COORDINATING CONGESTION RELIEF ACROSS MULTIPLE REGIONS: COMPUTATIONAL TESTING

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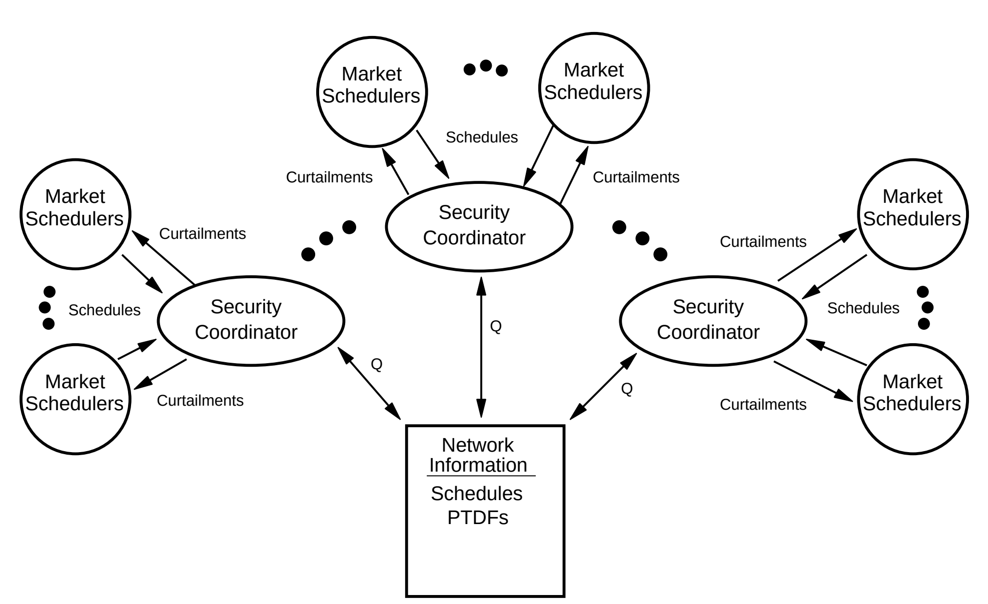
To relieve transmission overloads, the existing NERC system exchanges quantity information about scheduled loads to determine the impact on the grid. Administrative rules and priorities determine schedule curtailments.

NERC ADMINISTRATIVE TRANSMISSION LOADING RELIEF



Movement to greater use of market forces would require an alternative to the NERC transmission loading relief procedures.

- **Prices.** The use of markets implies pricing and the associated incentives. Participants must have economic information and face real prices to induce market support of transmission loading relief.

- **Schedules, Bids and Economic (Re)Dispatch.** The ISO framework of schedules supplemented by incremental and decremental bids provides the opportunity to use security constrained economic dispatch to redispatch schedules and respect security limits to achieve efficient transmission loading relief.

- **Iteration.** Regional system operators or security coordinators could exchange information about both schedules and prices in an iterative process to establish a mutually consistent redispatch for transmission loading relief.

- **Settlements.** A system-wide settlements system could handle payments between and among the regional system operators.

- **Integration of Markets and Reliability.** The supposed dichotomy between markets and reliability is false. And the implied separation between reliability (ISOs) and short-term markets (Power Exchanges) is counterproductive. At best, the false separation is expensive. At worst, it is dangerous. Both markets and reliability can be improved if the essential interactions are recognized and integrated.

A market oriented system would require information on scheduled loads, bids and prices to determine an economic redispatch of the system.

The basic outline involves a communication between system operators and market participants to obtain market information, and among system operators to achieve coordinated congestion relief:

1. Market Participants Submit Schedules and Bids for Dispatch Hour.

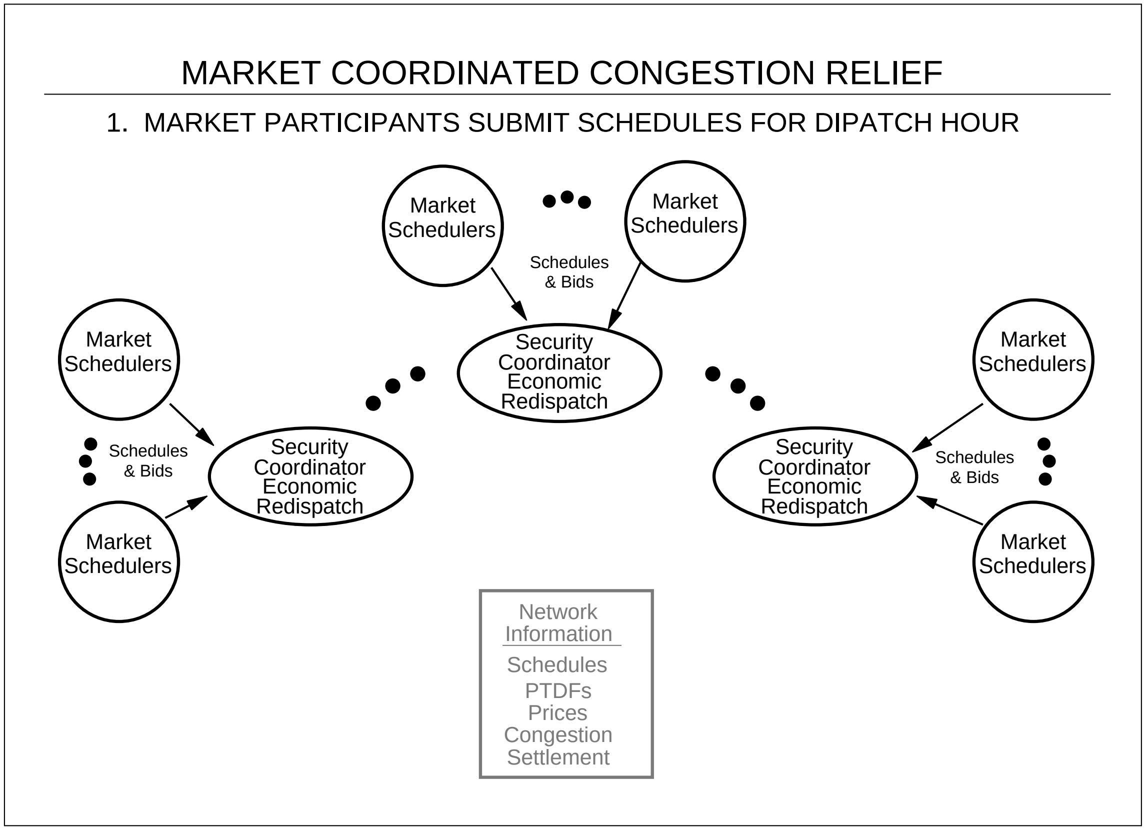
2. System Operators Interact to Achieve Coordinated Congestion Relief.

