Robust and Dynamic Reserve Policies

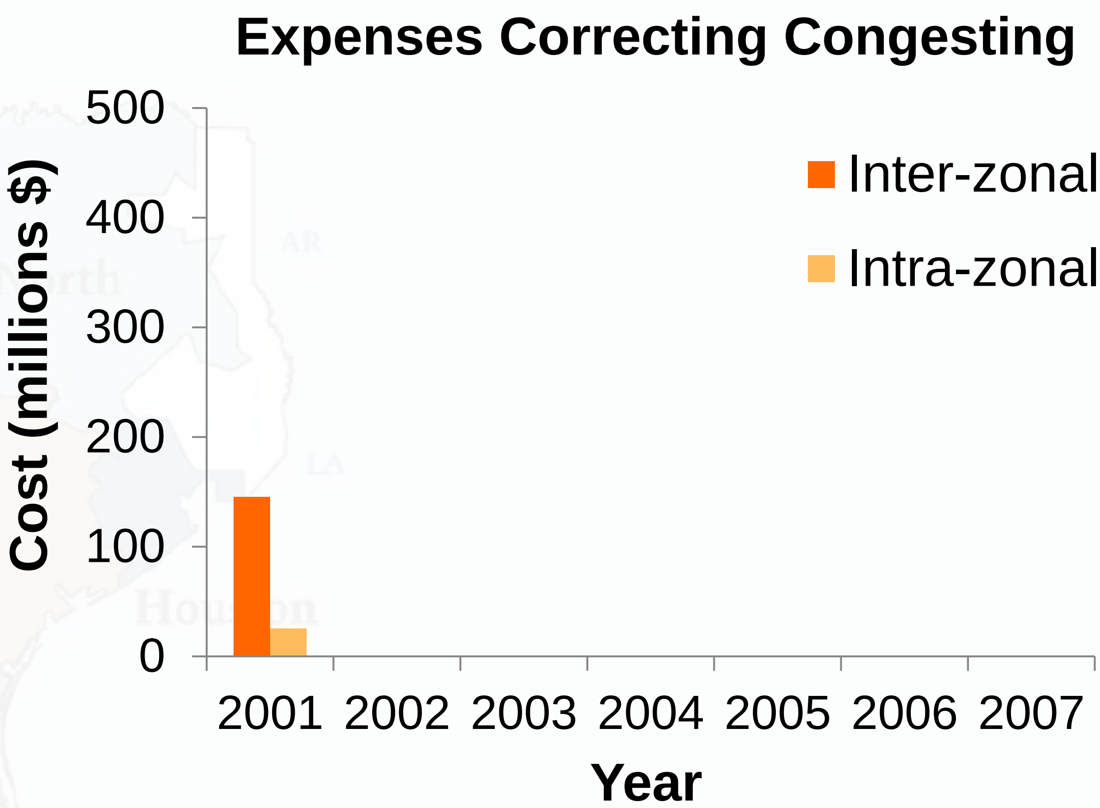
Dr. Kory Hedman Electrical Engineering
Dr. Muhong Zhang Industrial Engineering
Joshua Lyon Industrial Engineering
Fengyu Wang Electrical Engineering

Arizona State University

Zonal models assume power is deliverable within zones

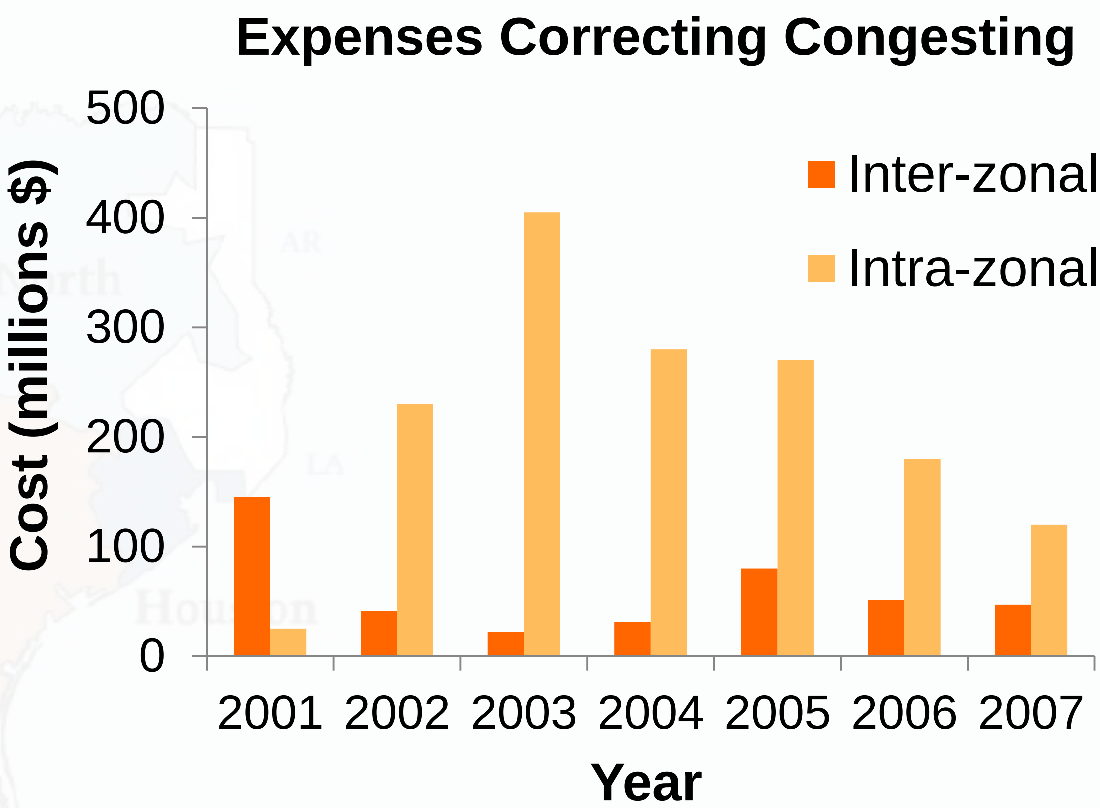
Texas electric market: overview and focal points, FERC, Nov. 2011. [Online]

ERCOT would adjust the solution to manage congestion



Report on existing and potential electric system constraints and needs, ERCOT, Dec. 2007. [Online]

ERCOT would adjust the solution to manage congestion



Report on existing and potential electric system constraints and needs, ERCOT, Dec. 2007. [Online]

Takeaways from zonal energy markets:

1. It can be difficult for zones to characterize congestion
2. Need effective ways to correct invalid zonal assumptions

Outline

- Motivation
- Day-ahead scheduling process
- Contributions:
  - Offline
  - Within unit commitment (UC)
  - Ex-post
- Future work

Motivation and Background

Motivation:

- Improve existing reserve policies
- Create reserve policies for renewable resources

Background:

- Reserve requirements ensure backup capacity

capacity ≠ availability

- Ensuring **deliverable** reserves will be increasingly difficult with renewables

Reserve Quantity vs. Deliverability

Reserve quantity

Deliverability

Balance:

Better deterministic methods will improve scalability of stochastic programming

Probabilistic reserves	[7]-[11]
Relax expensive requirements[1]	[12]-[17]
Iterative schemes	[18]-[21]
Robust optimization	[22]

Transfer capabilities	[1]
Congestion management	[2]
Reserve zones	[3]-[4]
Reserve disqualification	[5]-[6]

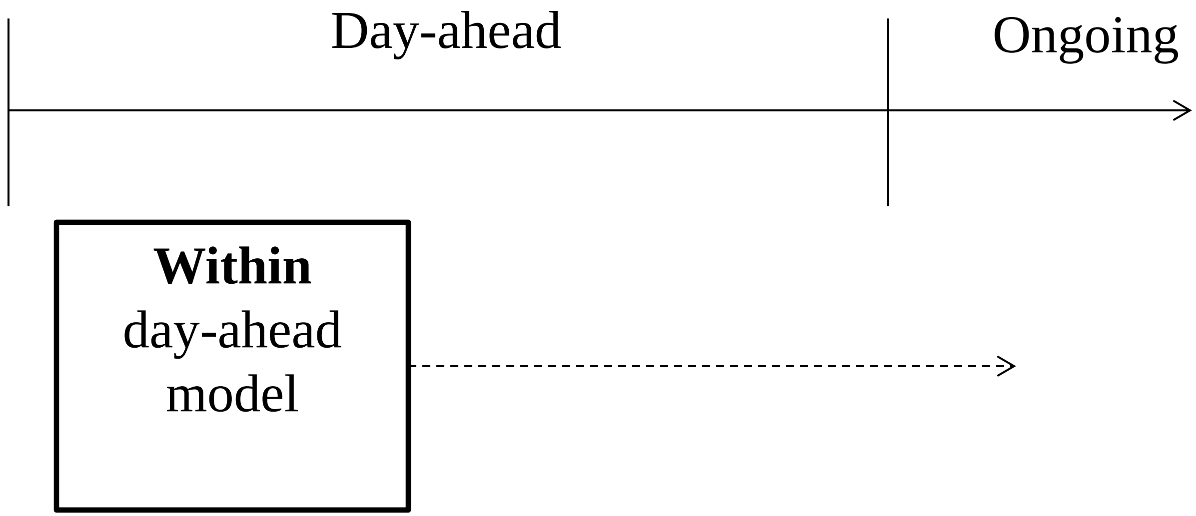
Stochastic programming[2]	[23]-[29]
Robust optimization[2]	[30]-[32]
Dynamic reserve sharing	[33]
Congestion-based reserves	

(Preferred)

