Applying Robust Optimization to MISO Look-ahead Unit Commitment

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Background

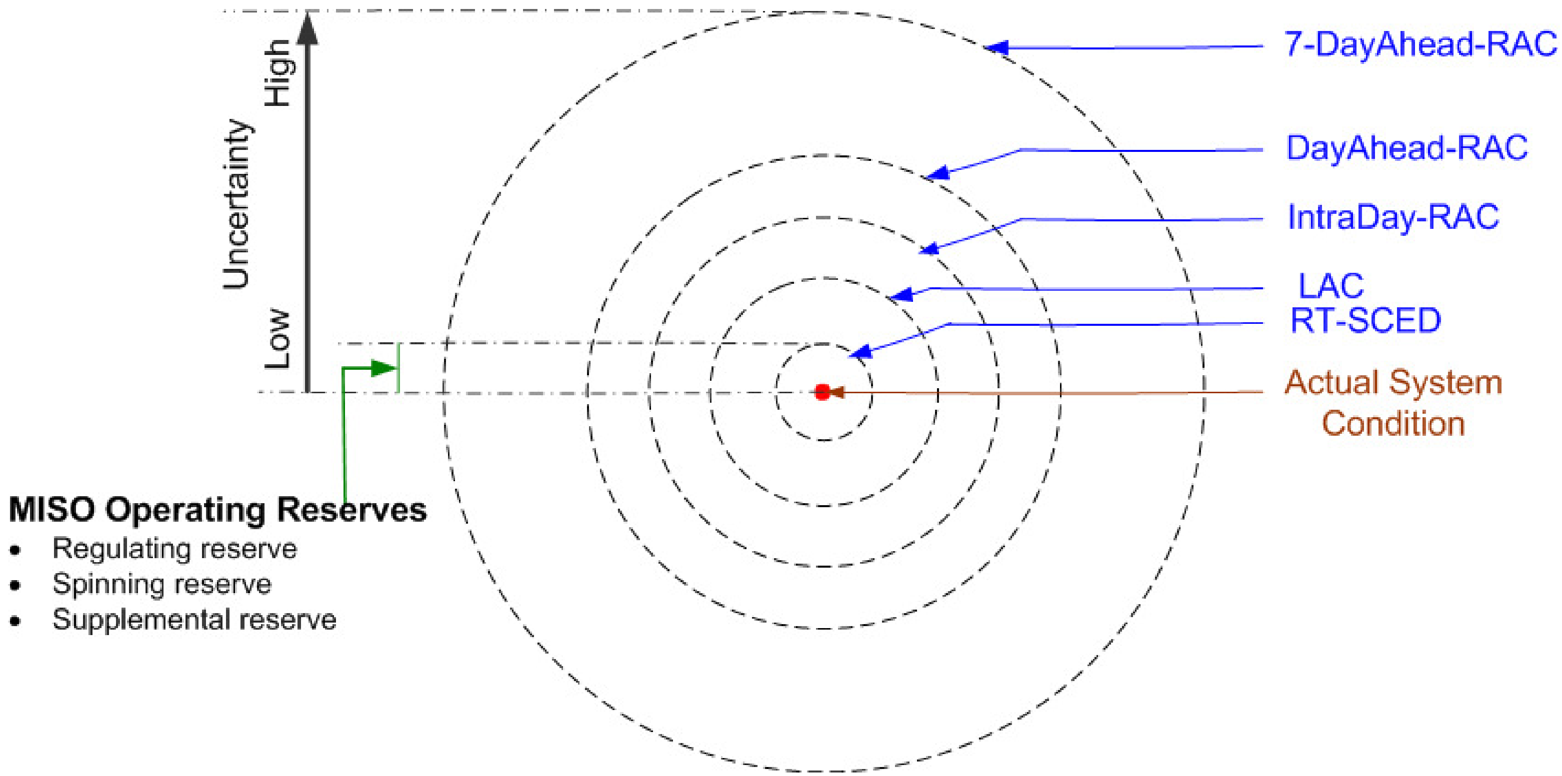
- Market operations need to manage uncertainties
  - Examples of ways to manage uncertainties:
    - Operating reserves from the market clearing processes
    - Multiple commitment stages
    - Other operational procedures
  - Challenging with more renewable integration
- MISO is collaborating with Alstom Grid and University of Florida
  - To explore the possibility of using advanced optimization approaches to incorporate uncertainties in the market clearing processes
  - To evaluate the benefit from applying those approaches