3. System Operators Publish (Re)Dispatch and Prices.

Further details of the redispatch protocol can be found in:

Michael Cadwalader, Scott Harvey, William Hogan, and Susan Pope, "Coordination of Congestion Relief Across Multiple Regions," Center for Business and Government, Harvard University, October 7, 1999.

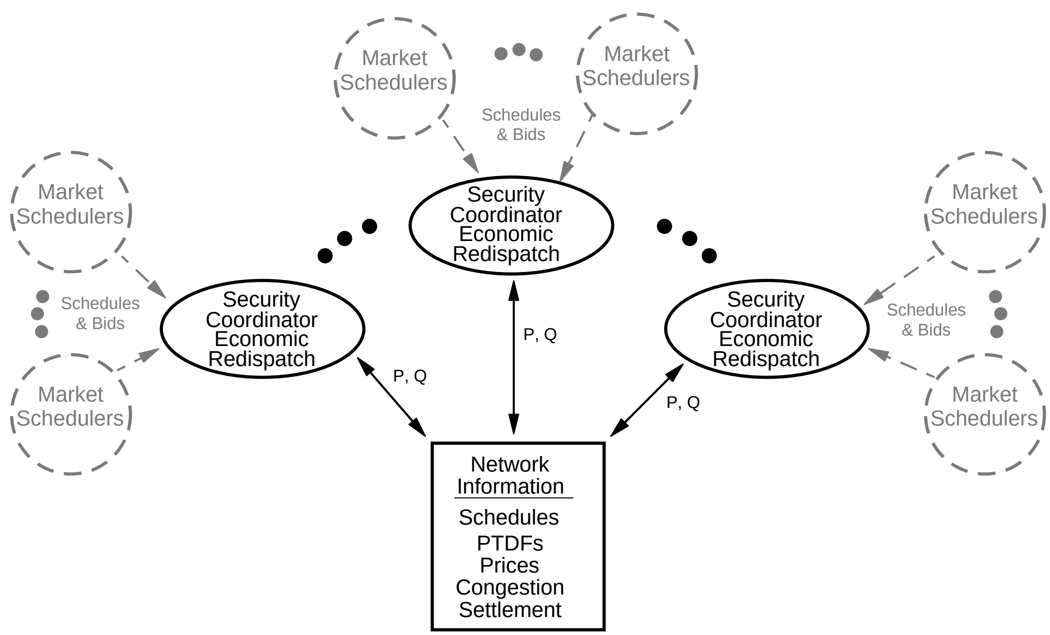
A market oriented system would begin with market participants submitting both schedules and bids to adjust those schedules.



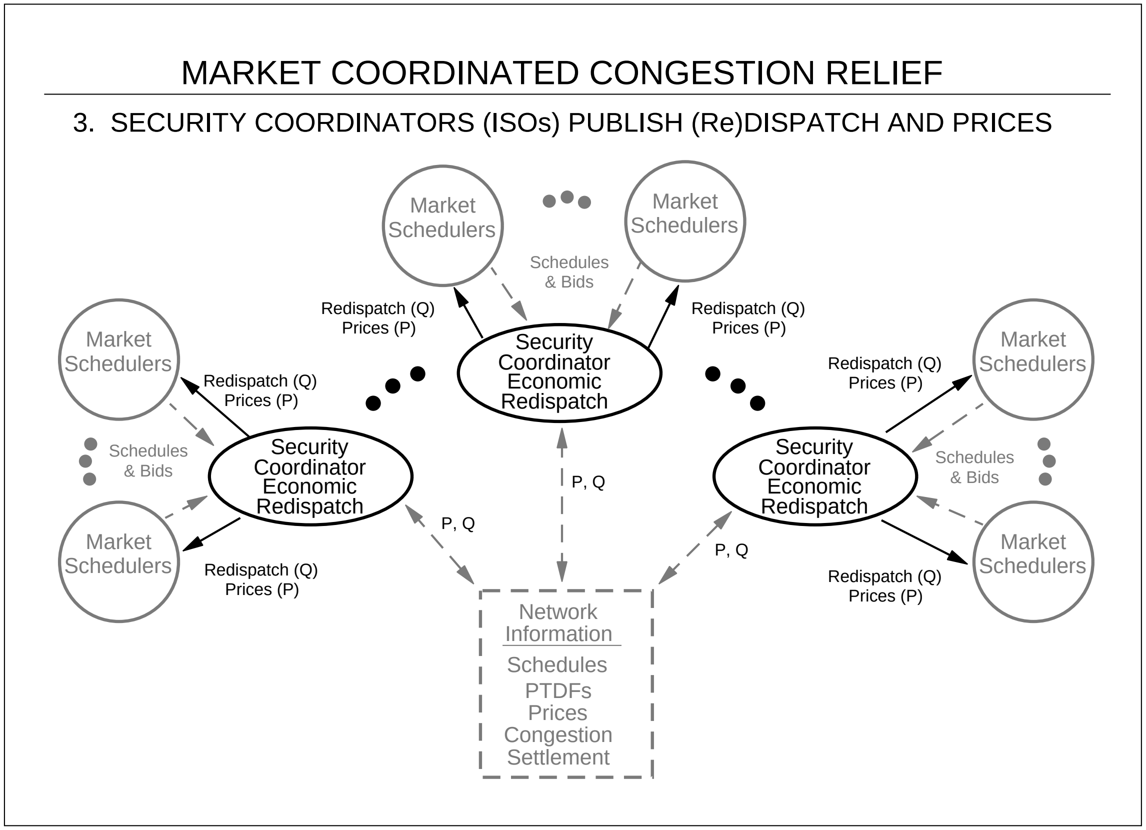
Given the schedules and bids, the system operators would interact to find an efficient market solution that balanced the system and relieved transmission constraints.