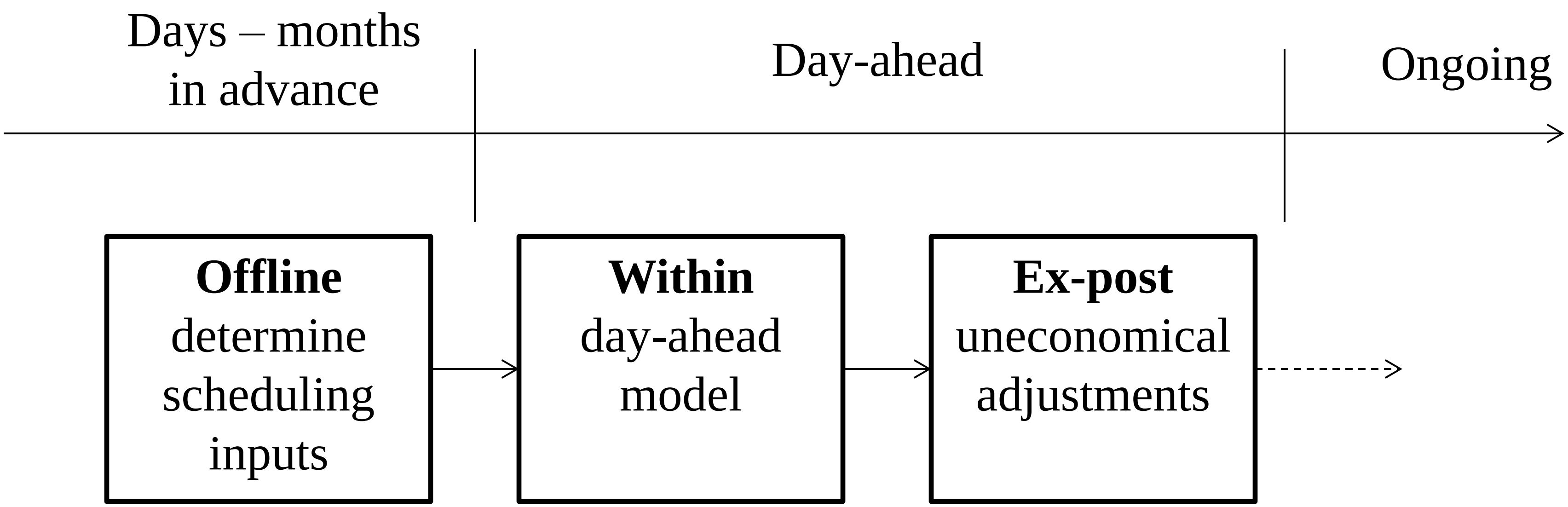
[1] By penalizing constraint violations or minimizing a weighted sum of cost and reliability

[2] Reserve deliverability considered in multi-stage models that simulate recourse

Path to Reliability

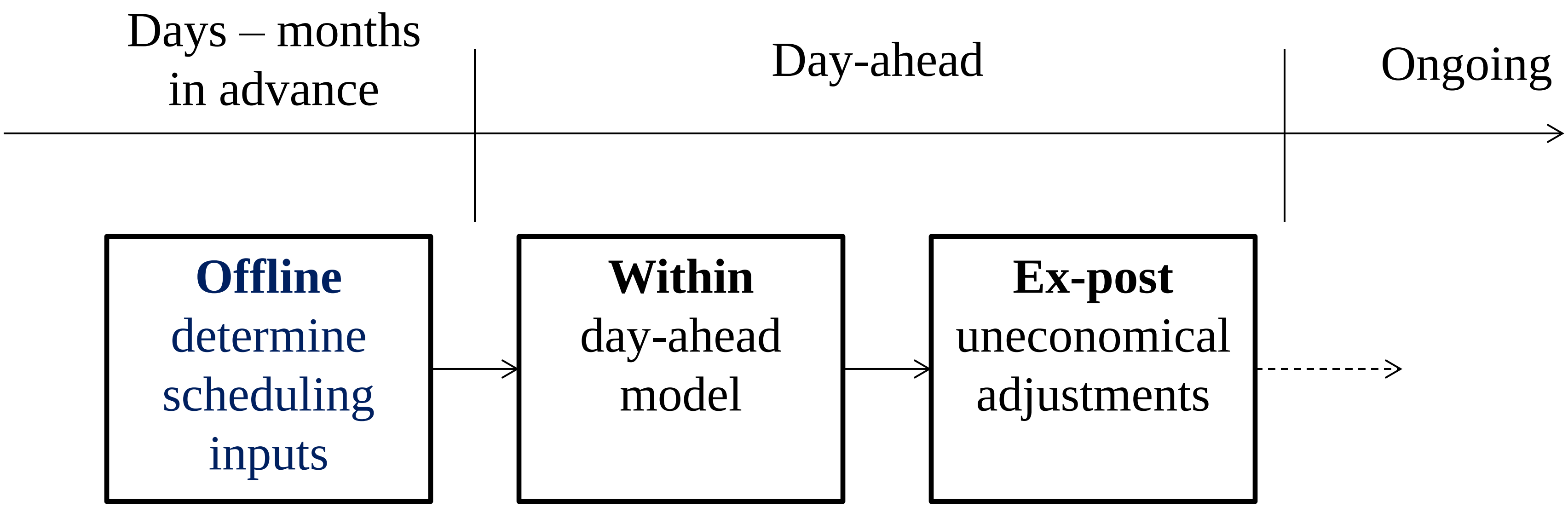


Path to Reliability



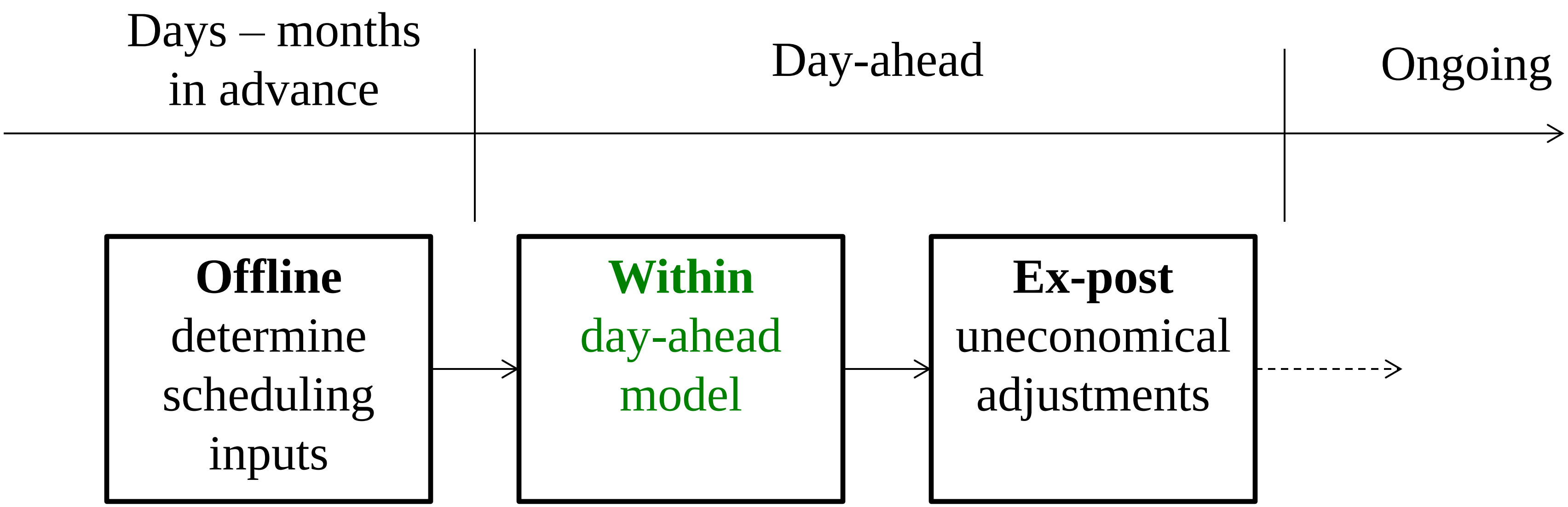
Approximations are made for day-ahead scheduling and checked ex-post

Path to Reliability



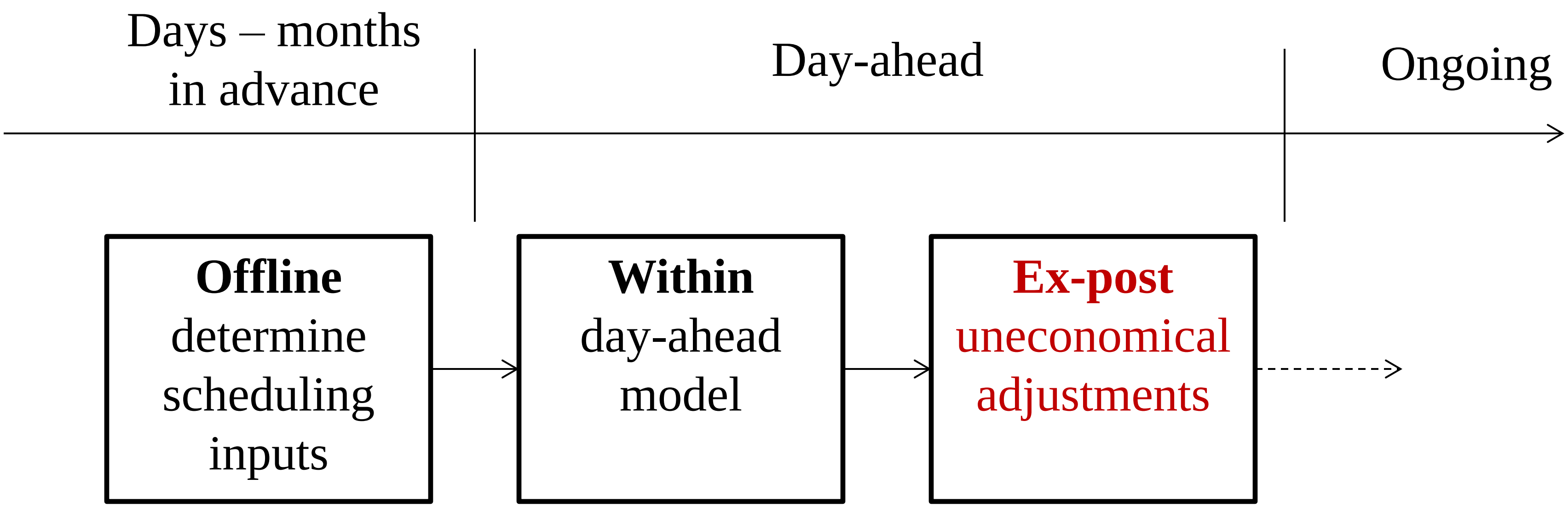
- Transfer capabilities / interface limits / nomograms
- **Reserve requirements** (**zones** and levels)
- Reliability must run (RMR) units

