

Study of Two-Stage Robust Unit Commitment

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Outline

- Background
- Deterministic Unit Commitment
- Two-stage Robust Adaptive Unit Commitment
- Solution Methodology
- **Testing Results on ISO-NE system**
- Conclusion

Overview of Real-Time Markets and Operations in ISO New England

- ISO NE's Two-settlement Market System
 - Day-ahead Energy Market
 - Real-time Co-optimized Energy and Ancillary Services Market
- Major Processes In Real-Time Operations
 - Load Forecasting
 - **Reliability Unit Commitment**
 - Security Analysis
 - Coordination with Neighboring Control Areas
 - Outage Coordination
 - Real-time dispatch and Pricing
 - SCADA & EMS
 - Automatic Generation Control

Uncertain Factors in Power Systems

- Power System Model
 - Generation and Transmission Parameters
 - Topology
- System Conditions
 - Load Forecasting
 - Resource Performance
 - Interchange Schedules
 - Wind Power Output
 - Demand response
- Equipment Forced Outages
 - Generator
 - Transmission Element

Risk Management in Operations

- Operating Criteria
 - **N-1 Security:** The system should be able to sustain the loss of any single element
 - 2nd contingency protection for certain import-constrained area
- Risk Control Actions (Preventive vs. Corrective)
 - **Security-constrained unit commitment and economic dispatch**
 - Ancillary Service Requirements
 - Fast-start resources
 - Load frequency control
 - Transaction curtailment
 - Emergency procedure: emergency help from neighboring areas, voltage reduction, load shedding, etc

Operational Challenges

- Recent industry trends create a more dynamic environment for the grid operation:
 - **Increasing renewable and demand resources**
 - Real-time operating parameter re-declaration
 - Real-time performance of dispatchable resources
- Existing tools
 - **Increase reserve requirements**
 - Rely on real-time actions such as fast start units
- Is there **a better unit commitment** schedule to reduce the operational risk by incorporating uncertainty in SCUC?

Deterministic UC Problem

- The objective is to minimize the total commitment cost and dispatch cost

$$\min_{x,y} c^T x + b^T y$$

$$s.t. \quad Fx \leq f, \quad x \text{ is binary} \quad (\text{Feasibility constraints of } x)$$

$$Hy \leq h, \quad (\text{Feasibility constraints of } y)$$

$$Ax + By \leq g \quad (\text{Coupling constraints of } x \text{ and } y)$$

$$I_u y = \bar{d} \quad (\text{Fixed Generation or Consumption Constraints})$$

where

x is the vector of commitment variables

y is the vector of energy and reserve output

\bar{d} is the demand or the fixed output for variable resources

Robust Unit Commitment

- Robust unit commitment ensures the system can operate under the N-1 protection for a set of system conditions
 - It yields a UC decision “immunized against uncertainty”
- “Worst-case-oriented” philosophy
 - Similar to the N-1 criterion
- Robust Optimization is a risk management technique
 - Offers control of the tradeoff between economics and robustness

Two-stage Robust Adaptive UC

- The objective is to minimize the commitment cost and the worst-case dispatch cost

$$\min_{x, y(\cdot)} c^T x + \max_{d \in D} b^T y(d)$$

$$s.t. \quad Fx \leq f, \quad x \text{ is binary} \quad (\text{Feasibility constraints of } x)$$