MARKET COORDINATED CONGESTION RELIEF

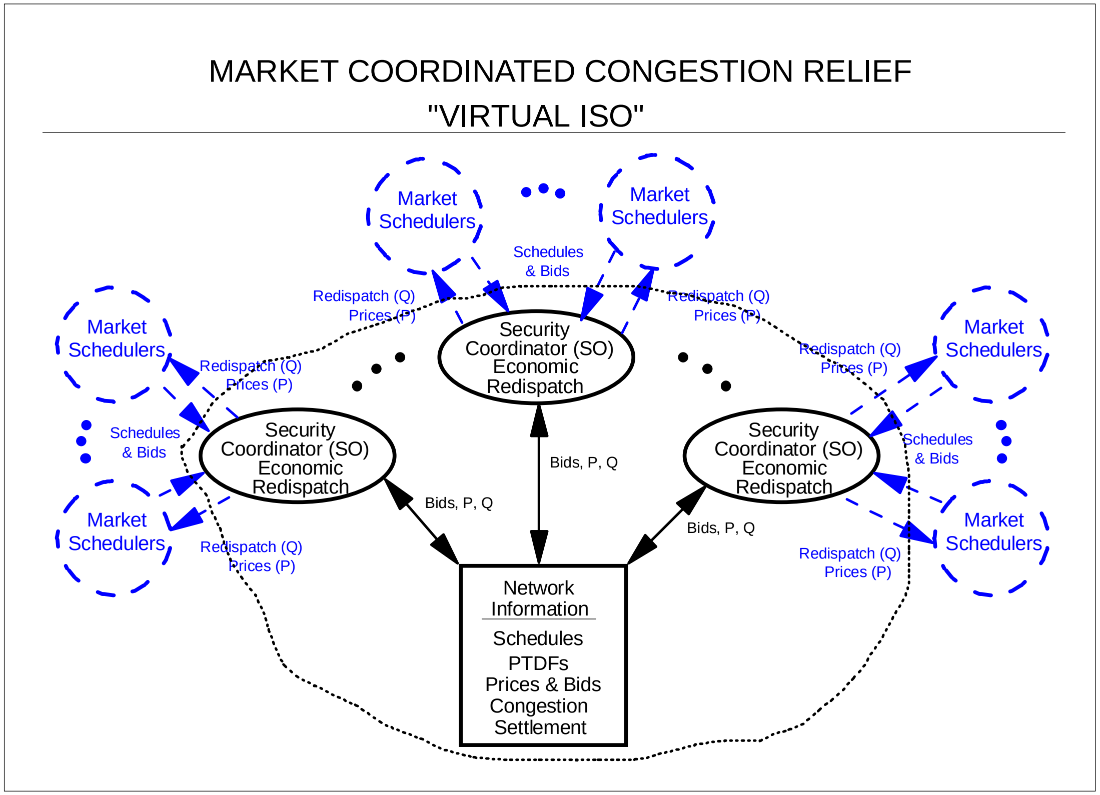
2. SECURITY COORDINATORS (ISOs) INTERACT TO ACHIEVE EFFICIENT TLR



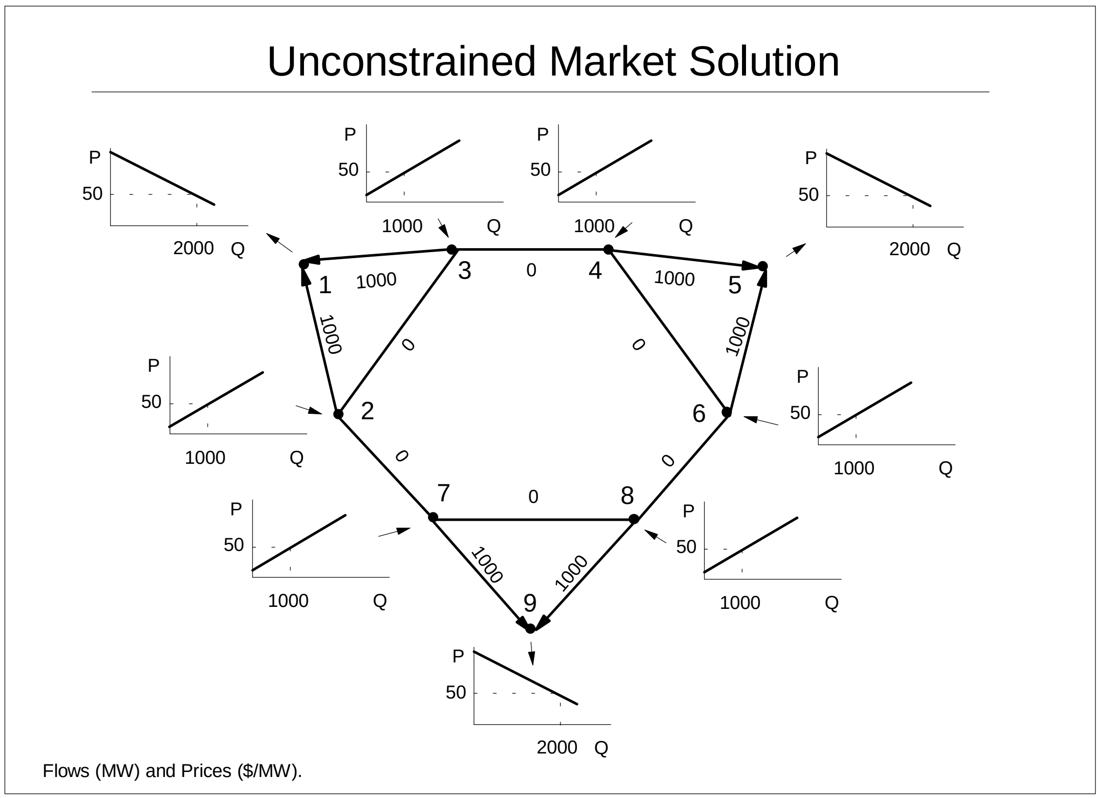
Finally, system operators inform the market participants of the (re)dispatch for the hour and the prices that will apply for balancing charges, transmission congestion charges, and settlements.



Through repeated exchange of information in a common data base, the regional system operators would solve their local problems to update the schedules and price estimates. A consistent solution would be an overall market equilibrium as though obtained by a "virtual ISO."

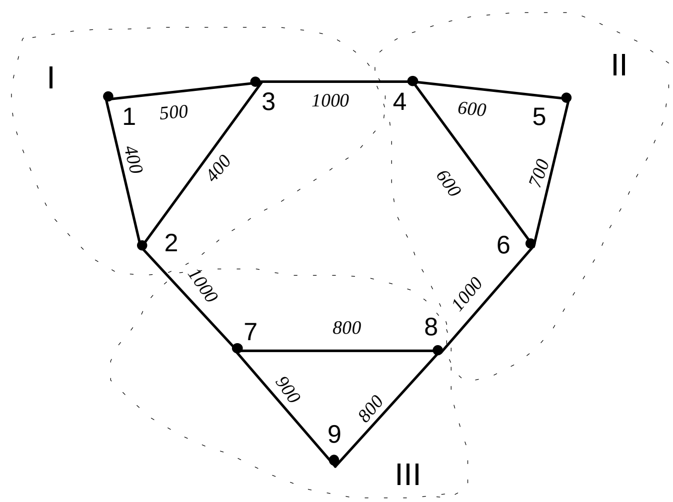


An example network with nine locations and provides an illustration of a "virtual ISO" operating by coordinating inputs across the full grid. The unconstrained solution provides a starting point.