Path to Reliability



- Deterministic UC
- Reserve sharing
- **Congestion-based reserves**

Path to Reliability

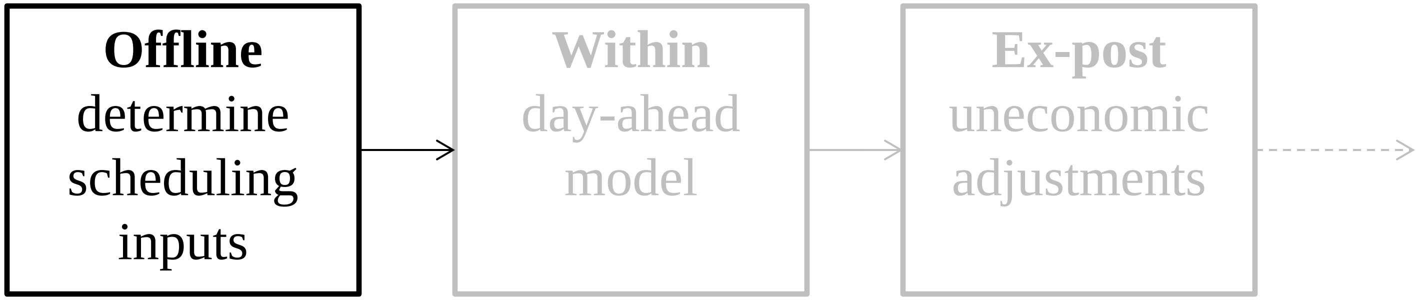


Modeling:

- Contingency analysis
- Uncertainty modeling

Actions:

- **Reserve disqualification (reserve down flags)**
- RMR, out-of-sequence units

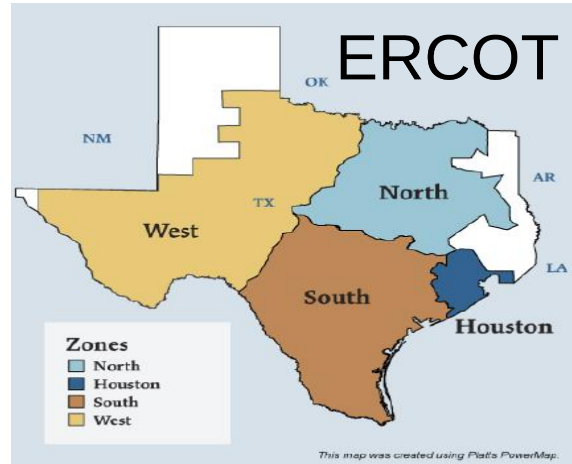


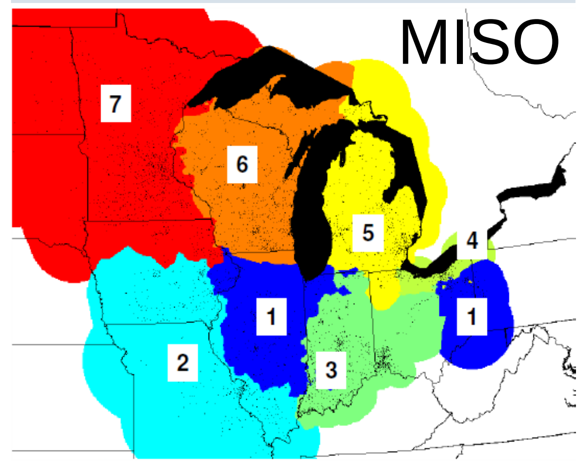
(Offline)
Daily dynamic reserve zones

Current Industry Practices: Reserve Zones

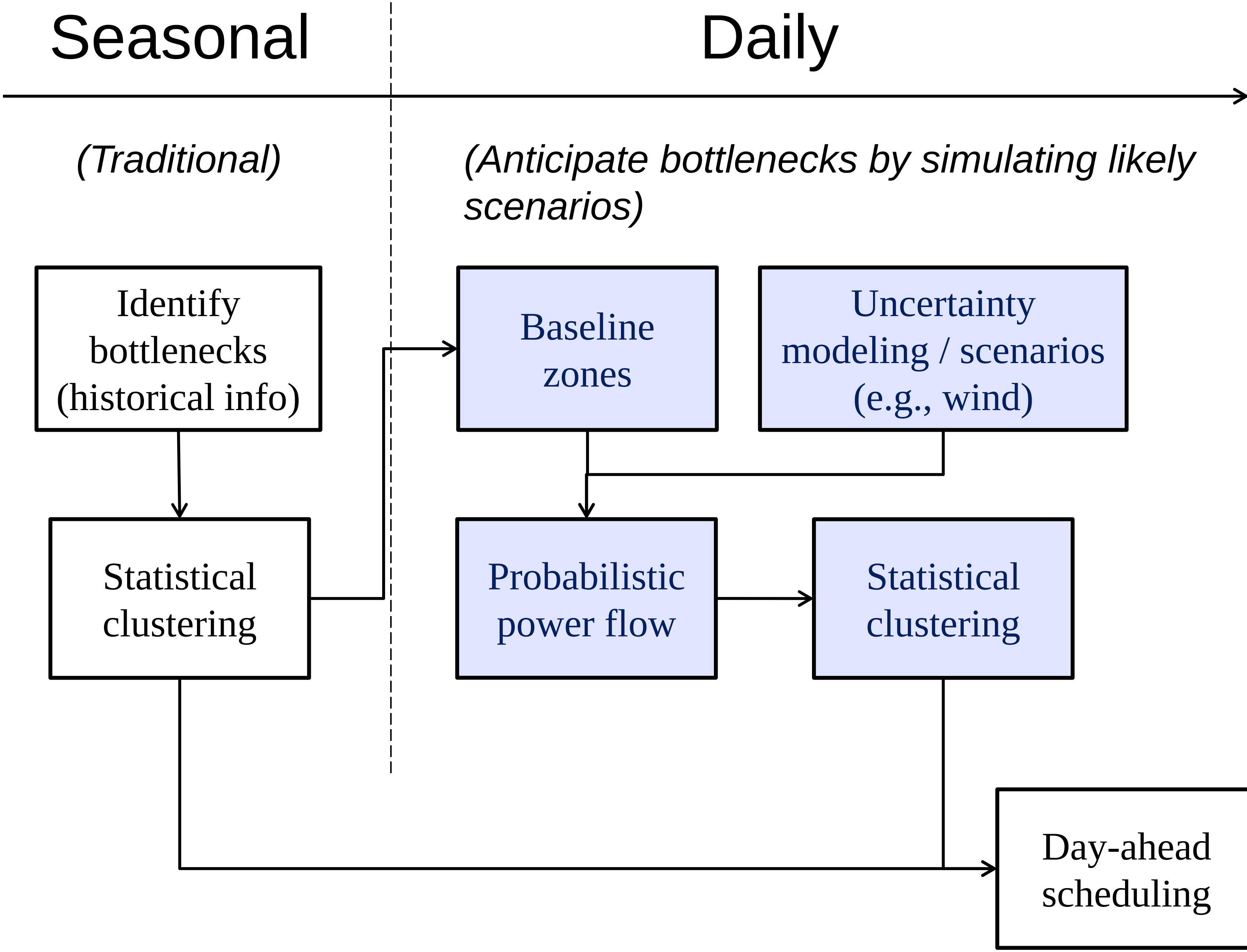
- ERCOT: zones defined relative to critical transmission bottlenecks [3]
  - Statistical clustering methods
  - Nodes in same zone have a similar effects on commercially significant constraints
- Similar approach taken by MISO [4]

Zones are infrequently updated



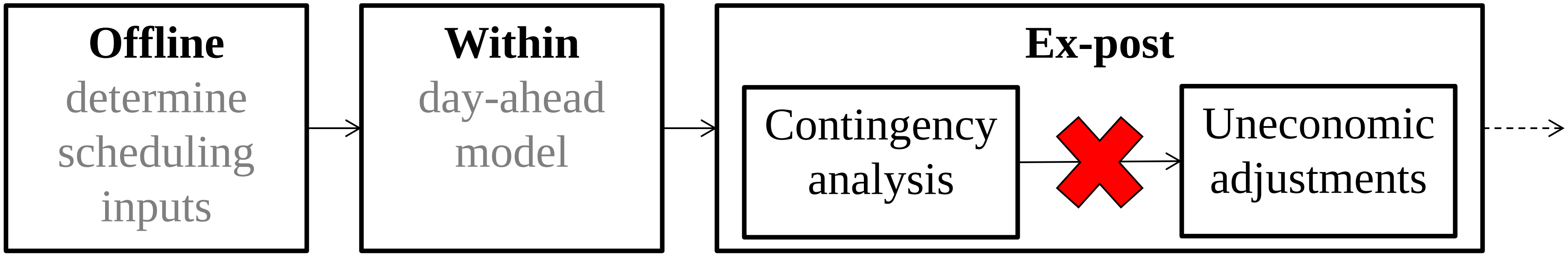


(Area 1 is part of PJM)