$$Hy(d) = h(d), \quad (\text{Feasibility constraints of } y)$$

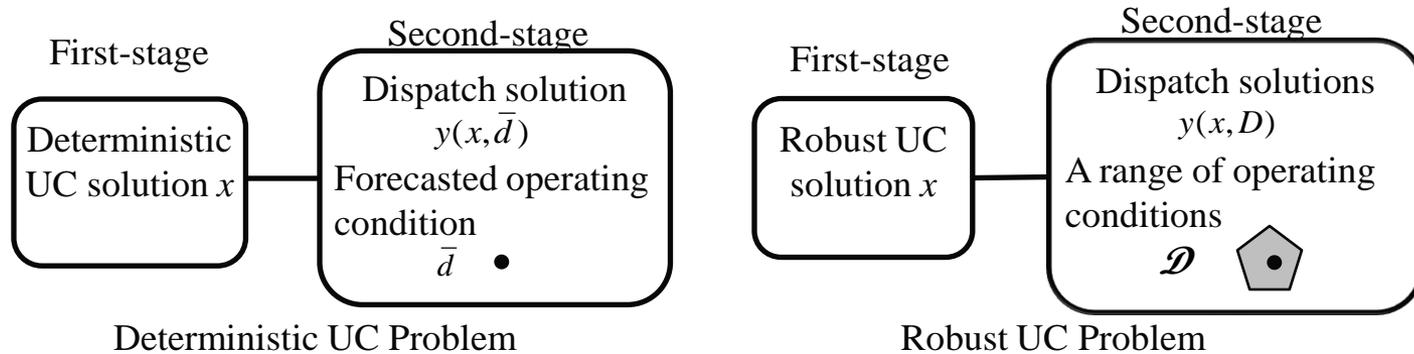
$$Ax + By(d) \leq g, \quad (\text{Coupling constraints of } x \text{ and } y)$$

$$I_u y(d) = d, \quad \forall d \in D \quad (D \text{ is the uncertainty set})$$

- The first-stage UC solution x is feasible for any realization of d in uncertainty set D (“Robust”)
- The second-stage dispatch solution $y(d)$ are fully adaptive to any realization of d (“Adaptive”)

Robust v.s. Deterministic

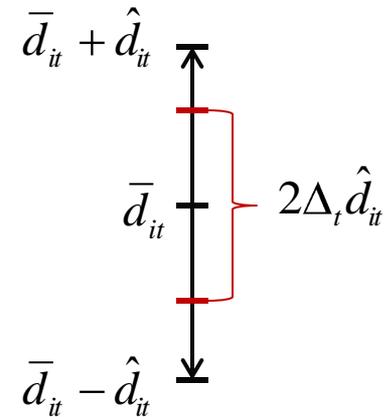
- Deterministic UC problem is a special case of its robust counterpart



- Robust solution takes into account real-time operational uncertainties such as:
 - Load forecast errors and demand response
 - Resources' generating capabilities: wind, solar

Uncertainty Set

$$D = \left\{ d : \sum_i \frac{|d_{it} - \bar{d}_{it}|}{\hat{d}_{it}} \leq \Delta_t, \quad d_{it} \in [\bar{d}_{it} - \hat{d}_{it}, \bar{d}_{it} + \hat{d}_{it}] \right\}$$



- Δ_t is the “budget of uncertainty” for hour t
- $\Delta_t = 0$ yields the deterministic problem
- As Δ_t increases, the uncertainty set enlarges
 - The solution is more robust
- A proper size of the uncertainty set yields a good trade-off between robustness and economics

Reformulation of Robust UC

- The robust model can be rewritten as

$$\min_x c^T x + \max_{d \in D} \min_{y \in \Omega(u, d)} b^T y$$

$$s.t. \quad Fx \leq f, \quad x \text{ binary}$$

$$\text{where } \Omega(x, d) = \{y : Ax + By \leq g \quad (\lambda), \quad Hy \leq h \quad (\varphi), \quad I_u y = d \quad (\eta)\}$$

- The second-stage max-min problem is equivalent to the following bilinear optimization problem

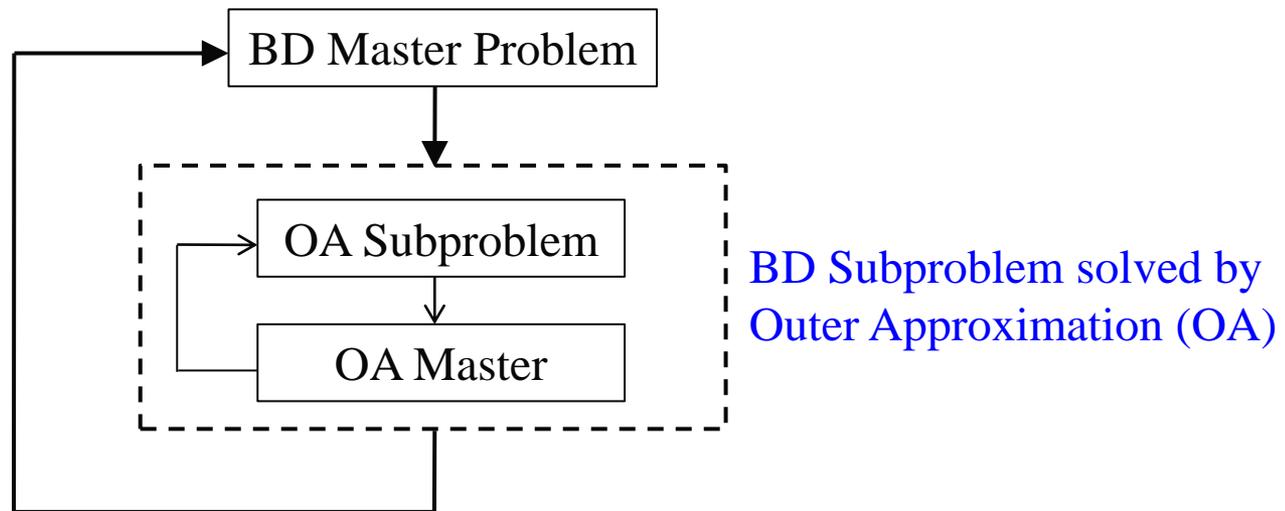
$$\max_{d, \varphi, \lambda, \eta} \lambda^T (Ax - g) - \varphi^T h + \eta^T d$$