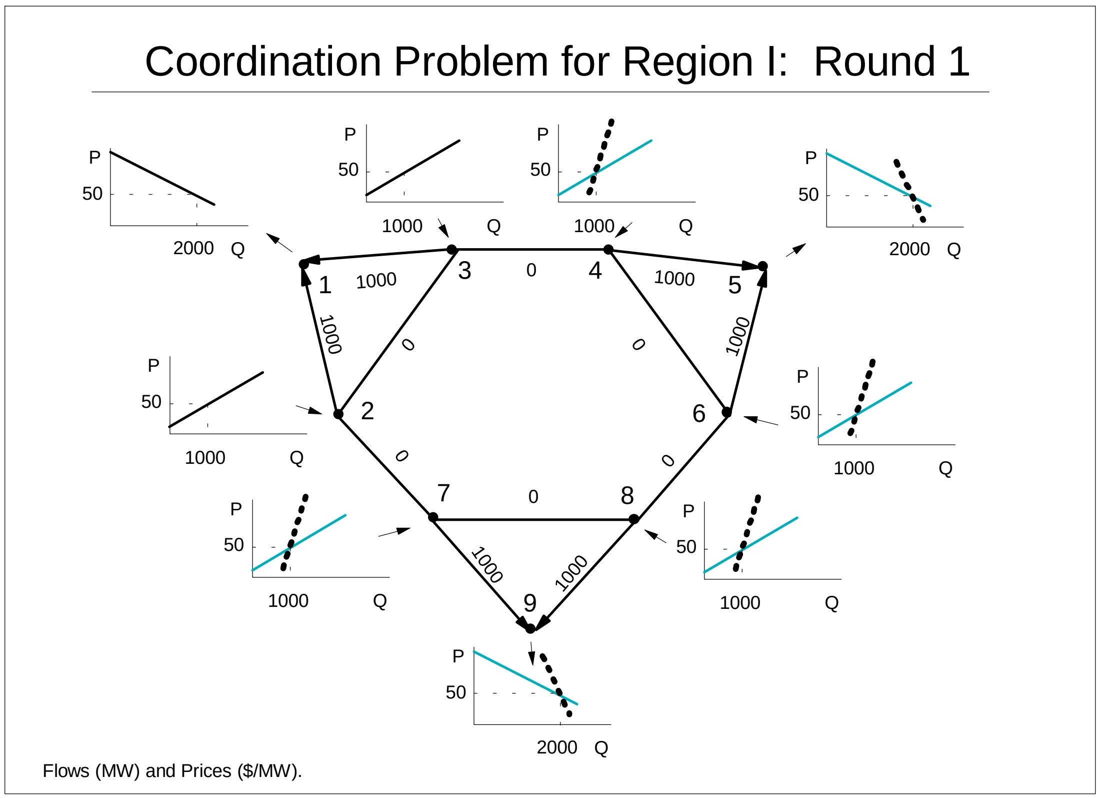
Three security coordinators or ISOs coordinate the operations within each region and exchange information with each other. Each ISO sees the flows on the full grid, but monitors only its own transmission constraints.

Regional Groupings and Transmission Limits



Thermal limits on transmission lines (MW).

In the first round, Region I sees the adjustment bids from the other regions. This produces a modified economic dispatch problem where Region I uses its own bids from market participants and the adjustment bids for external locations to redispatch and meet its Region I constraints.



Region I produces a redispatch with a new schedule for the entire system. In addition, the redispatch produces estimates of the congestion cost associated with the constraints in Region I.

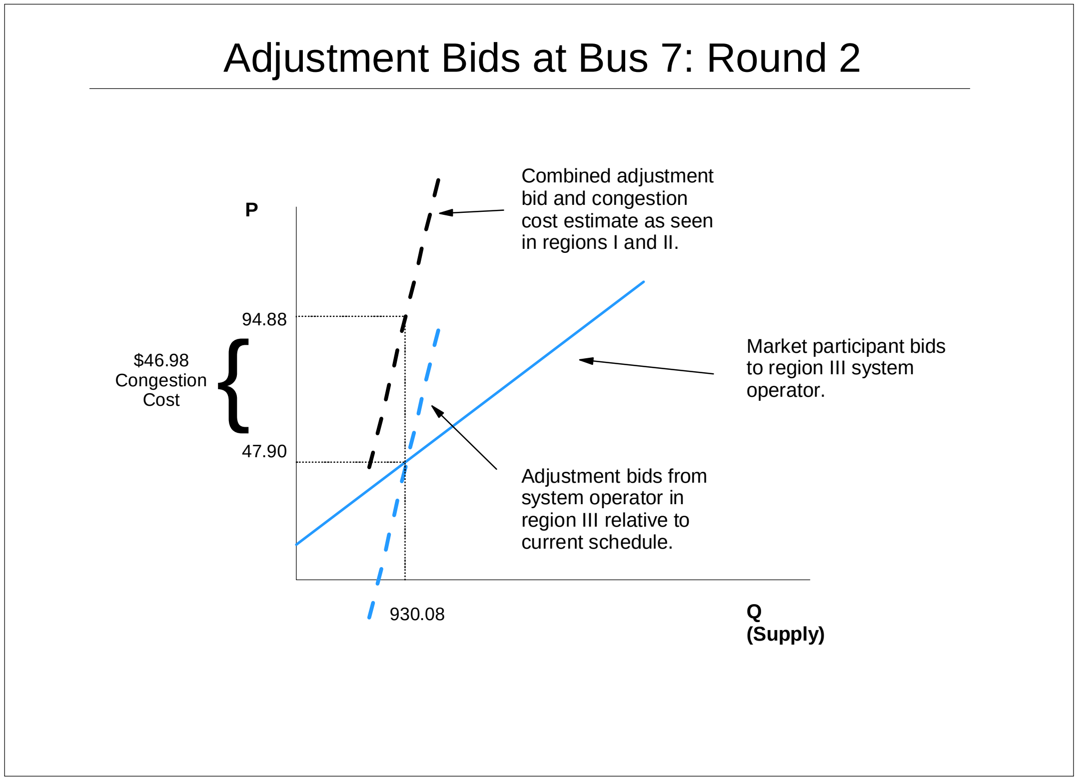
Round 1

Location		Tentative Schedule	Adjustment	New Schedule
1	p	50.00	33.00	83.00
	q	2000.00	-1100.00	900.00
2	p	50.00	-16.22	33.78
	q	-1000.00	540.51	-459.49
3	p	50.00	-6.54	43.46
	q	-1000.00	218.11	-781.89
4	p	50.00	-1.32	48.68
	q	-1000.00	43.87	-956.13
5	p	50.00	-1.43	48.57
	q	2000.00	47.60	2047.60
6	p	50.00	-1.54	48.46
	q	-1000.00	51.32	-948.68
7	p	50.00	-2.10	47.90
	q	-1000.00	69.92	-930.08
8	p	50.00	-1.87	48.13
	q	-1000.00	62.48	-937.52
9	p	50.00	-1.99	48.01
	q	2000.00	66.20	2066.20