Seasonal
Daily
(Traditional)
(Anticipate bottlenecks by simulating likely scenarios)
Identify bottlenecks (historical info)
Baseline zones
Uncertainty modeling / scenarios (e.g., wind)
Statistical clustering
Probabilistic power flow
Statistical clustering
Day-ahead scheduling

Numerical Analysis

- Day-ahead UC (IEEE 118 test system):
  - Traditional zones
  - Proposed daily zones
  - Two-stage stochastic programming (10 scenarios)
- Performed contingency analysis on N-1 and 1000 wind scenarios across 12 days = **4.5 Million simulations**



(solutions reported prior to ex-post adjustments)

Average Results Over 12 Days

	Cost (millions $)[1]	Expected Violations[2] (MW)	Solution Time (s)
Traditional (3 zones)	0.651	13.5	18
Daily (3 zones)	**0.666**	**10.5**	**26**

[1] Costs do not reflect uneconomical adjustments

[2] Violations only occur when reserve is not deliverable

Average Results Over 12 Days

	Cost (millions $)[1]	Expected Violations[2] (MW)	Solution Time (s)
Traditional (3 zones)	0.651	13.5	18
Daily (3 zones)	**0.666**	**10.5**	**26**
Stochastic[3] (1 zone)	0.636	20.4	339

[1] Costs do not reflect uneconomical adjustments

[2] Violations only occur when reserve is not deliverable

[3] Stochastic does not model all scenarios

Average Results Over 12 Days

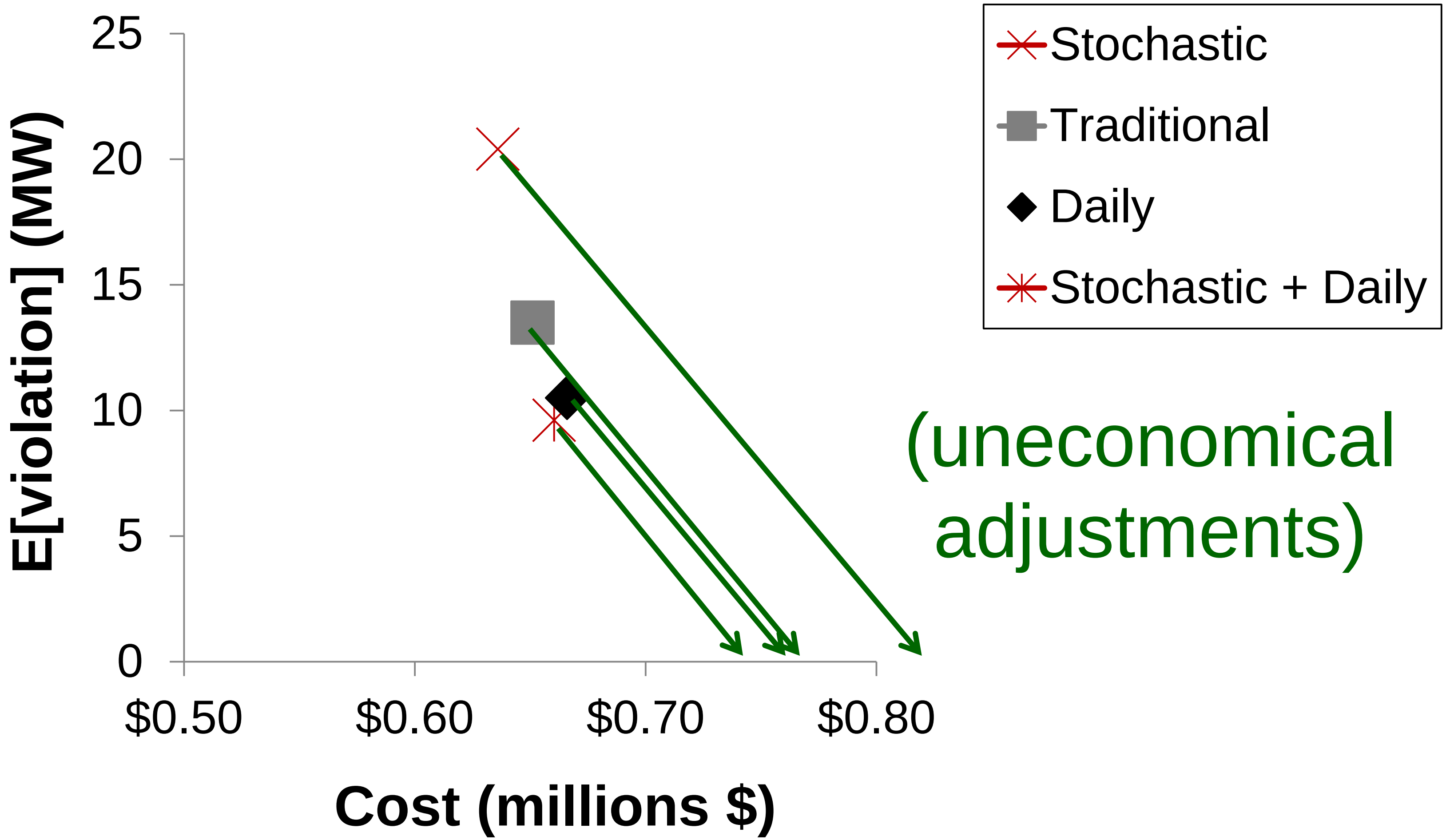
	Cost (millions $)[1]	Expected Violations[2] (MW)	Solution Time (s)
Traditional (3 zones)	0.651	13.5	18
Daily (3 zones)	**0.666**	**10.5**	**26**
Stochastic[3] (1 zone)	0.636	20.4	339
Stochastic + Daily	0.660	9.61	505

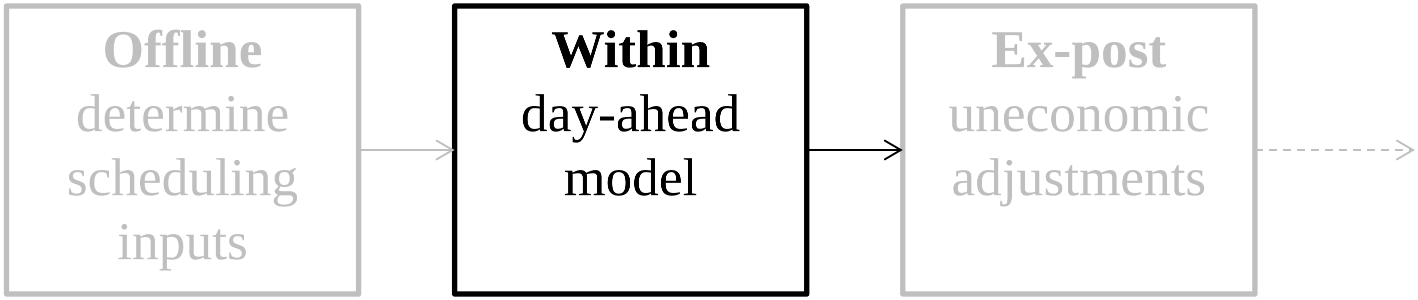
[1] Costs do not reflect uneconomical adjustments

[2] Violations only occur when reserve is not deliverable

[3] Stochastic does not model all scenarios

Average Results Over 12 Days

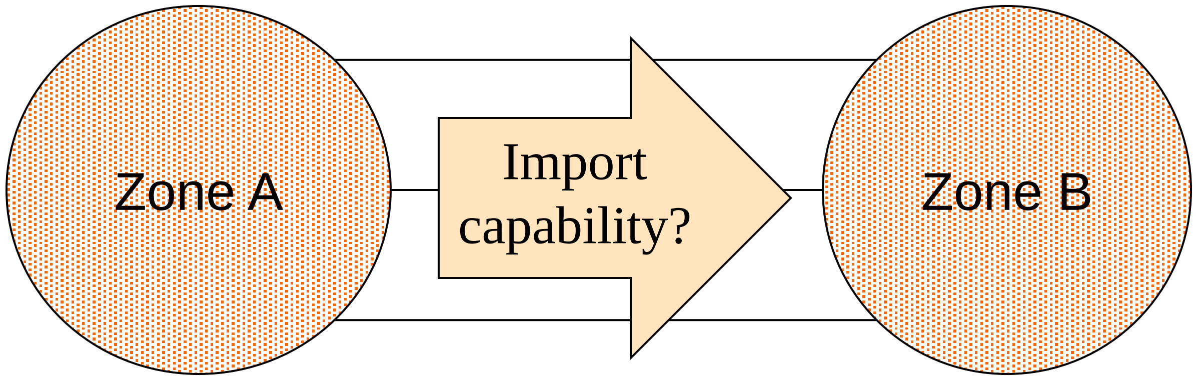




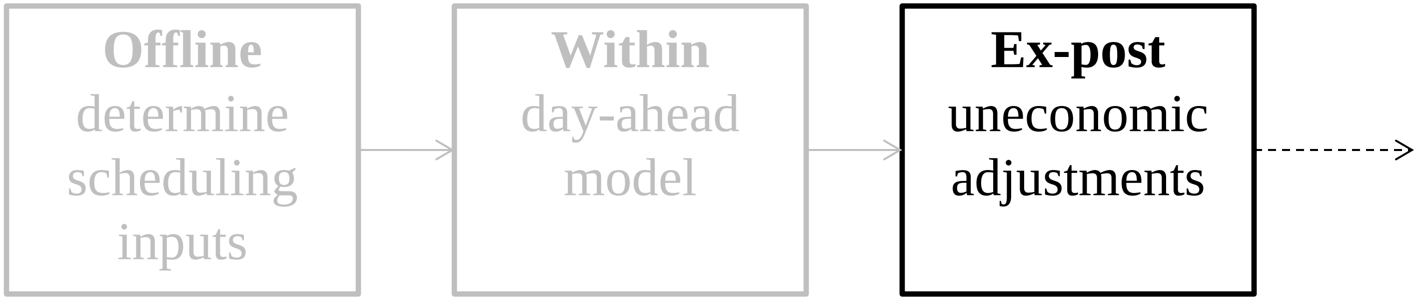
(Within)
Congestion-based reserves

Congestion-Based Reserves

- ISO-NE dynamically predicts ability to share reserve between zones [33]