$$s.t. \quad -\lambda^T B - \varphi^T H + \eta^T I_u = b^T$$

$$d \in D, \varphi \geq 0, \lambda \geq 0$$

Solution Methodology

- Benders decomposition is used as the overall algorithm
 - The master problem with Benders cuts solves commitment \mathbf{x}
 - The subproblem with fixed \mathbf{x} is a bilinear optimization problem
- The bilinear subproblem is solved by outer approximation



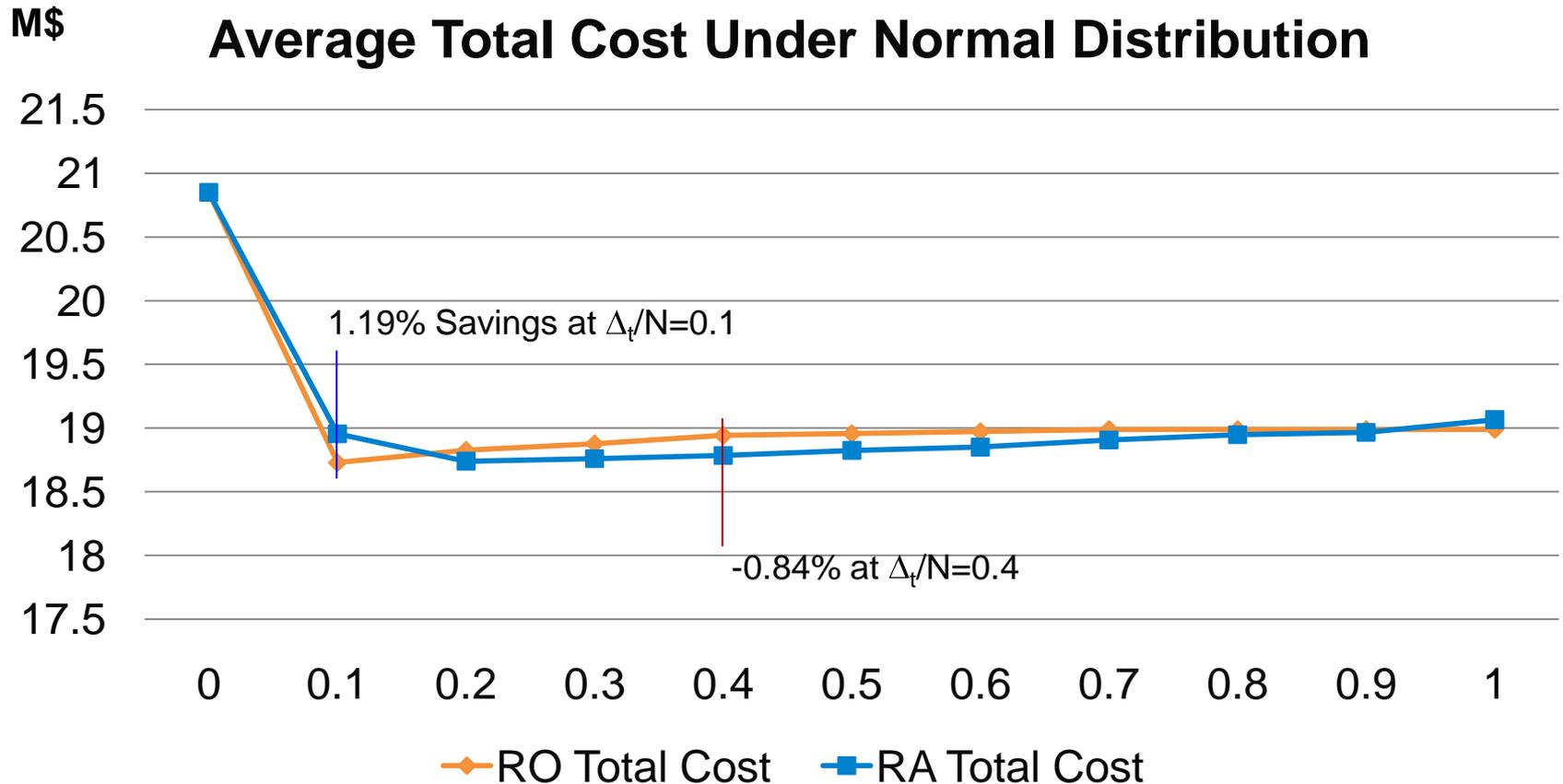
Case Study

- A case of the ISO-NE system
 - 2816 buses, 312 generators, 170 loads