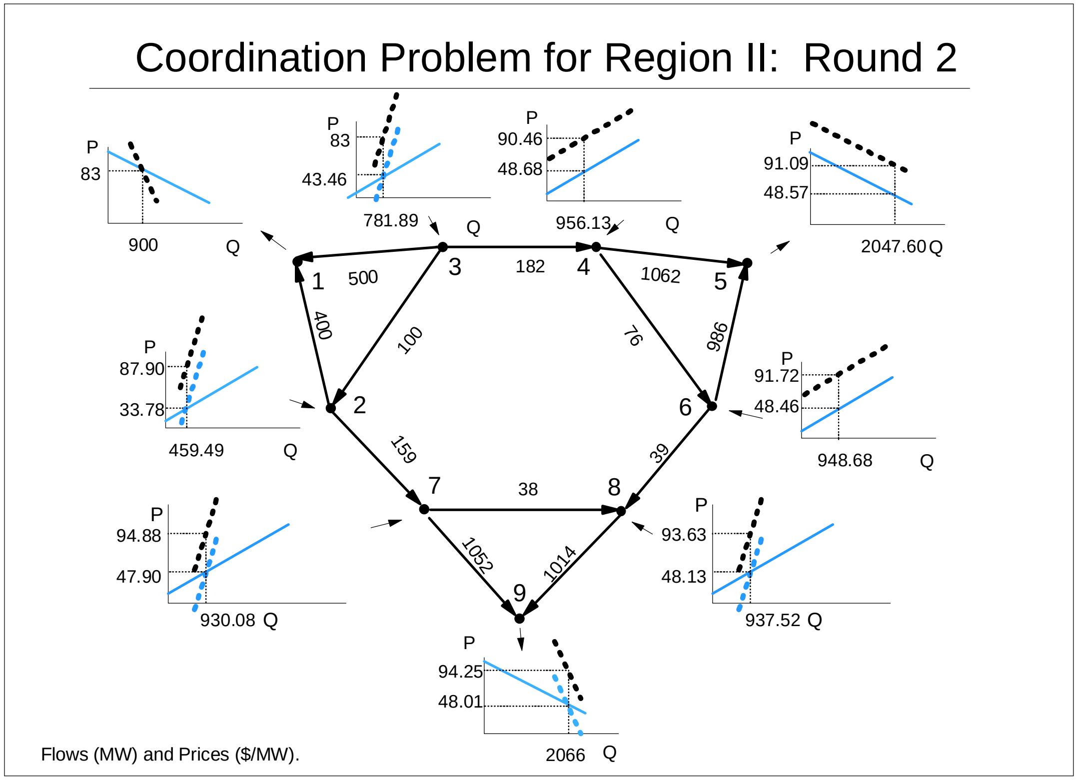
Congestion Costs from Region I

Bus	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	0	49.22	39.54	41.78	42.52	43.26	46.98	45.50	46.24

The adjustment bids from other regions provide the representation of the both the congestion costs and an estimate of the redispatch costs.



In the second round, Region II sees the external adjustment bids and congestion costs. This produces a modified economic dispatch problem. Region II uses this information to redispatch for its Region II constraints.

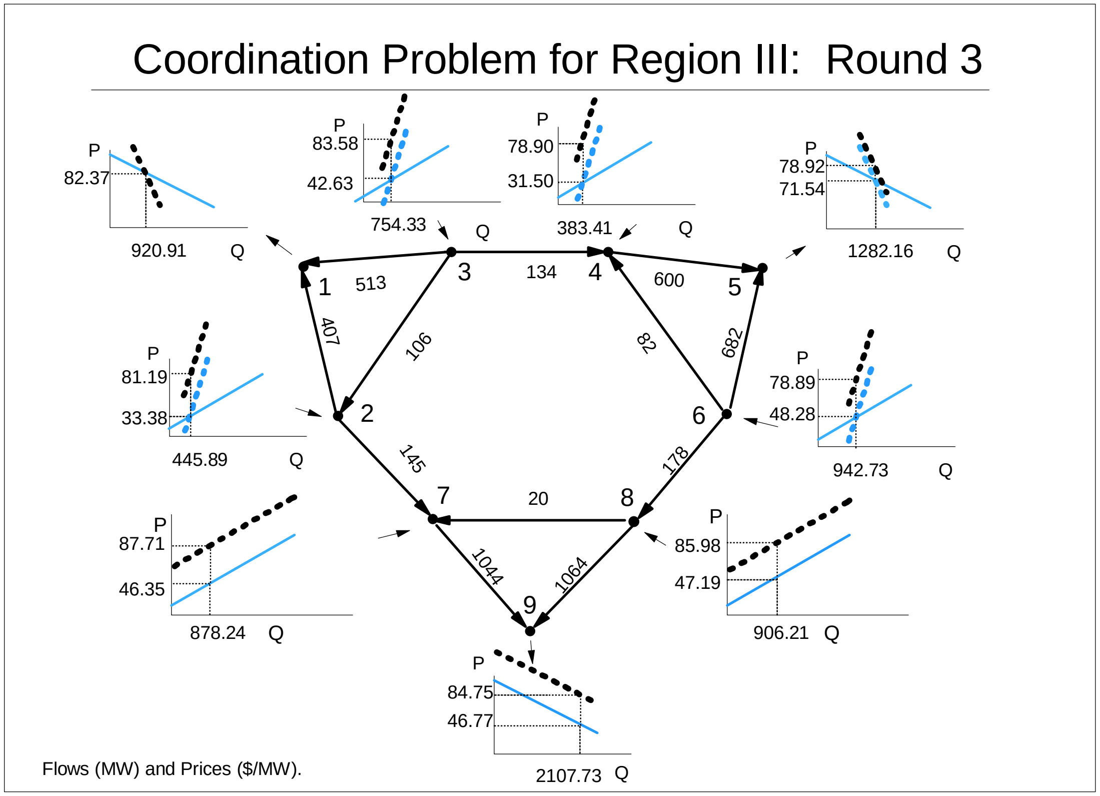


Region II produces a redispatch with a new schedule for the entire system. In addition, the redispatch produces estimates of the congestion cost associated with the constraints in Region II.

Congestion Cost Estimates after Round 2

	Bus 1	2	3	4	5	6	7	8	9
From I	0	49.22	39.54	41.78	42.52	43.26	46.98	45.50	46.24
From II	0	-1.41	1.41	5.62	-35.14	-12.65	-5.62	-8.43	-7.03
From III	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Outside I	0	-1.41	1.41	5.62	-35.14	-12.65	-5.62	-8.43	-7.03
Outside II	0	49.22	39.54	41.78	42.52	43.26	46.98	45.50	46.24
Outside III	0	47.81	40.95	47.40	7.38	30.61	41.36	37.06	39.21

In round 3, Region III sees the external adjustment bids and congestion costs. This produces a modified economic dispatch problem. Region III uses this information along with its own bids from market participants to redispatch for its Region III constraints.