Managing Uncertainties under Daily Operations

- Operators need to manage uncertainties everyday
- Source of uncertainties:
  - Input data
  - Study interval length not granular enough to reflect the rate of changes
  - Unexpected events and behaviors
  - Simplified mathematical model to represent actual power system
- Result: deviation of actual system conditions from the market clearing models
- Possible consequences of not managing uncertainties well
  - Carrying excessive reserves
  - Insufficient capacity or ramp capability to meet power balance
  - Transmission violations
  - Committing expensive quick start resources

Level of Uncertainty Varies along the Processes

- Expected difference between the actual system condition and the market clearing models



RAC: Reliability Assessment Commitment
LAC: Look-ahead Unit Commitment
RT-SCED: real time Security Constrained Economic Dispatch

Ways to Manage Uncertainties at MISO

- The same operating reserve requirements are applied in all market clearing processes
  - Not sufficient to accommodate larger uncertainties in RAC and LAC
  - May not be able to account for the uncertainty caused by study interval differences
- Additional "capacity headroom" and ramp requirements
  - 7-DayAhead-RAC and DayAhead-RAC
    - Certain percentage of capacity headroom based on the analysis of uncertainties from historical input data
    - Committing slow start resources so that future actions (fast start resource commitment and economic dispatch) can satisfy additional changes beyond the deterministic input data
  - LAC
    - Additional capacity headroom requirement to prepare for the capacity and ramp uncertainty

Ways to Manage Uncertainties at MISO (Cont.)

- Solving multiple scenarios at the same time
  - LAC: Three scenarios of load, wind and NSI settings
    - Scenario 0: load at coincidental peak forecast level
    - Scenario 1: +500MW; Scenario 2: +1000MW
  - RT-SCED: Six scenarios of load settings
- Operators can respond to the latest system condition changes by selecting the proper LAC and RT-SCED scenario
  - Result in more targeted commitment and dispatch solution
  - Ability to choose from discrete scenarios can help reduce the amount of required regulating reserve
- Make it possible, in part, for only carrying 300MW~500MW of regulating reserves with ~100GW peak load

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Purpose of Stochastic and Robust Optimization UC

- Determine one set of commitment that can support operations under multiple discrete scenarios or within a range of uncertainties
- The mathematical model can better formulate SCUC under uncertainties
  - Ensure adequate future actions available for uncertainties under consideration
  - Unlike reserve and headroom, the solution from stochastic UC and robust optimization can ensure future actions satisfying commitment, dispatch and transmission constraints

Stochastic Unit Commitment (UC)

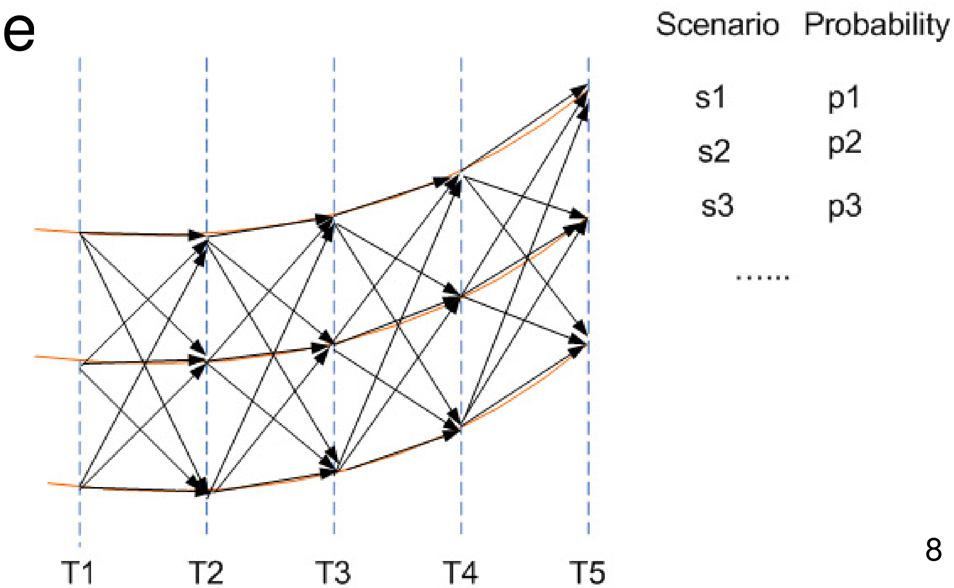
- One set of commitment to cover multiple scenarios
- Minimize the total of
  - Commitment cost: startup and no load cost under the set of commitment
  - Expected dispatch cost plus violation cost