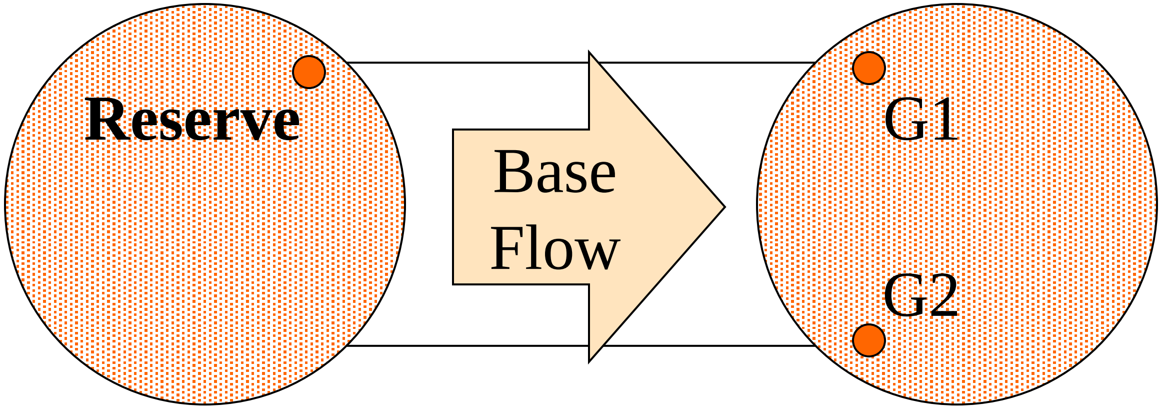
- May relate quantity to transmission stress inside of zone
  - Option to increase reserve or decrease transmission stress is embedded in the model
  - Numerical results in appendix



(Ex-post)
Reserve disqualification / down flag policies

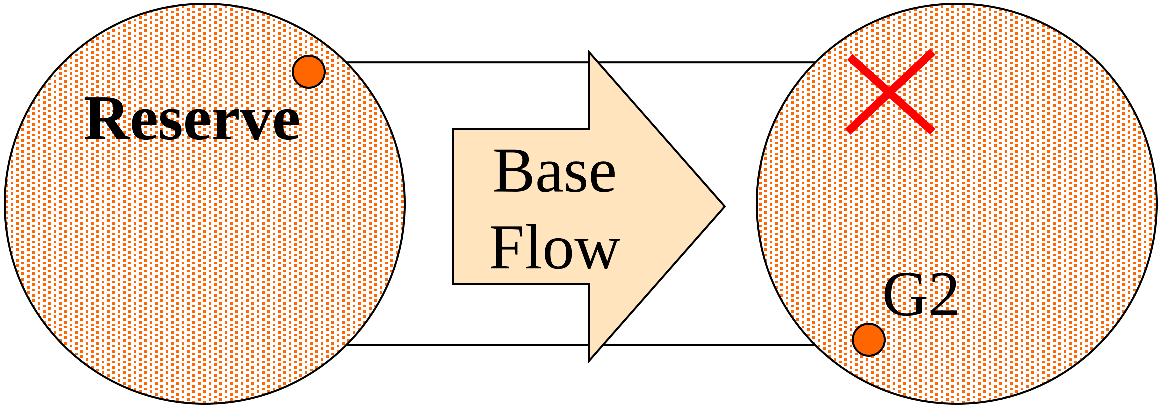
Reserve Disqualification

- MISO, ISO-NE manually disqualify reserve located behind transmission bottlenecks (reserve disqualification and reserve down flags respectively) [5], [6]
- Ongoing work:
  - Propose a generalized reserve down flag procedure
  - Determined via mathematical programming
  - Applied on a per-scenario basis



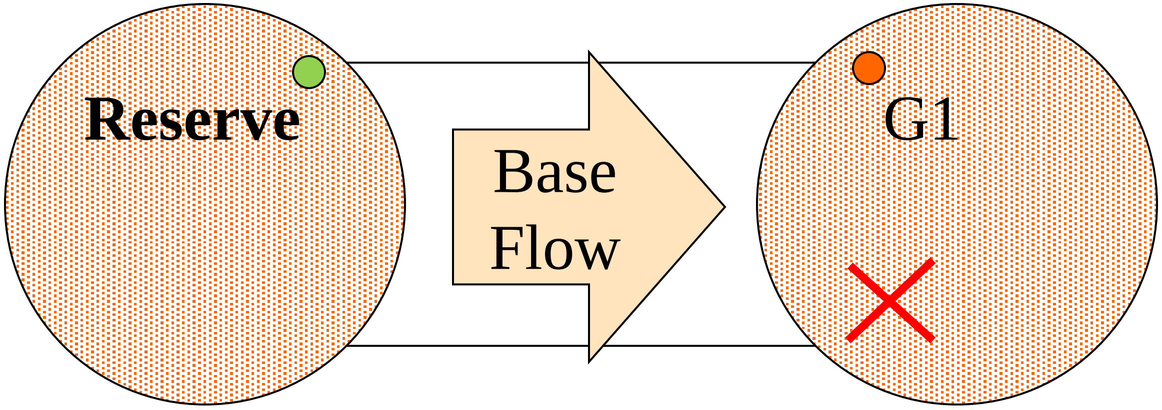
Reserve Disqualification

- MISO, ISO-NE manually disqualify reserve located behind transmission bottlenecks (reserve disqualification and reserve down flags respectively) [5], [6]
- Ongoing work:
  - Propose a generalized reserve down flag procedure
  - Determined via mathematical programming
  - Applied on a per-scenario basis



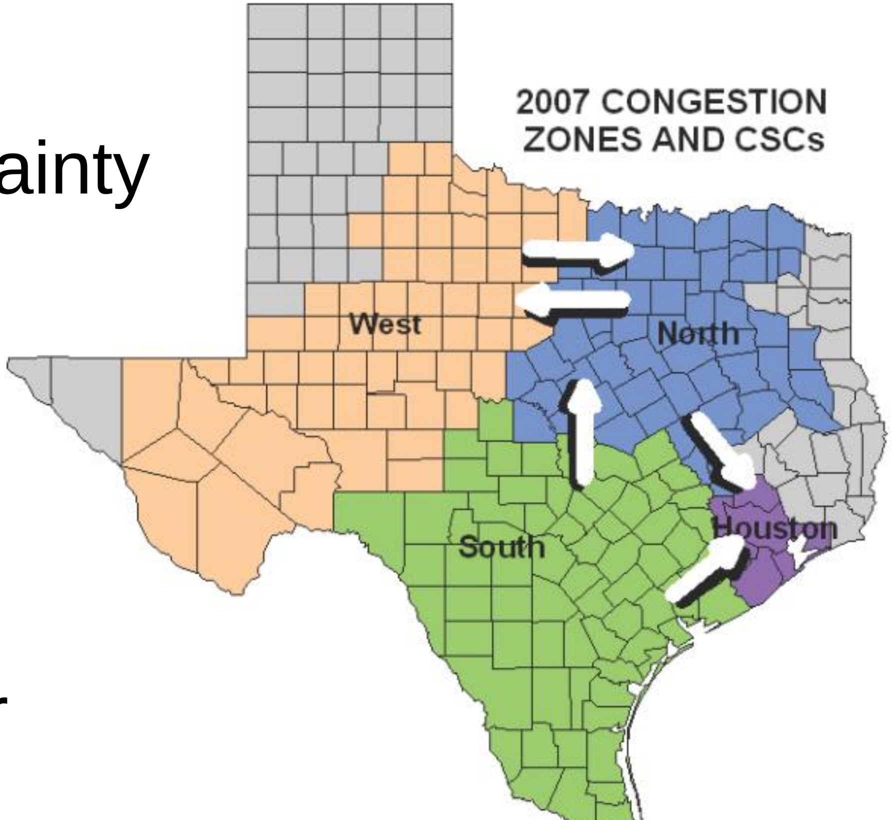
Reserve Disqualification

- MISO, ISO-NE manually disqualify reserve located behind transmission bottlenecks (reserve disqualification and reserve down flags respectively) [5], [6]
- Ongoing work:
  - Propose a generalized reserve down flag procedure
  - Determined via mathematical programming
  - Applied on a per-scenario basis