 - Average hourly load 14136 MW
 - 24 hours, 4 representative transmission constraints
- Max variation for each load is 10% of the expected value
- Compare Robust Optimization (RO) with the deterministic approach with Reserve Adjustment (RA)

$$R_{jt} = R_{jt}^0 + \frac{\Delta_t}{N} \sum_{i=1}^N \hat{d}_{it} \quad - \text{Adjusted type-}j \text{ reserve at hour } t$$

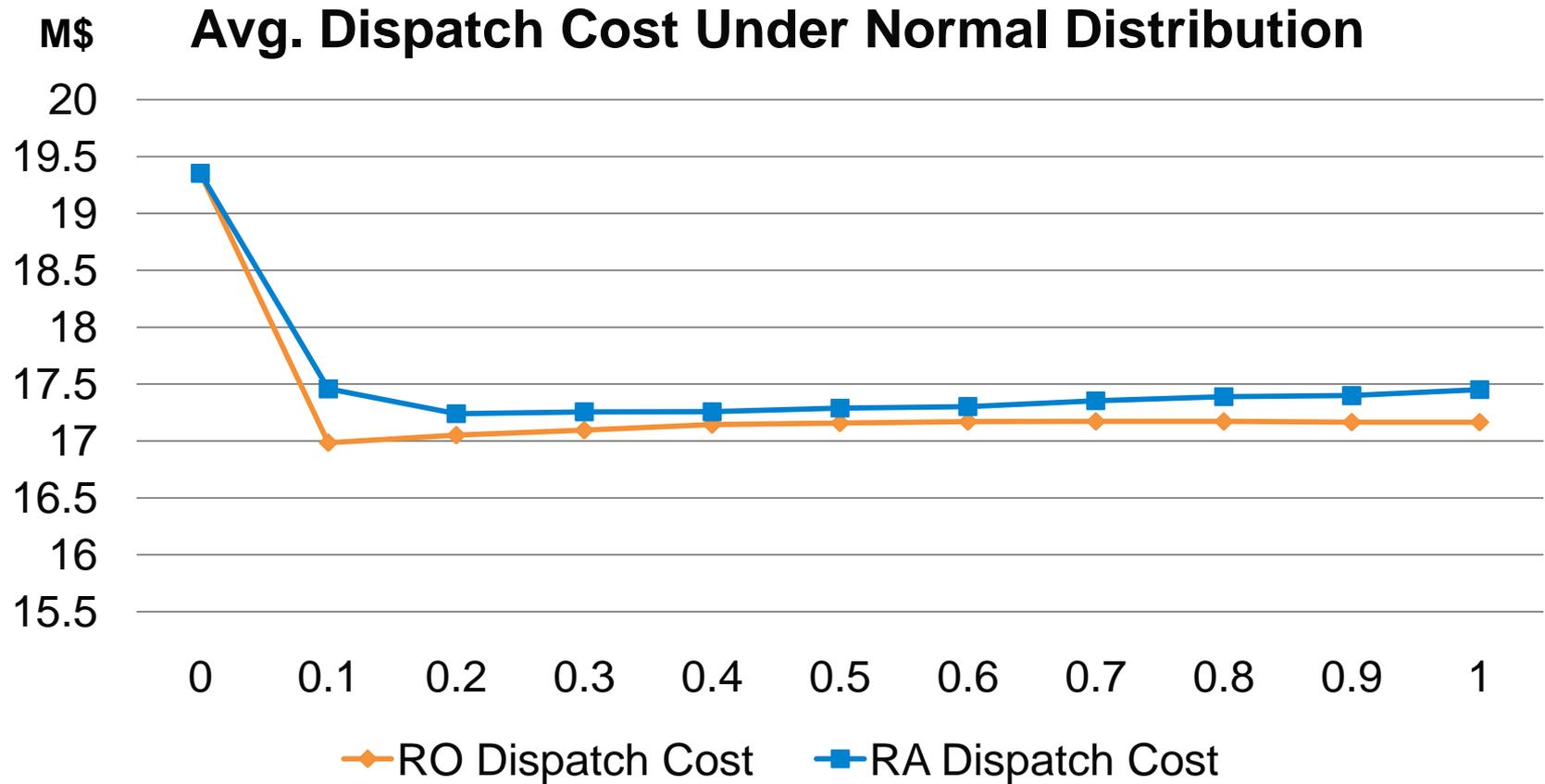
- MC simulation is used to evaluate the results
 - 1000 random samples were generated with different distribution assumptions