$$Min_{\boldsymbol{x}} \{\boldsymbol{c}^{\boldsymbol{T}}\boldsymbol{x} + \sum_{i \in I} [p_i * Min_{(y,s) \in \Omega(\boldsymbol{x}, \boldsymbol{d_i})} (\boldsymbol{b}^{\boldsymbol{T}}\boldsymbol{y} + \boldsymbol{v}^{\boldsymbol{T}}\boldsymbol{s})]\}$$

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

$$\text{where } \Omega(\boldsymbol{x}, \boldsymbol{d_i}) = \{(\boldsymbol{y}, \boldsymbol{s}): \boldsymbol{Hy} - \boldsymbol{H_s s} \leq \boldsymbol{h}, \boldsymbol{Ax} + \boldsymbol{By} - \boldsymbol{G_s s} \leq \boldsymbol{g}, \boldsymbol{I_u y} + \boldsymbol{D_s s} = \boldsymbol{d_i}\}$$

- Challenging to determine
  - Scenarios and
  - Probabilities



Robust Optimization UC

- One set of commitment to cover a range of uncertainties
- Minimize the total of:
  - Commitment cost
  - Worst scenario dispatch plus violation cost within an uncertainty range

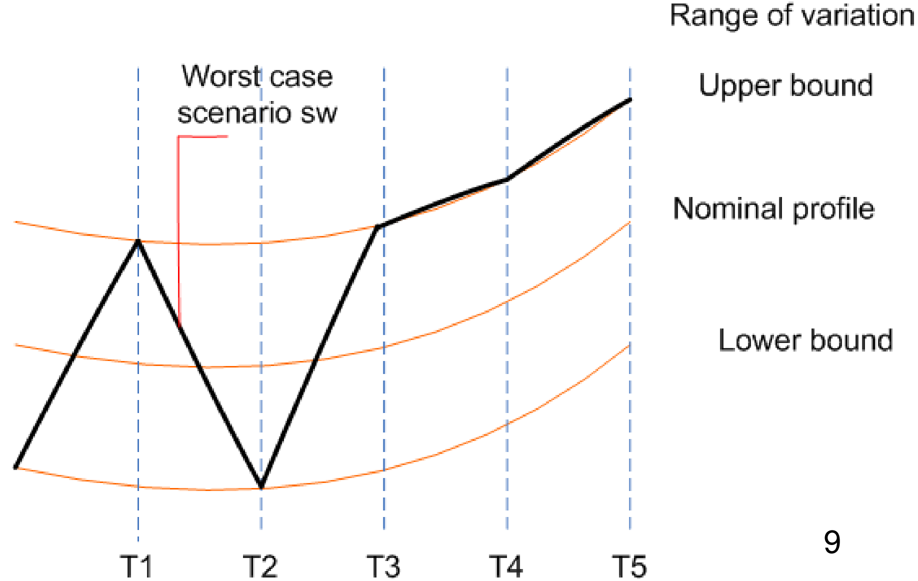
$$Min_{\boldsymbol{x}}\{\boldsymbol{c}^{\boldsymbol{T}}\boldsymbol{x} + Max_{\boldsymbol{d}\in\boldsymbol{\mathcal{D}}} Min_{(\boldsymbol{y},\boldsymbol{s})\in\Omega(\boldsymbol{x},\boldsymbol{d})}(\boldsymbol{b}^{\boldsymbol{T}}\boldsymbol{y} + \boldsymbol{v}^{\boldsymbol{T}}\boldsymbol{s})\}$$

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

$$\text{where } \Omega(\boldsymbol{x},\boldsymbol{d}) = \{(\boldsymbol{y},\boldsymbol{s}): \boldsymbol{Hy} - \boldsymbol{H_s s} \leq \boldsymbol{h}, \boldsymbol{Ax} + \boldsymbol{By} - \boldsymbol{G_s s} \leq \boldsymbol{g}, \boldsymbol{I_u y} + \boldsymbol{D_s s} = \boldsymbol{d}\}$$

- No need to generate scenarios
- Can be conservative

  to use the worst case scenario dispatch cost



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Unified Stochastic/Robust Optimization UC