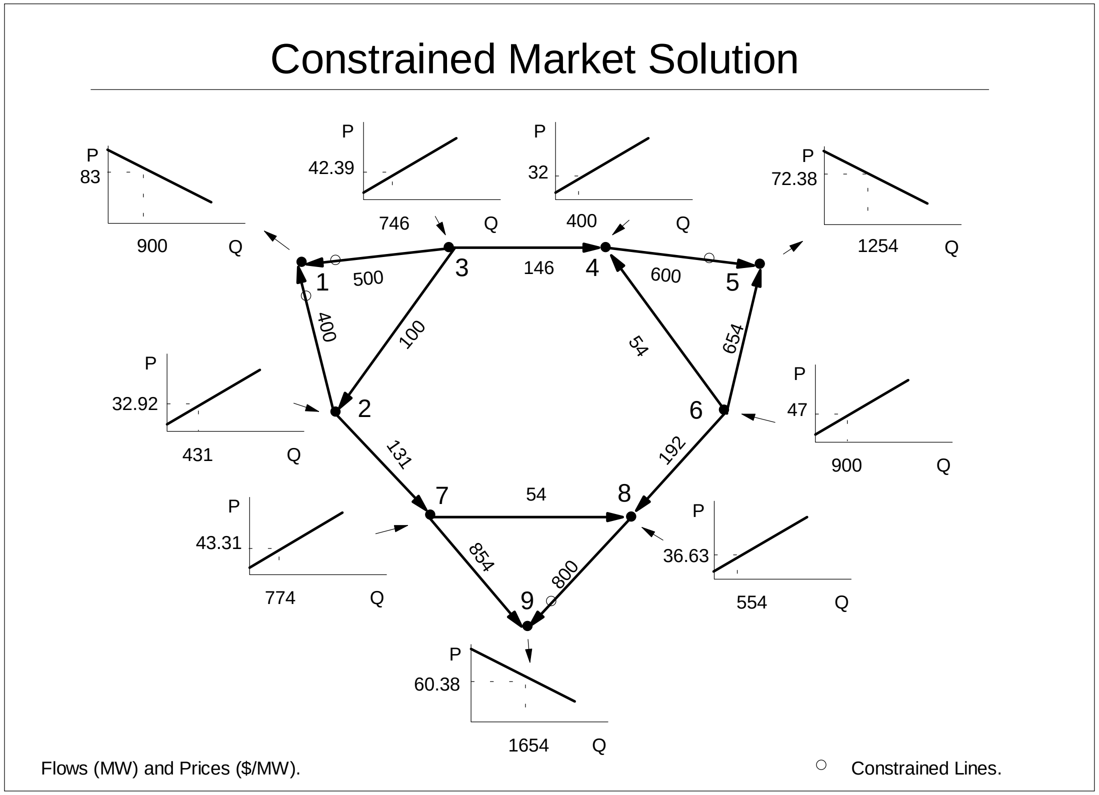


Region III produces a redispatch with new schedules for the entire system. In addition, the redispatch produces estimates of the congestion cost associated with the constraints in Region III.

Congestion Cost Estimates after Round 3

Bus	1	2	3	4	5	6	7	8	9
From I	0	49.22	39.54	41.78	42.52	43.26	46.98	45.50	46.24
From II	0	-1.41	1.41	5.62	-35.14	-12.65	-5.62	-8.43	-7.03
From III	0	-0.88	0.88	3.51	4.39	5.27	-3.51	7.90	-17.56
Outside I	0	-2.28	2.28	9.14	-30.75	-7.38	-9.14	-0.53	-24.59
Outside II	0	48.34	40.42	45.29	46.91	48.53	43.47	53.40	28.68
Outside III	0	47.81	40.95	47.40	7.38	30.61	41.36	37.06	39.21

Through the exchange of information, the ISOs find a constrained solution for the full system that is an overall market equilibrium. Payments could be handled through a settlements process.

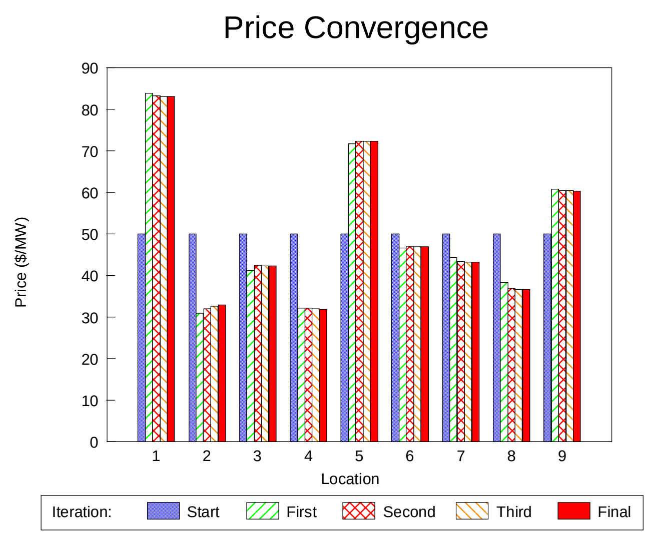


The coordinated redispatch for congestion relief produces a consistent set of final congestion costs.

Coordinated Congestion Cost Estimates

Bus	1	2	3	4	5	6	7	8	9
From I	0	52.45	38.25	41.52	42.62	43.71	49.17	46.98	48.08
From II	0	-1.46	1.46	5.85	-36.54	-13.15	-5.85	-8.77	-7.31
From III	0	-0.91	0.91	3.63	4.54	5.45	-3.63	8.17	-18.15
Outside I	0	-2.37	2.37	9.48	-32.00	-7.71	-9.48	-0.60	-25.46
Outside II	0	51.54	39.15	45.15	47.15	49.15	45.54	55.15	29.92
Outside III	0	50.98	39.71	47.37	6.08	30.55	43.32	38.22	40.77

If the "local" constraints and bids are the most important, convergence to a good solution could occur in a relatively few steps. For the example problem, with coordination across locational prices of loads, one cycle through the three ISOs gave a good approximation of the final solution.



Price coordination iteration for nine bus example.

