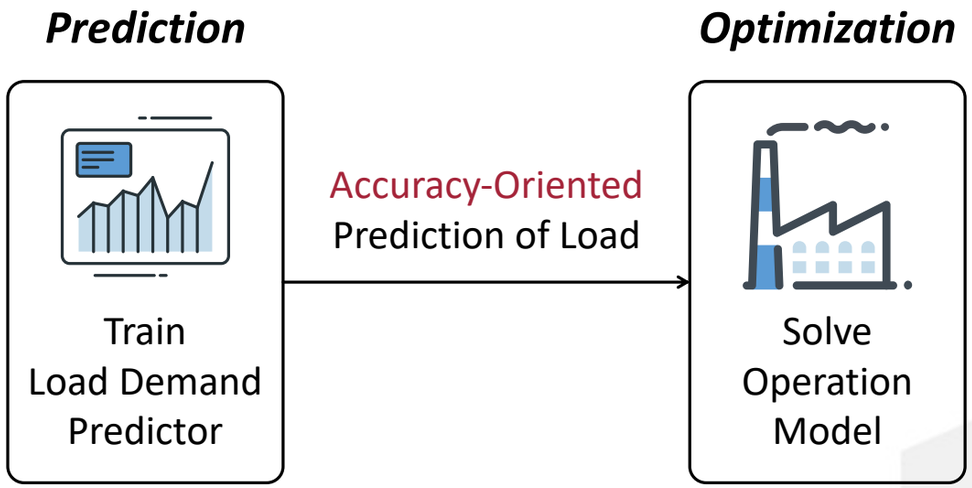
*"In many real-world applications, the **ultimate goal** is not to make good predictions, but rather to use the often noisy predictions to **make good decisions**."*

---- Yoshua Bengio

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

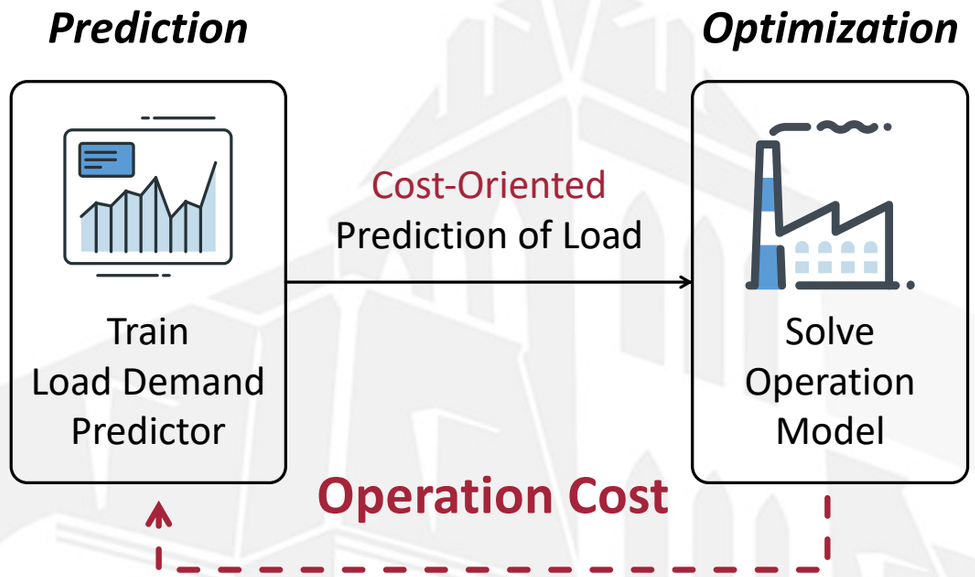
# *Closed-Loop Predict-then-Optimize Idea: What is It?*

## *Open-Loop* Predict-then-Optimize (O-PO)




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

## *Closed-Loop* Predict-then-Optimize (C-PO)




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

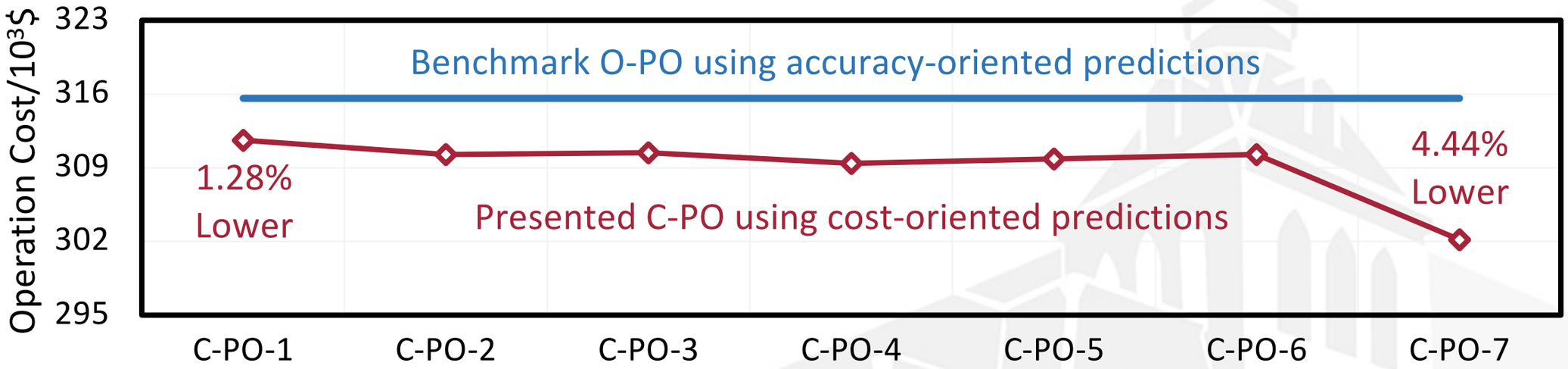
# C-PO Idea: How to Close the Opened Loop?