- Combine the two approaches
- Minimize the total of:
  - Commitment cost
  - Dispatch plus violation cost under nominal scenario (or multiple predetermined scenarios)
  - Worst scenario violation cost within an uncertainty range

$$Min_{\boldsymbol{x}} \{\boldsymbol{c}^T\boldsymbol{x} + \sum_{i\in I}[p_i * Min_{(y,s)\in\Omega(\boldsymbol{x},\boldsymbol{d_i})}(\boldsymbol{b}^T\boldsymbol{y} + \boldsymbol{v}^T\boldsymbol{s})] + [Max_{d\in\boldsymbol{\mathcal{D}}}\, Min_{(y,s)\in\Omega(\boldsymbol{x},\boldsymbol{d})}\boldsymbol{v}^T\boldsymbol{s}]\}$$

$$s.t.\ \boldsymbol{Fx} \le \boldsymbol{f}, \boldsymbol{x} \text{ binary}$$

$$\text{where } \Omega(\boldsymbol{x},\boldsymbol{d}) = \{(\boldsymbol{y},\boldsymbol{s}): \boldsymbol{Hy} - \boldsymbol{H_s s} \le \boldsymbol{h}, \boldsymbol{Ax} + \boldsymbol{By} - \boldsymbol{G_s s} \le \boldsymbol{g}, \boldsymbol{I_u y} + \boldsymbol{D_s s} = \boldsymbol{d}\}$$

$$\Omega(\boldsymbol{x},\boldsymbol{d_i}) = \{(\boldsymbol{y},\boldsymbol{s}): \boldsymbol{Hy} - \boldsymbol{H_s s} \le \boldsymbol{h}, \boldsymbol{Ax} + \boldsymbol{By} - \boldsymbol{G_s s} \le \boldsymbol{g}, \boldsymbol{I_u y} + \boldsymbol{D_s s} = \boldsymbol{d_i}\}$$

- Benefit
  - Minimize total cost for nominal scenario (or multiple predetermined scenarios) while maintaining maximal feasibility within the uncertainty range

Problem Setup for MISO LAC

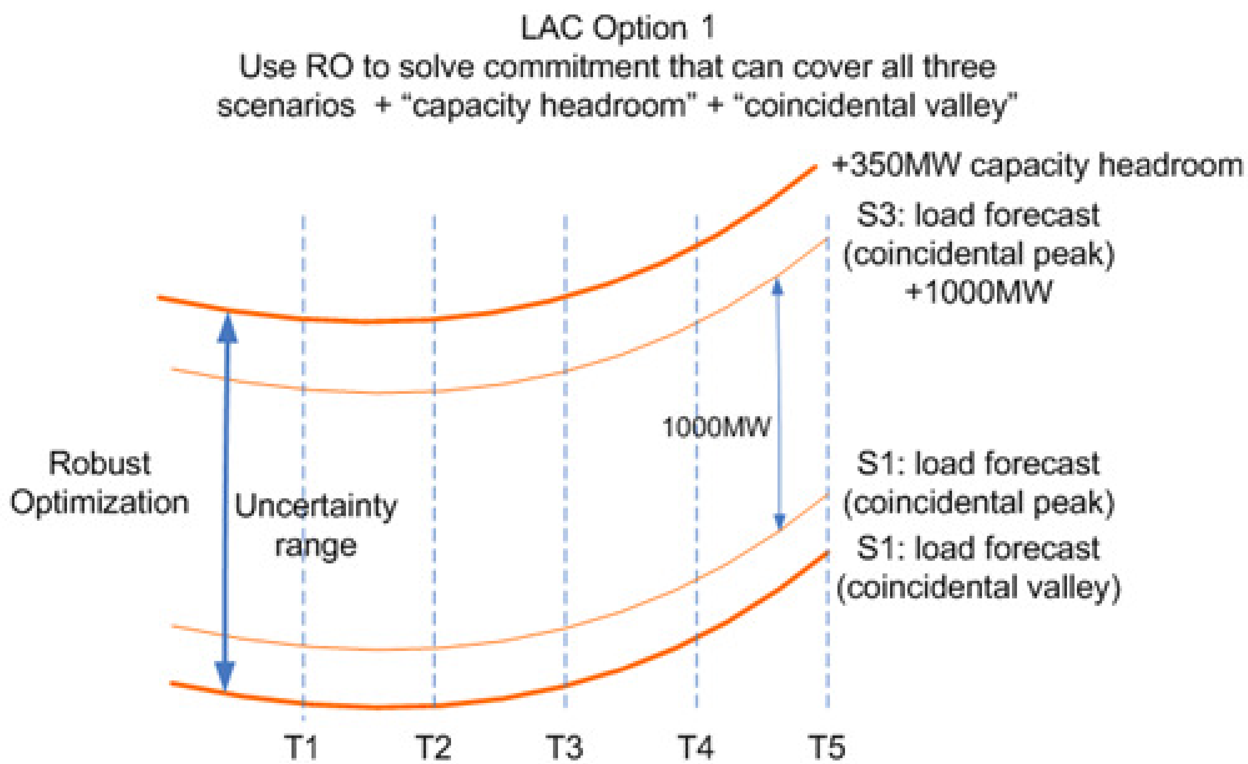
- LAC is primarily used to commit fast start resources in real time
  - Run every 15 minutes; Study window: [t+15min, t+3hr]
  - Interval length:15-min to 30-min (~10 intervals)
  - Relatively small problem size and narrow range of uncertainty
- Prototype Robust Optimization LAC
  - A range of variations on load forecast from each of the 28 Local Balancing Authorities
  - Can be extended to other input data such as scheduled interchanges and wind forecast
- Based on the discussion with MISO operations
  - Operating reserves are required by NERC and MISO tariff
    - Not looking for replacing operating reserves at this stage
  - Using robust optimization to model the uncertainties currently addressed by headroom requirement in LAC