Conclusions

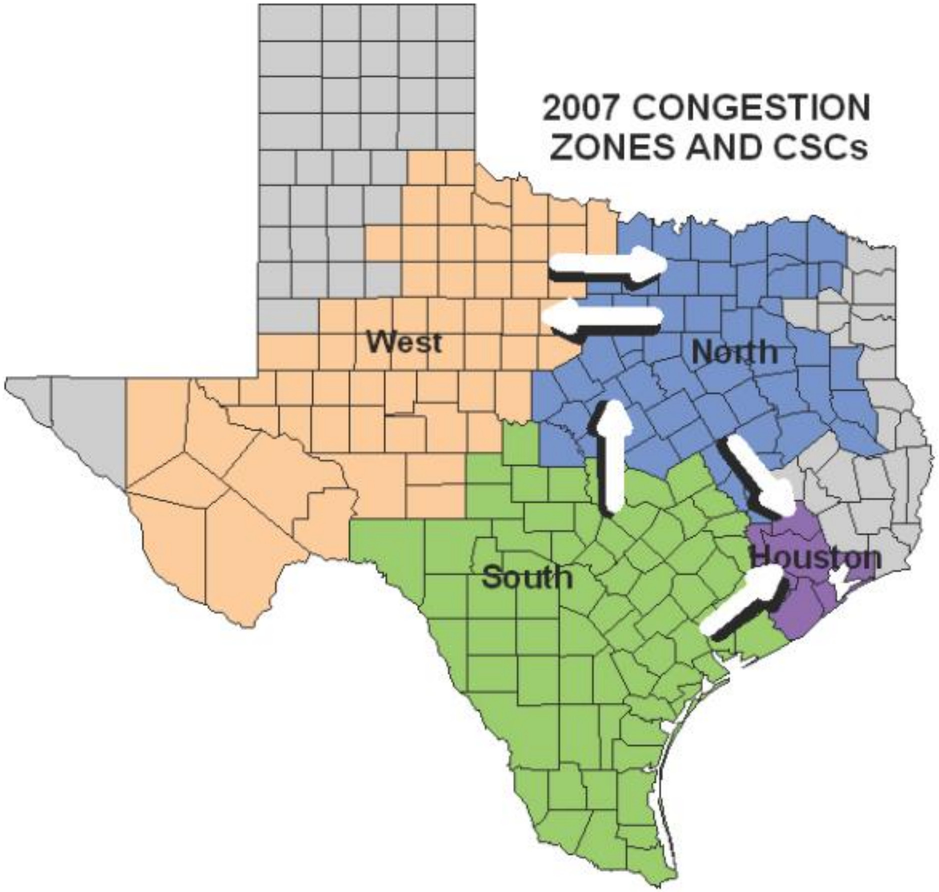
- Renewables will make it harder to predict transmission bottlenecks
- Stochastic programming cannot capture all uncertainty
- Reserve zones may not perfectly characterize congestion
- Developing a portfolio of deterministic methods for day-ahead scheduling

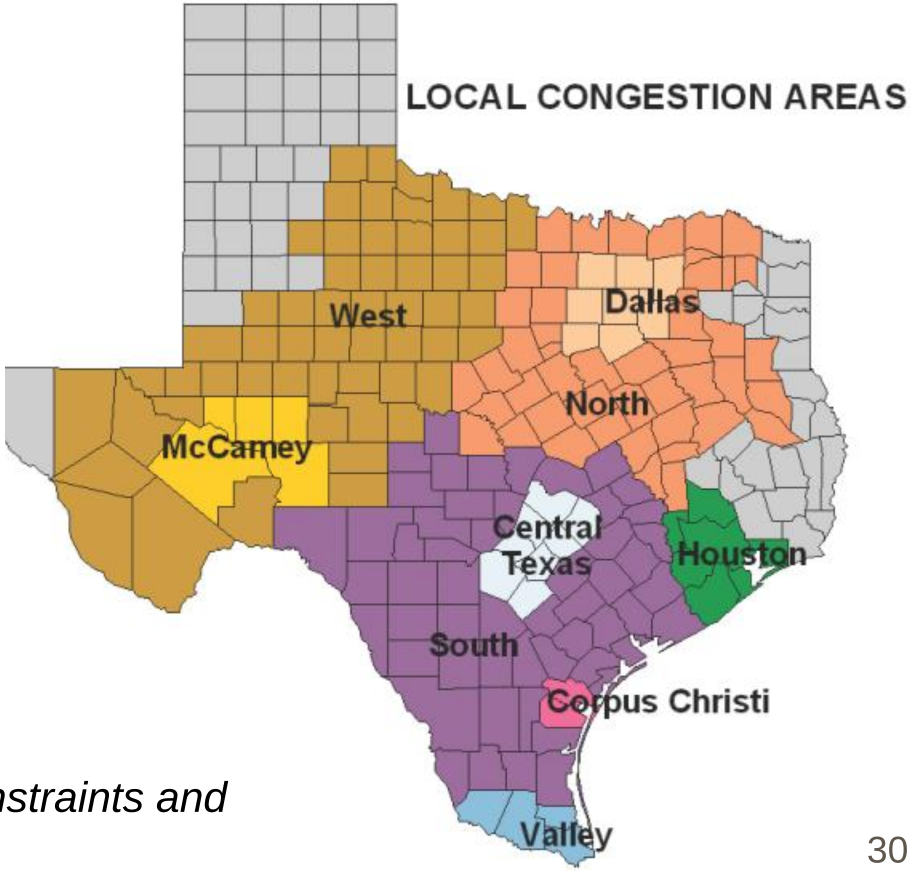


Future Work

- Create reserve policies to work in tandem with stochastic programming to improve scalability
- Currently testing policies on large-scale networks (FERC/PJM 15,000-bus test case)
- Model refinement based on industry feedback – please contact us if you would like further information or would like to provide additional feedback (kory.hedman@asu.edu)

Questions?





Report on existing and potential electric system constraints and needs, ERCOT, Dec. 2007. [Online]

Appendix A

References

Reserve Deliverability

- Transfer capabilities:
  - [1] R. M. Maliszewski, N. A. Brown, G. C. Rozier, H. R. Peterson, and et. al, “Available transfer capability definitions and determination,” NERC, Tech. Rep., Jun. 1996.
- Congestion management:
  - [2] B. J. Kirby, J. W. Van Dyke, C. Martinez, and A. Rodriguez, “Congestion management requirements, methods and performance indices,” CERTS, Tech. Rep., Jun. 2002.
- Zone determination:
  - [3] *ERCOT Protocols, Section 7: Congestion Management*, ERCOT, July, 2010. [Online].
  - [4] Personal discussion with James Mitsche, President, PowerGEM, June 2012.
- Reserve disqualification:
  - [5] A. W. Iler, “Docket no. er11-2794-000,” MISO, Jan. 2011. [Online].
  - [6] *SOP-RTMKTS.0120.0030 Implement Transmission Remedial Action Revision 20*, ISO-NE, Jun. 2012. [Online]

Reserve Quantities

- Probabilistic:
  - [7] H. Gooi, D. Mendes, K. Bell, and D. Kirschen, “Optimal scheduling of spinning reserve,” *IEEE Trans. Power Syst.*, vol. 14, no. 4, pp. 1485–1492, Nov. 1999.
  - [8] H. Wu and H. B. Gooi, “Optimal scheduling of spinning reserve with ramp constraints,” in *Proc. IEEE PES Winter Meeting*, vol. 2, Jan. 1999, pp. 785–790.
  - [9] D. Chattopadhyay and R. Baldick, “Unit commitment with probabilistic reserve,” in *Proc. IEEE PES Winter Meeting*, vol. 1, Aug. 2002, pp. 280–285.
  - [10] L. M. Xia, H. B. Gooi, and J. Bai, “Probabilistic spinning reserves with interruptible loads,” in *Proc. IEEE PES General Meeting*, vol. 1, Jun. 2004, pp. 146–152.
  - [11] F. Aminifar, M. Fotuhi-Firuzabad, and M. Shahidehpour, “Unit commitment with probabilistic spinning reserve and interruptible load considerations,” *IEEE Trans. Power Syst.*, vol. 24, no. 1, pp. 388–397, Feb. 2009.

Reserve Quantities

- Penalizing constraint violations or minimizing a weighted sum of cost and reliability:
  - [12] X. Guan, P. B. Luh, and B. Prasannan, "Power system scheduling with fuzzy reserve requirements," *IEEE Trans. Power Syst*., vol. 11, no. 2, pp. 864–869, May 1996.
  - [13] C.-L. Tseng, S. Oren, A. J. Svoboda, and R. B. Johnson, "Price-based adaptive spinning reserve requirements in power system scheduling," *Elect. Power and Energy Syst*., vol. 21, pp. 137–145, May 1999.
  - [14] M. Flynn, P. Sheridan, J. D. Dillan, and M. J. O'Malley, "Reliability and reserve in competitive electricity market scheduling," *IEEE Trans. Power Syst*., vol. 16, no. 1, pp. 78–87, Feb. 2001.
  - [15] K. M. Radi and B. Fox, "Power system economic loading with flexible emergency reserve provision," in *IEE Proceedings-c*, vol. 138, no. 4, Jul. 1991, pp. 257–262.
  - [16] J. Bai, H. B. Gooi, L. M. Xia, G. Strbac, and B. Venkatesh, "A probabilistic reserve market incorporating interruptible load," *IEEE Trans. Power Syst*., vol. 21, no. 3, pp. 1079–1087, Aug. 2006.
  - [17] S. Porkar, M. Fotuhi-Firuzabad, A. A.-T. fard, and B. Porkar, "An approach to determine spinning reserve requirements in a deregulated electricity market," in *IEEE Power Syst. Conf. and Exp*., Oct. 2006, pp. 1341–1344.

Reserve Quantities

- Iterative schemes:
  - [18] J. W. O'Sullivan and M. J. O'Malley, "A new methodology for the provision of reserve in an isolated power system," *IEEE Trans. Power Syst*., vol. 14, no. 2, pp. 519–524, May 1999.
  - [19] L. M. Xia, H. B. Gooi, and J. Bai, "A probabilistic reserve with zero-sum settlement scheme," *IEEE Trans. Power Syst*., vol. 20, no. 2, pp. 993–1000, May 2005.
  - [20] M. A. Ortega-Vazquez and D. S. Kirschen, "Optimizing the spinning reserve requirements using a cost/benet analysis," *IEEE Trans. Power Syst*., vol. 22, no. 1, pp. 24–33, Feb. 2007.
  - [21] U. A. Ozturk, M. Mazumdar, and B. A. Norma, "A solution to the stochastic unit commitment problem using chance constrained programming," *IEEE Trans. Power Syst*., vol. 19, no. 3, pp. 1589-1598, Aug. 2004.
- Robust optimization:
  - [22] A. Street, F. Oliveira, and J. M. Arroyo, "Contingency-constrained unit commitment with n-k security criterion: A robust optimization approach," *IEEE Trans. Power Syst*., vol. 26, no. 3, pp. 1581–1590, Aug. 2011.