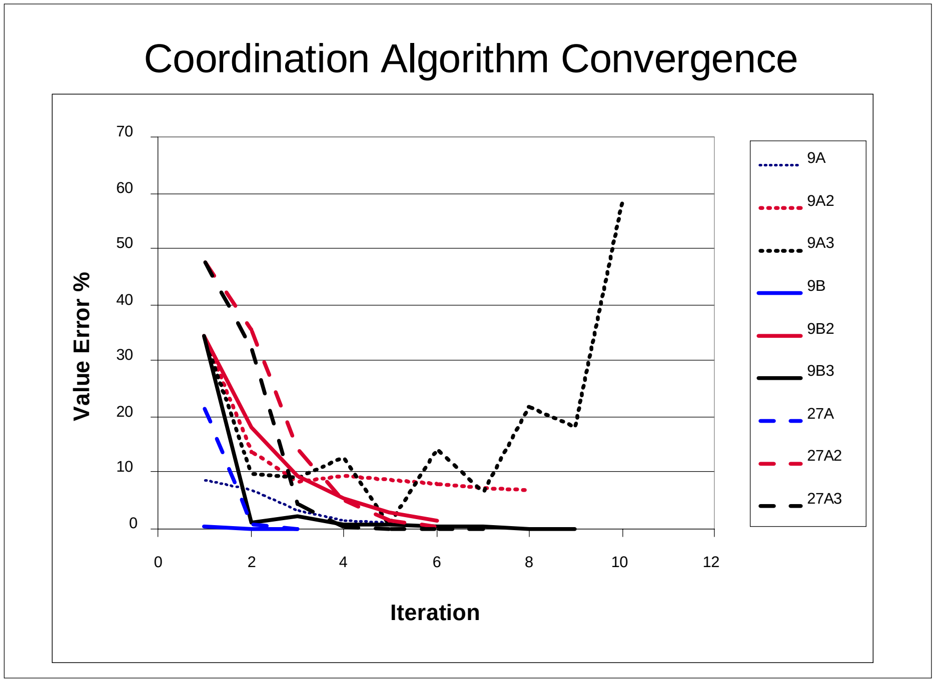
Baldick, Kim, Chase and Loo (1998) report similar fast convergence in a test without contingency constraints for a 2578 line representation of the Texas ERCOT system and coordination on connecting variables.

The possible coordination algorithms include many variants that might affect the rate of convergence. The experiments included different implementations:

- **Order among regions.** The choice of the degree of updated information available to each region as it does a hypothetical redispatch.
  - **Sequential.** Each region goes in order, with the latest information from the other regions used in the redispatch.
  - **Parallel.** Each region works in parallel on each round of updates, providing new estimates simultaneously.
- **Step Size.** How far to move in the direction of the hypothetical solution to provide a new dispatch and new estimates of congestion costs.
- **Adjustment Bids.** The effective penalty function to apply for significant deviations from the current dispatch estimates and prices.

The tests with the hypothetical networks were used to provide some guidance in the design of the tests with more realistic networks.

The algorithms could be applied to larger networks. In one scaling experiment we evaluated combinations of the nine bus network and sequential (A) versus parallel algorithms with step size 0.5 (B) and 1.0 (C). The only problematic case was 9A3 which has very elastic supply and demand.



Scaling tests with and 81 bus and 243 bus versions produced results with rapid convergence. Furthermore, a test of the Oren "counterexample" also converged rapidly.

The hypothetical model may differ from the real network. The interaction between transfer factors and congestion in the real system might produce different convergence results. The next step is to examine the performance on a more realistic network.

- **GE MAPS.** The GE MAPS model provides an available tool for defining realistic networks with many constraints. In principle, we could have a GE MAPS representation for each of the regions and simulate the coordination algorithm by alternating between regions and changing the inputs for the MAPS model in each region depending on the outputs in the other regions.

- **GE Mini- MAPS.** The MAPS model linearizes the network representation around a solved load flow. The full model contains more detail, but for our purposes it is useful to have a simplified version of the MAPS model. The important information extracted from the detailed MAPS runs includes:

- **Network Constraints.** The shift factors for the binding constraints and the MAPS solution can be used to create a linear representation of the binding constraints in the MAPS solution.

- **Bid Curves.** Interpolation between the unconstrained and constrained MAPS solutions provides an approximate representation of the bid curves.

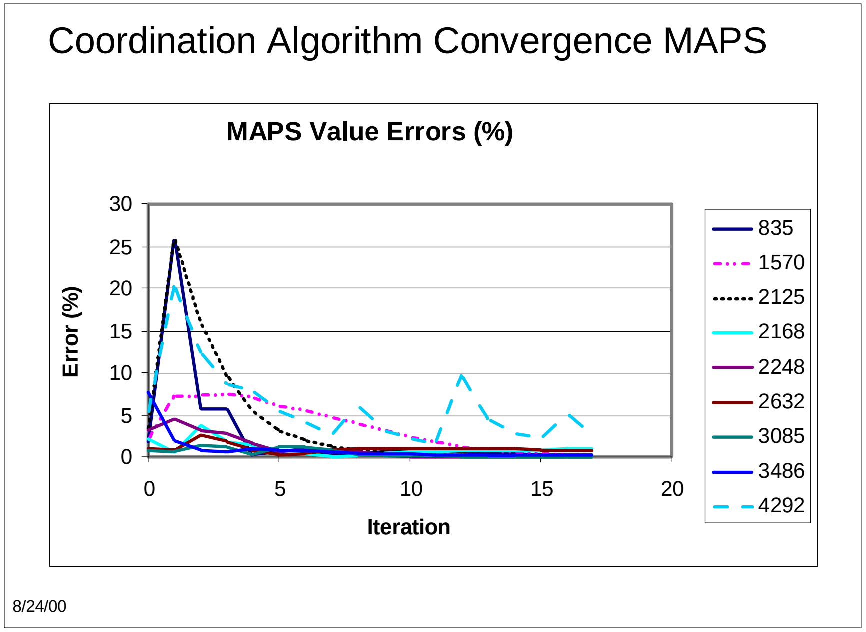
- **Regional Coordination.** Given the mini-MAPS model for each region, simulation of the coordination algorithm is simplified without much loss in reality. Non-binding constraints are ignored, and the shape of the bid curves is not realistic. But the network representation is faithful to GE MAPS.