LAC Problem Setup

- Production LAC setup for uncertainties
  - Capacity headroom: 350MW
  - Three (3) scenarios of load, wind and NSI settings
    - Scenario 1: with load, wind and NSI at <u>coincidental peak forecast level</u>
    - Scenario 2: load+500MW;   Scenario 3: load+1000MW
  - Each scenario includes system and zonal operating reserve requirements
- Options of setting up robust optimization LAC
  - Option 1: Configure uncertainty range to cover all LAC scenarios as well as headroom requirement and coincidental valley
  - Option 2: Configure uncertainty range to cover headroom requirement and coincidental valley within each scenario

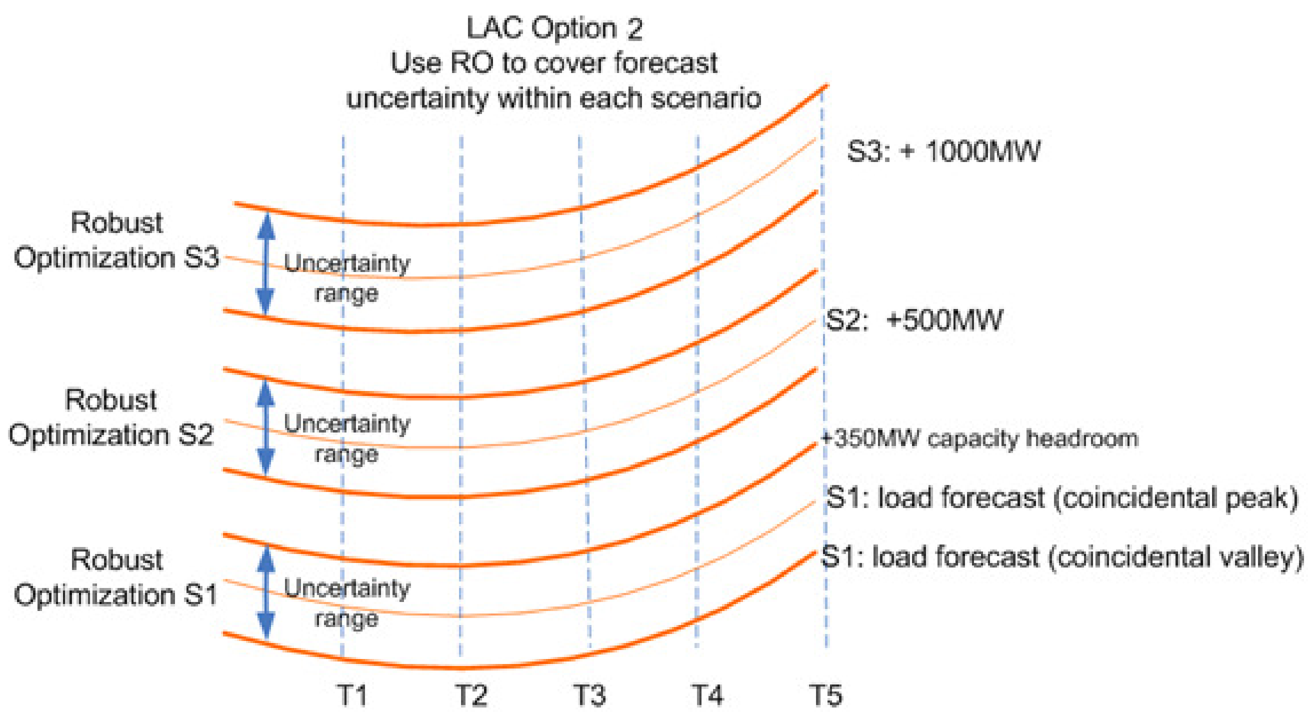
Robust Optimization LAC Setup Option 1

- Configure uncertainty range to cover all LAC scenarios as well as headroom requirement and coincidental valley
  - Comprehensive commitment solution
  - Can be very expensive



Robust Optimization LAC Setup Option 2

- Configure uncertainty range to cover headroom requirement and coincidental valley within each scenario
  - Operators continue picking the proper scenario based on latest information
- Option 2 is the approach chosen for the prototype study



Preliminary Study Results

- Solution method: two-stage Bender's Decomposition Algorithm with bilinear heuristic algorithm to solve the sub problem
  - Robust optimization [2][3]
  - Unified stochastic/robust approach [4]
    - Only consider one nominal scenario dispatch cost and include it in the master problem; no need to generate the stochastic cut
    - Generating feasibility cuts from the robust optimization sub problem
- Select 96 LAC cases from one operation day in Jan. 2013.
  - With ~130 commitment actions taken on ~50 resources per LAC suggestion in production
    - Including starting new CT or extending existing commitment