Two-Stage Models with Transmission Constraints in Second Stage

- Stochastic programming
  - [23] J. M. Arroyo and F. D. Galiana, “Energy and reserve pricing in security and network-constrained electricity markets,” *IEEE Trans. Power Syst*., vol. 20, no. 2, pp. 634–643, May 2005.
  - [24] F. D. Galiana, F. Bouffard, J. M. Arroyo, and J. F. Restrepo, “Scheduling and pricing of coupled energy and primary, secondary, and tertiary reserves,” in *Proceedings of the IEEE*, vol. 93, no. 11, Nov. 2005, pp. 1970–1983.
  - [25] F. Bouffard, F. D. Galiana, and A. J. Conejo, “Market-clearing with stochastic security - part i: formulation,” *IEEE Trans. Power Syst*., vol. 20, no. 4, pp. 1818–1826, Nov. 2005.
  - [26] L. Wu, M. Shahidehpour, and T. Li, “Stochastic security-constrained unit commitment,” *IEEE Trans. Power Syst*., vol. 22, no. 2, pp. 800–811, May 2007.

Two-Stage Models with Transmission Constraints in Second Stage

- Stochastic programming continued…
  - [27] L. Wu, M. Shahidehpour, and T. Li, “Cost of reliability analysis based on stochastic unit commitment,” *IEEE Trans. Power Syst*., vol. 23, no. 3, pp. 1364–1374, Aug. 2008.
  - [28] K. W. Hedman, M. C. Ferris, R. P. O’Neill, E. B. Fisher, and S. Oren, “Co-optimization of generation unit commitment and transmission switching with n-1 reliability,” *IEEE Trans. Power Syst*., vol. 25, no. 2, pp. 1052–1063, May 2010.
  - [29] H. A. Hejazi, H. R. Mohabati, S. H. Hosseinian, and M. Abedi, “Differential evolution algorithm for security-constrained energy and reserve optimization considering credible contingencies,” *IEEE Trans. Power Syst*., vol. 26, no. 3, pp. 1145–1155, Aug. 2011.

Two-Stage Models with Transmission Constraints in Second Stage

- Robust optimization:
  - [30] D. Bertsimas, E. Litvinov, X. A. Sun, J. Zhao, T. Zheng, “Adaptive robust optimization for the security constrained unit commitment problem,” *IEEE Trans. Power Syst*., vo. 28, no. 1, pp 52-63, Mar. 2011
  - [31] R. Jiang, M. Zhang, G. Li, Y. Guan, “Benders decomposition for the two-stage security constrained robust unit commitment problem,” Jul. 2011. [Online].
  - [32] Q. Wang, J.-P. Watson, and Y. Guan, “Two-stage robust optimization for n-k contingency-constrained unit commitment,” Nov. 2012. [Online].
- Dynamic reserve sharing:
  - [33] T. Zheng and E. Litvinov, “Contingency-based zonal reserve modeling and pricing in a co-optimized energy and reserve market,” *IEEE Transactions on Power Systems*, vol. 23, no. 2, pp. 277–286, May 2008.

Publications

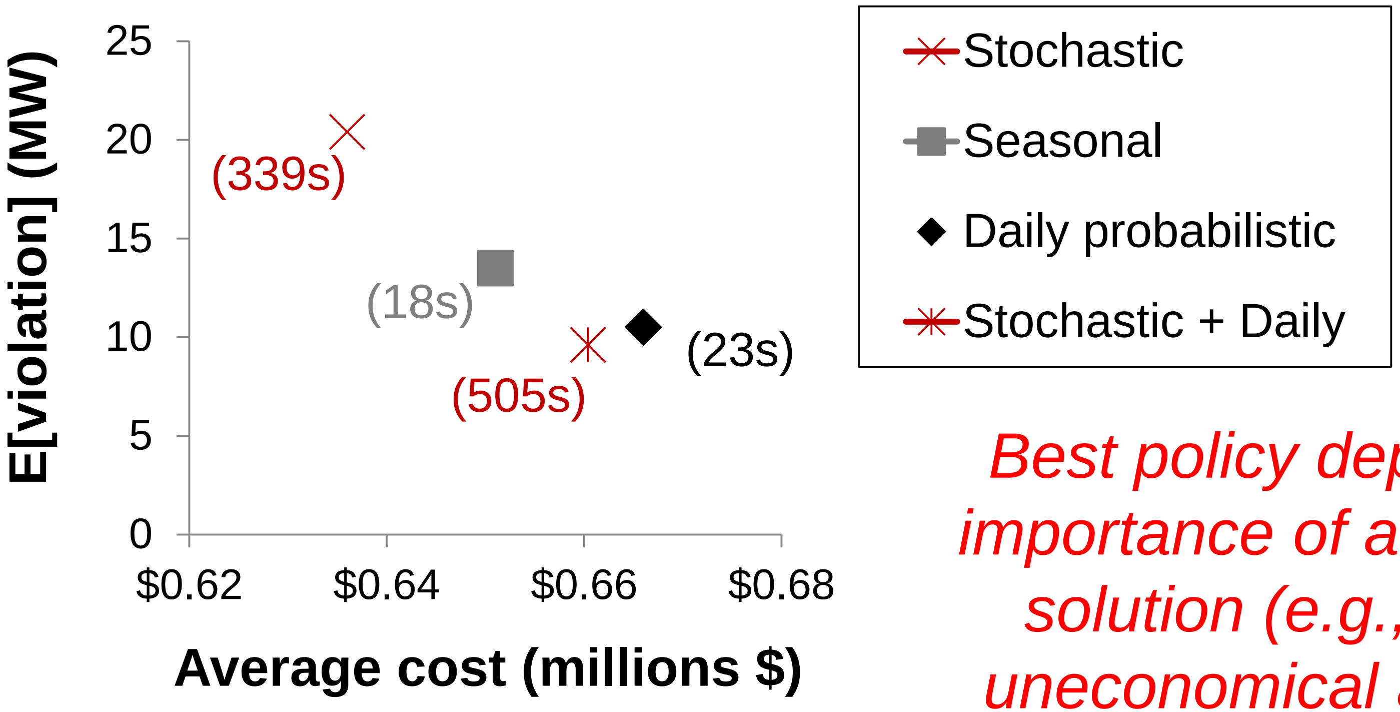
- Zone determination
  - [34] F. Wang and K. W. Hedman, "Dynamic Reserve Zones for Day-Ahead Unit Commitment with Renewable Resources," *IEEE Trans. Power Syst.*, submitted.
  - [35] F. Wang and K. W. Hedman, "Reserve zone determination based on statistical clustering methods," in *NAPS*, Sep. 2012, pp. 1–6.
- Congestion-based reserves
  - [36] J. D. Lyon, K. W. Hedman, and M. Zhang, "Reserve requirements to efficiently mitigate intra-zonal congestion," *IEEE Trans. Power Syst.*, submitted.
- Reserve disqualification
  - [37] J. D. Lyon, M. Zhang, and K. W. Hedman, "Dynamic reserve zones for distinct scenarios," In preparation.

Appendix B

Additional Results

Day-Ahead Dynamic Zones

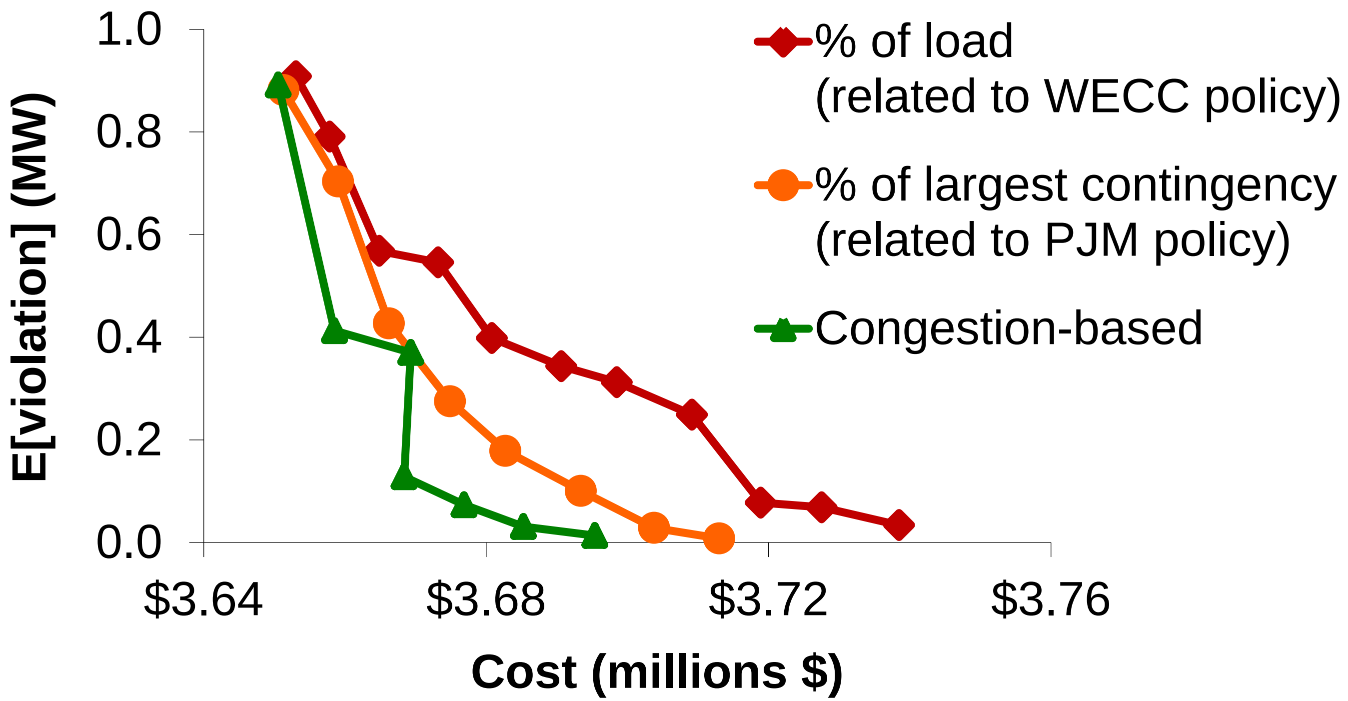
- Unit commitment for IEEE 118 bus test system
  - Average results over 12 days
  - E[violation] measures unreliability due to congestion