Average Total Cost

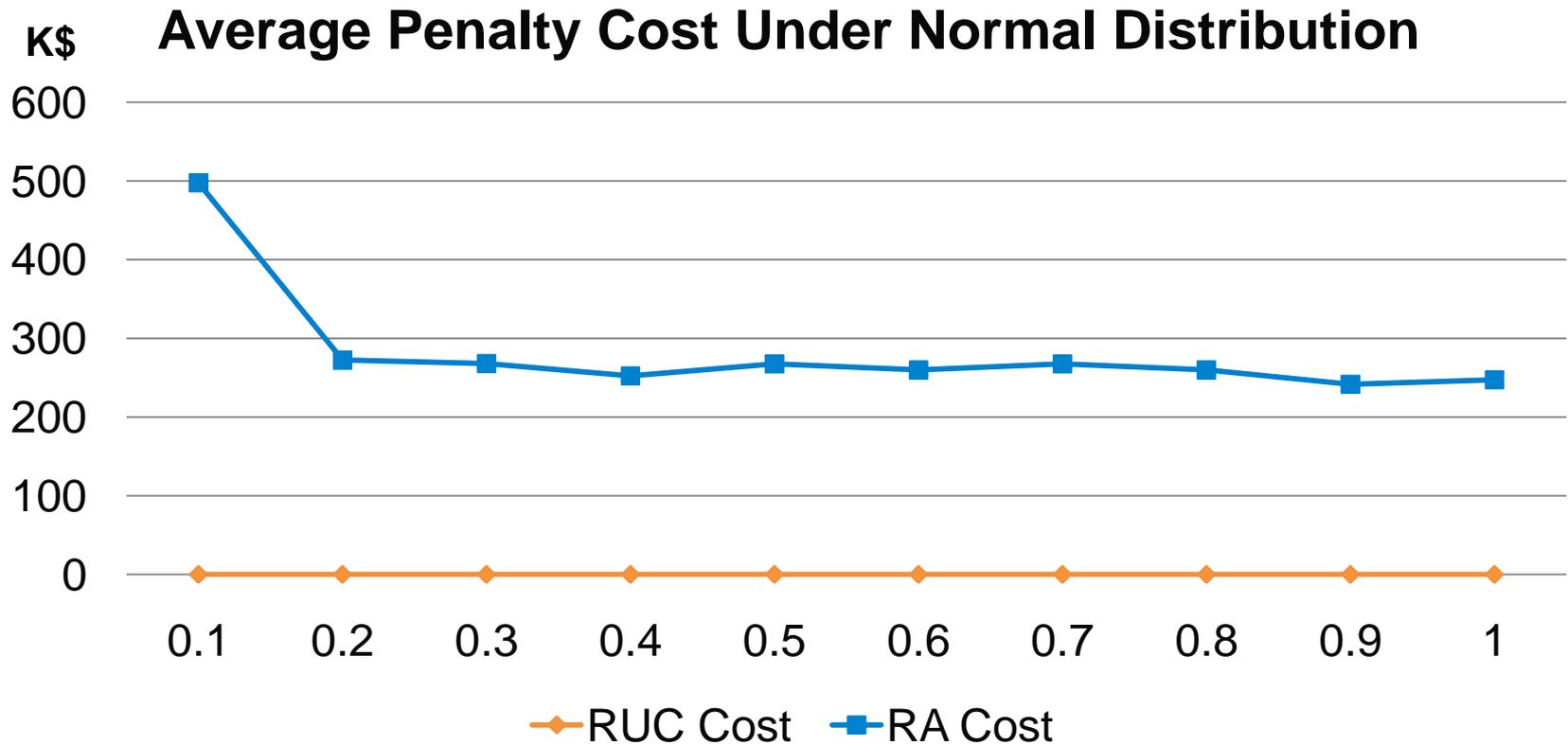


X-axis indicates the normalized budget of uncertainty (Δ_t/N) ; level of 1 implies roughly 2000 MW of total load variation