  - A mild day with some relatively small violations

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Preliminary Study Results (Cont.)

- Three approaches of commitment are studied
  - Deterministic approach with headroom requirement (Deterministic)
  - Robust optimization approach (Robust)
  - Unified Stochastic/Robust optimization approach (Unified)
- For Robust and Unified approaches
  - Most cases converge within two cuts [5][6][7]
    - Robust (52 out of 96)
    - Unified (72 out of 96)
  - Master problem solution time increases tremendously with the third cut
    - Robust: ~2h
    - Unified: ~0.5h

*Results from Intel(R) Core™ i5-2410M CPU 2.3GHz RAM 4GB laptop on AIMMS 3.12 CPLEX 12.4

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Observations from Preliminary Study

- Set maximum number of cuts to be 2
- Unified approach converges faster than Robust approach

	Average Optimization Solution Time (sec.)				
	Total	Master1	Sub1	Master2	Sub2
Deterministic	35	-	-	-	-
Robust	509	42	29	403	34
Unified	158	40	34	61	34

- Both Robust and Unified approaches can help reduce the violations

	Sum of SCED 1st intervals Violation in MWh	
	Spin Violations	Xmission Violations
Deterministic	87.56	171.04
Robust	1.73	139.30
Unified	35.70	130.18

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* After each commitment run, fix all integer variables to run a SCED for comparison purpose

Observations from Preliminary Study (Cont.)

- Both Robust and Unified approaches slightly increase the commitment and dispatch costs
  - Unified approach has less cost increase than Robust approach

	Sum of SCED 1st Interval Costs		
	Total Production Cost (Commitment + Dispatch)	Commitment	Dispatch
(Robust-Deterministic)/ Deterministic%	0.61%	2.43%	0.25%
(Unified-Deterministic)/ Deterministic%	0.09%	1.37%	-0.16%