- ***Train Machine Learning-based Predictor $\mathcal{P}$ via Cost-Oriented Loss Function (Don't Simply Pursue Prediction Accuracy!)***

$$\min_{\mathcal{P}} \frac{1}{S} \sum_{s=1}^{S} \left| \text{Operation Cost}(\mathcal{P})_s - \text{Operation Cost}_s^{\text{Perfect}} \right|$$

  - $\text{Operation Cost}(\mathcal{P})_s$ is the cost induced by predictor $\mathcal{P}$ in scenario $s$
    $\text{Operation Cost}_s^{\text{Perfect}}$ is the perfectly low cost in scenario $s$
  - Measure operation cost increment induced by predictor $\mathcal{P}$
  - Predictor $\mathcal{P}$ learns to generate cost-oriented predictions that can make the operation cost closer to its perfection

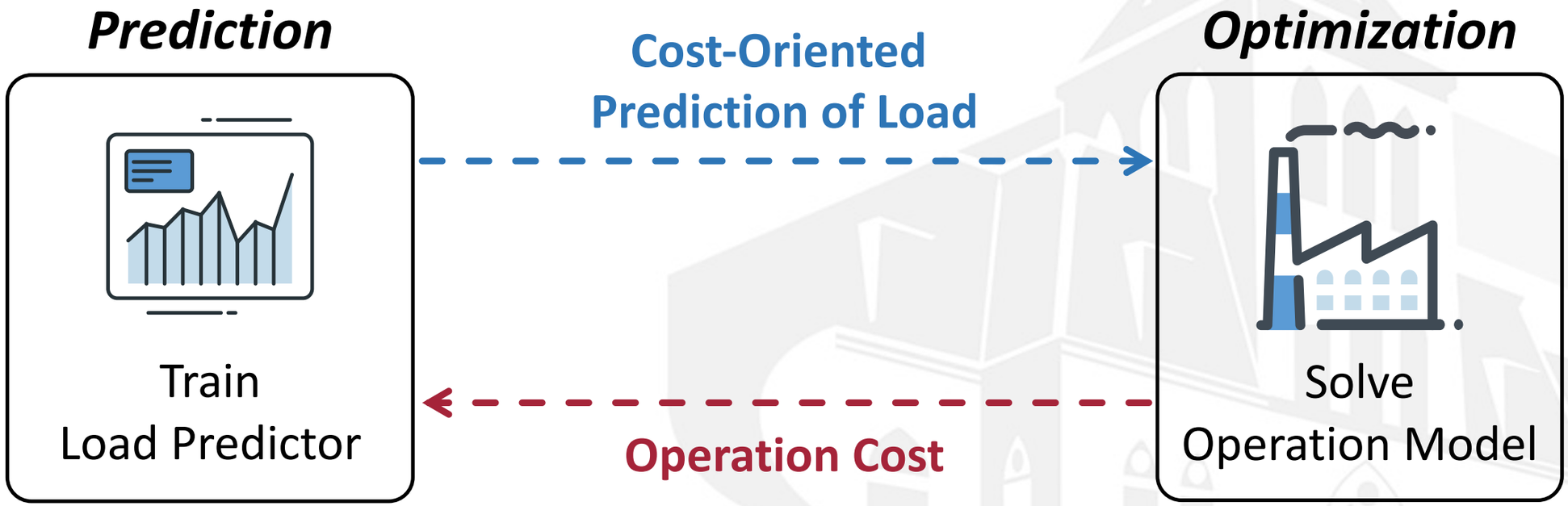
# *Case Studies: C-PO vs O-PO on Real-World Dataset*




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

# Summary

- ***Back to Essence: What is Closed-Loop Predict-then-Optimize?***
  Idea that feeds the optimization back to the prediction for improving the optimization performance. Don't simply pursue the accuracy!!! Pursue the ultimate goal!!!



# *Summary*

- ***Tools to Realize This Idea***
  Deep learning, reinforcement learning, and so on.

- ***Industry Applications***
  Power system operation, supply chain scheduling, and so on.

- ***Works based on This Idea***


1. Xianbang Chen, Yafei Yang, Yikui Liu, Lei Wu, “Feature-Driven Economic Improvement for Network-Constrained UC: A Closed-Loop Predict-and-Optimize Framework,” *IEEE Transactions on Power Systems*.

2. Xianbang Chen, Yikui Liu, Lei Wu, “Towards Improving UC Economics: An Add-On Tailor for Renewable Energy and Reserve Predictions,” *IEEE Transactions on Sustainable Energy (Under Second-Round Review)*.