Best policy depends on the importance of a reliable initial solution (e.g., the cost of uneconomical adjustments)

Congestion-Based Reserves

- Unit commitment for IEEE 73 bus test system
  - Policies tested with different levels of conservatism
  - Pareto dominant solutions attributable to reducing congestion



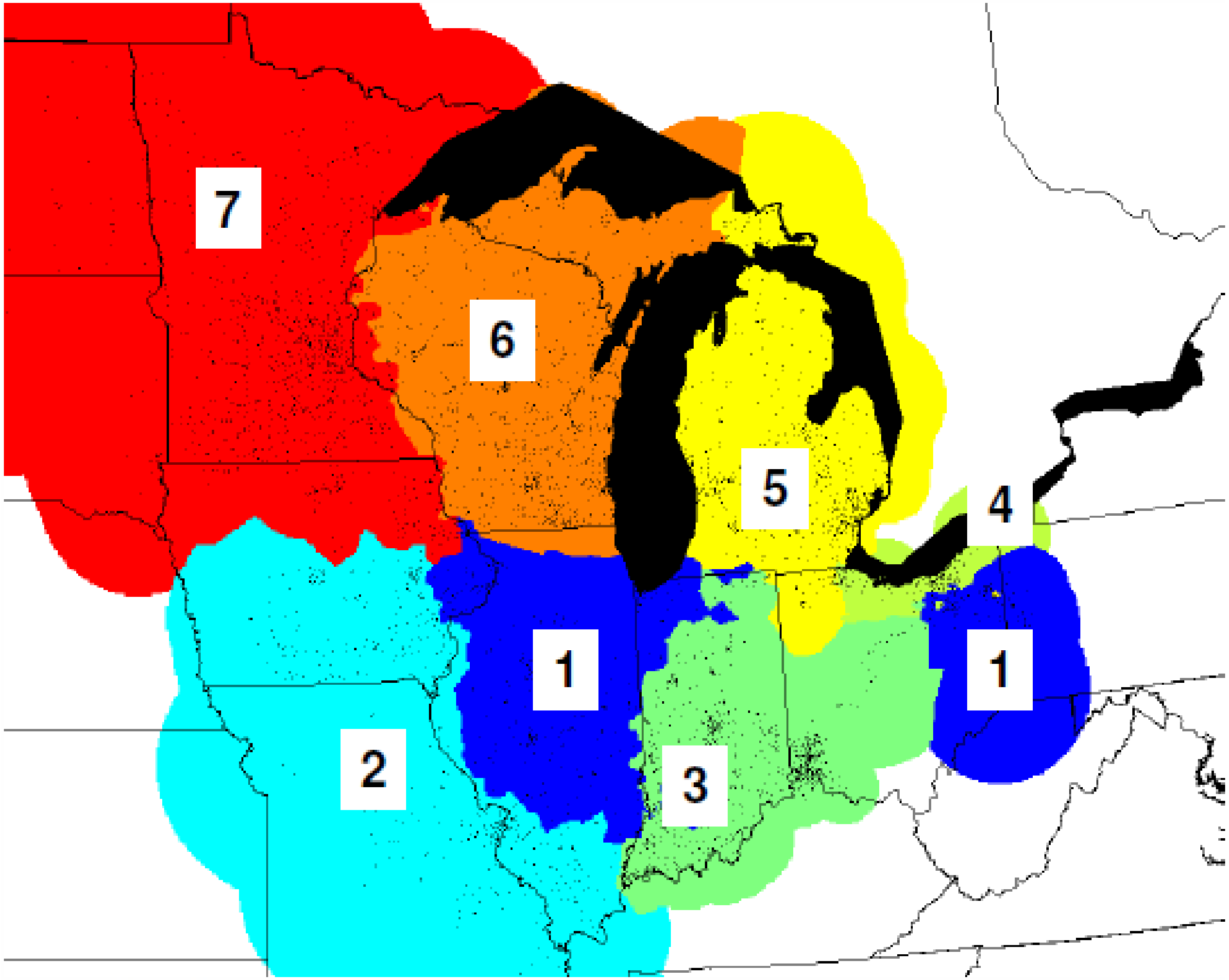
Appendix C

Other

Markets

- The goal of the ISO is to maximize market surplus
- We do not anticipate the proposed methods will require changes to market structure
- We do anticipate:
  - Market surplus will improve
  - Identification of scarce resources will reduce the need for uneconomical adjustments and the associated uplifts
  - Uncertainty about zones will make it harder for participants to exercise market power

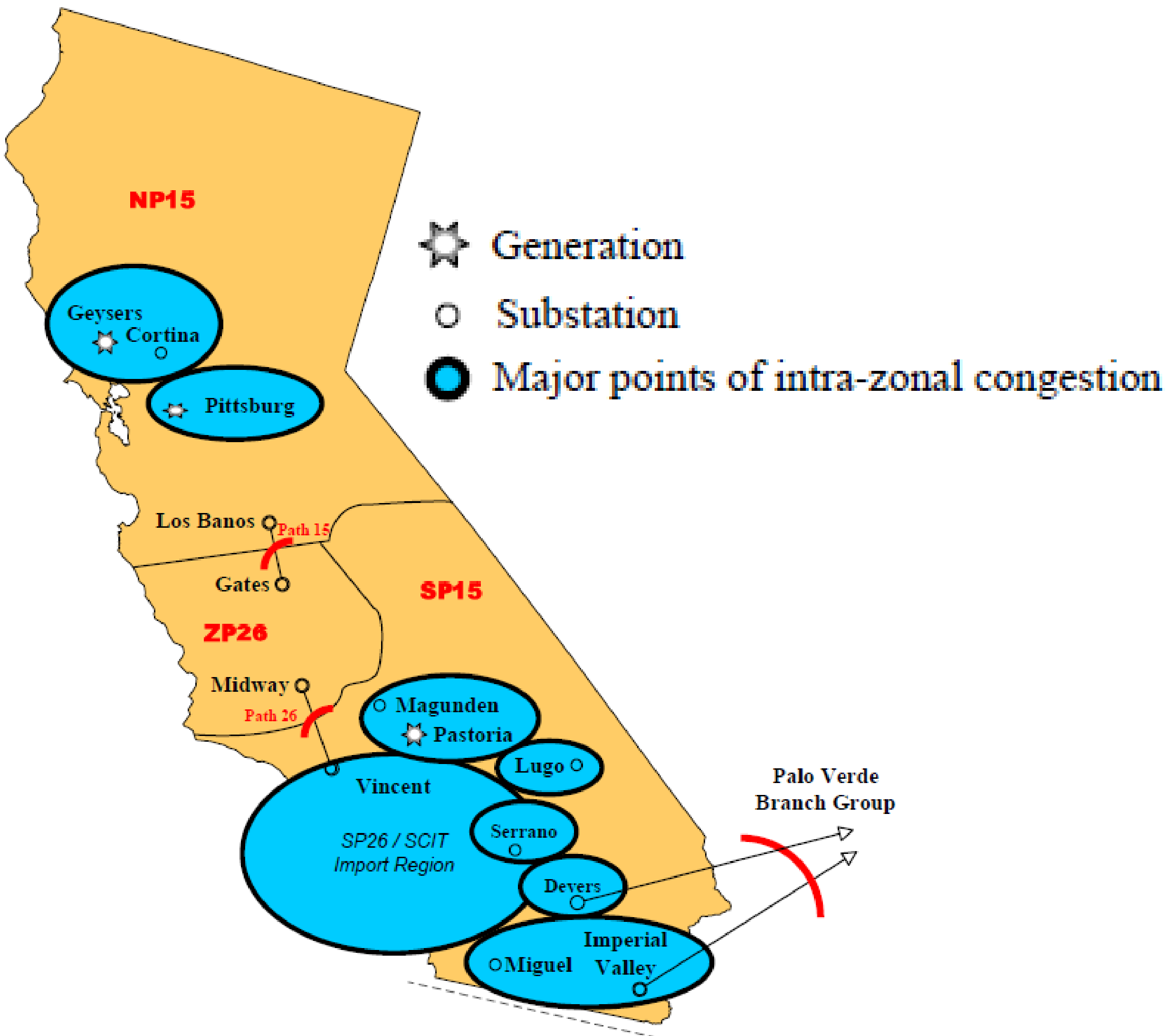
Midwest ISO Reserve Zones



(Area 1 is part of PJM)

Operating reserve zone modeling, September – November 2008, MISO. [Online]

California ISO Energy and Reserve Zones



Intra-zonal congestion, CAISO Department of Market Monitoring, Apr. 2008. [Online]