- Need more studies on different types of days to draw further conclusion

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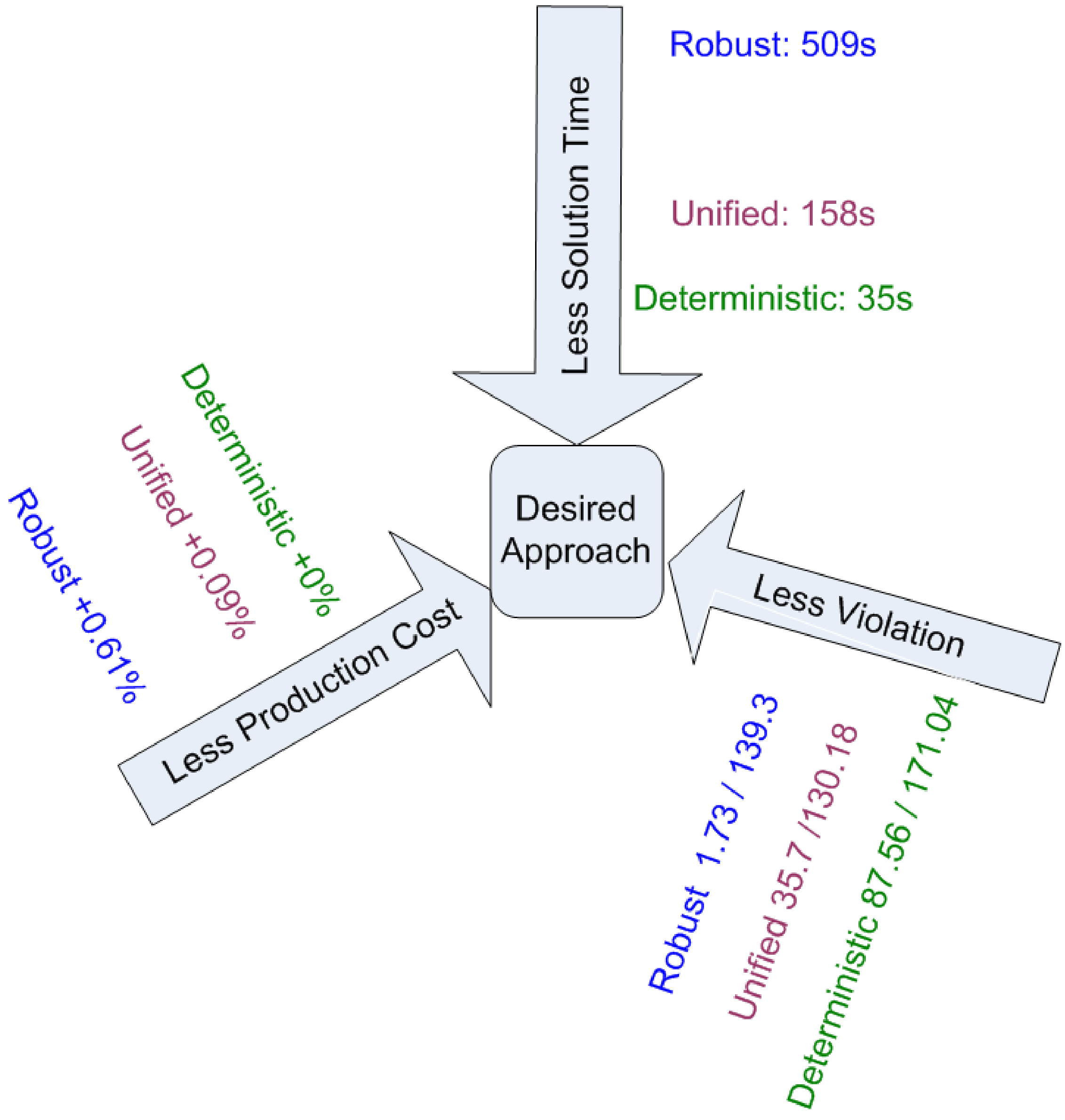
Observation from Preliminary Study (Cont.)



Next Steps

- LAC
  - Performance improvement
  - Model improvement
    - Better model the range of uncertainty: e.g. different ranges of uncertainty for each interval
    - Group areas with similar load pattern to reduce the number of uncertainty variables
    - Penalty settings
- IRAC/FRAC
  - Current practice
    - Minimize:

(Slow start and fast start commitment cost)

+ (nominal scenario violation cost)

ε * (nominal scenario dispatch cost)

ε is a very small number

Next Steps (Cont.)

- IRAC/FRAC with robust optimization
  - Determine one set of commitment so that future actions (“dispatch and fast start”) can cover a range of uncertainties
  - Potential robust optimization objective
    - Minimize:

      {(Slow start commitment cost)

      + (first stage fast start commitment)

      + ε * (nominal scenario dispatch cost)}

      + (Worst scenario violation cost within an uncertainty range under the slow start commitment and first stage fast start commitment)
    - Future actions in the second stage include economic dispatch and commitment of fast start resources that are not committed in the first stage

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References

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