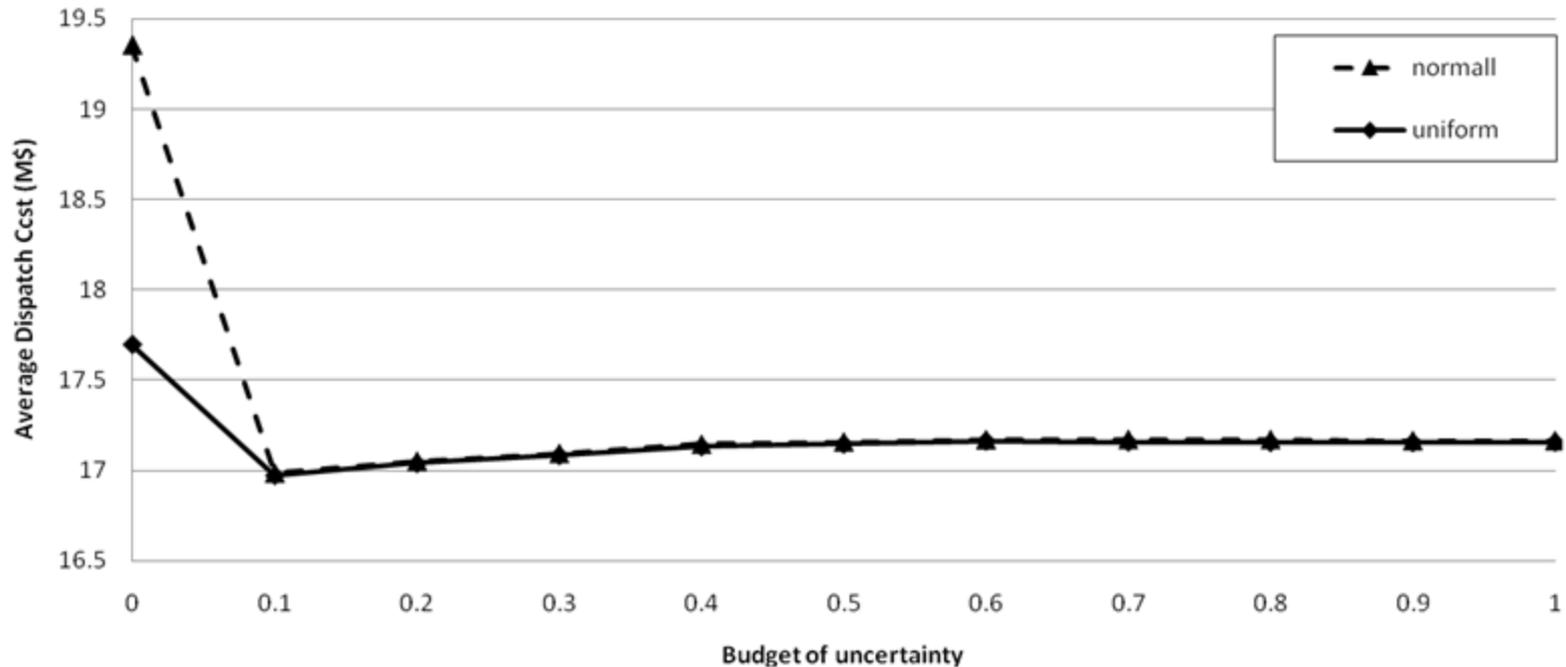
Average Dispatch Cost



Robustness of the Solution

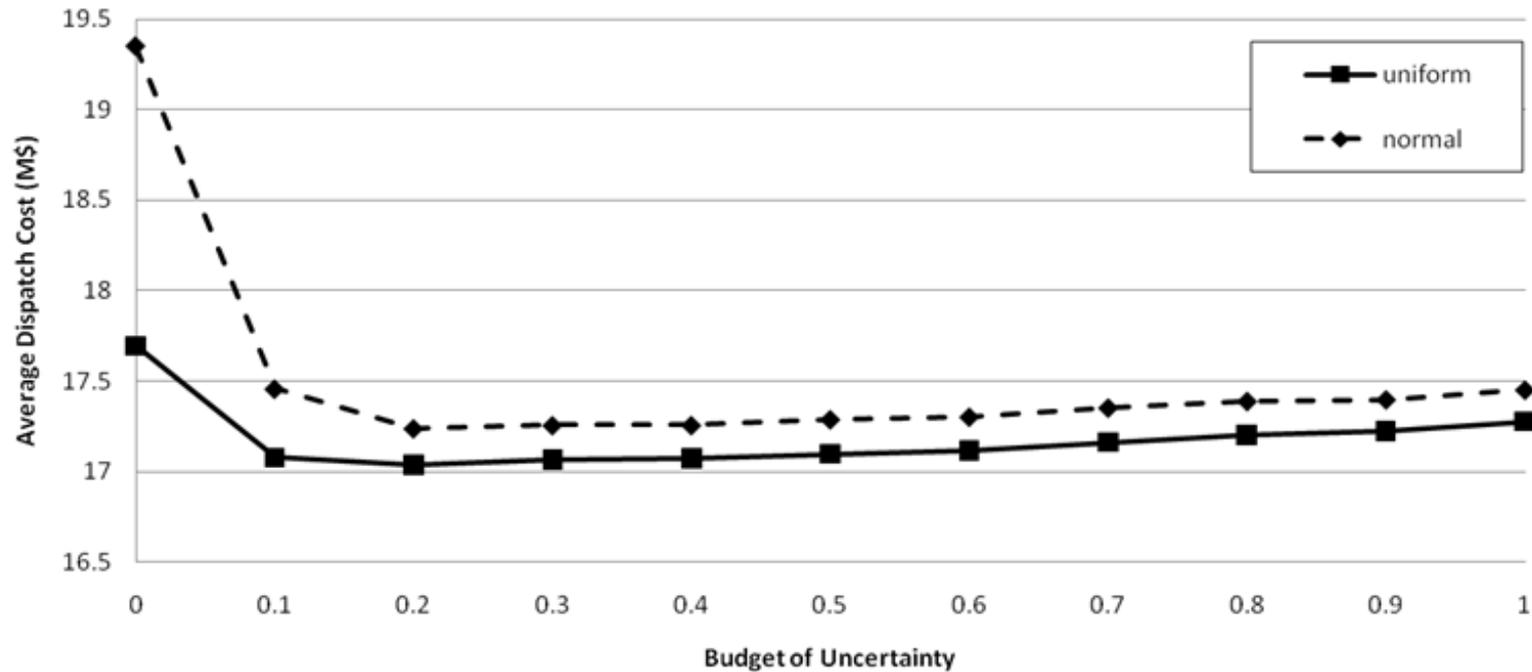


Sensitivity to Probability Distribution (RO)



The Robust UC solution is not sensitive to the probability distribution of the uncertain parameters

Sensitivity to Probability Distribution (RA)



The relative difference is between 1.0% to 2.2%.

Conclusion

- Robust UC provides a systematic way to manage the increasing level of uncertainty in system operations
- Compared with the existing deterministic UC, robust UC achieves better robustness and economic efficiency
- Robust UC does not require probability distributions of the uncertain parameters, and its solution is not sensitive to the probability distributions
- Computational efficiency is a challenging problem for robust UC

Thank you!

Questions?