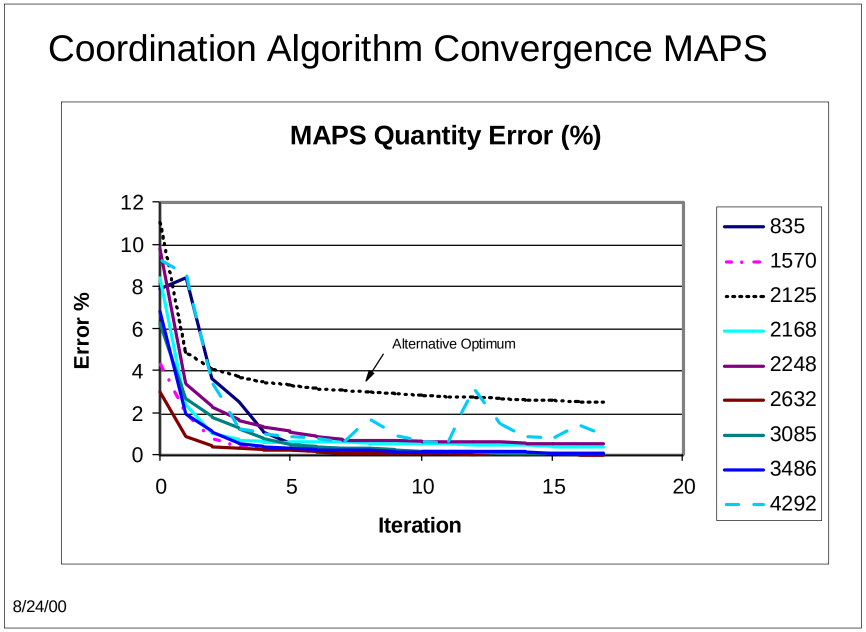
For the simulation purposes of understanding the convergence properties, the detail of the solution is not important. The test used a readily available model for two sets of data. Four constrained hours were uses to try various versions of the algorithms. The final five hours were tested in the best algorithm.

	MAPS Hour								
	835	***1570***	***2125***	***2168***	***2248***	***2632***	***3085***	***3486***	***4292***
Locations	1103	1103	1103	1103	1103	1103	1103	1103	1103
Constraints	33	37	30	37	41	31	27	29	33
Flexible Generators	54	39	38	61	62	32	22	32	66
Hi Price	41.25	79.42	27.20	114.64	116.50	43.94	23.58	40.03	70.26
Lo Price	-0.97	-0.97	4.64	-0.99	-15.15	15.18	18.15	20.68	-79.29

The selected MAPS representation had no detail for Ontario, which was combined with New York as a single region. There were relatively few binding constraints in PJM compared to what would be expected. However, the problems provided enough complexity in the network representation to serve as a reasonable test of how the mechanism might work on a real system.

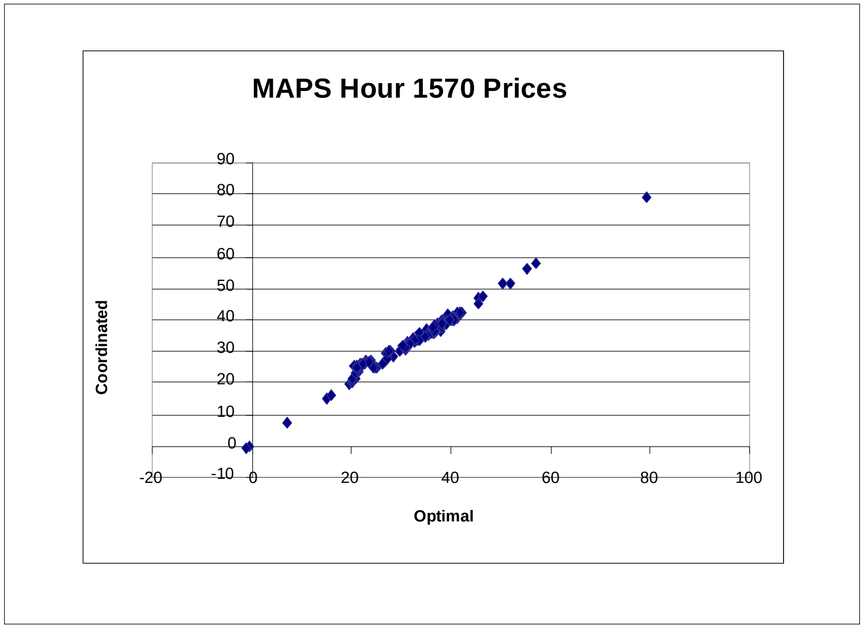
For the results reported here, the preliminary tests with the parallel algorithm did not work well and all the results are for sequential solution of each region in turn. The two measures of solution error are the value error as a percent of total and the dispatch quantity error as a percent of total generation.

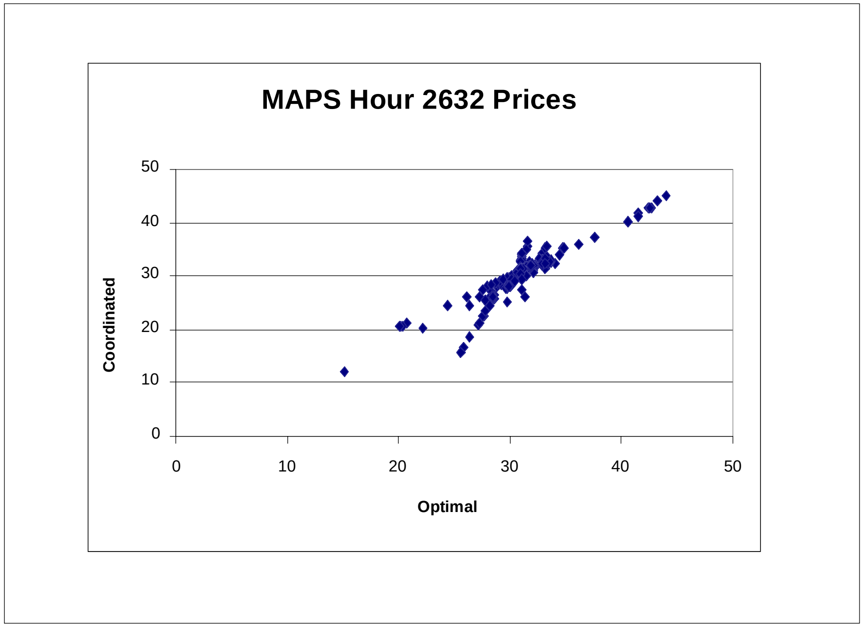




The convergence results are slightly slower than for the hypothetical problem. The apparent slower convergence in the value errors arises because of locations with fixed quantities where the prices can be difficult to estimate.

The tests show that all prices eventually converge to the correct prices at the adjustable locations but may be slow to converge at locations where the quantities are fixed.





The locations where quantities are fixed but prices are estimated may be difficult to pin down simply through a few iterations of the pure price directive decomposition. Knowledge of shift factors would greatly improve the process of price estimation.

The lessons from these simulations test include:

- The redispatch quantities converge rapidly.

- The prices at the flexible buses converge rapidly, but computing prices at buses with fixed quantities may require further iteration.

- Calculation of all prices could be simplified by reporting the shift factor data once the redispatch is determined and allowing for a joint estimation of prices in all regions. This would be much simpler than joint optimization of prices and quantities.

- The mini-MAPS approach provides a great deal of what is needed in the computer simulations, and there would not be much advantage in trying for more realistic computer simulations.

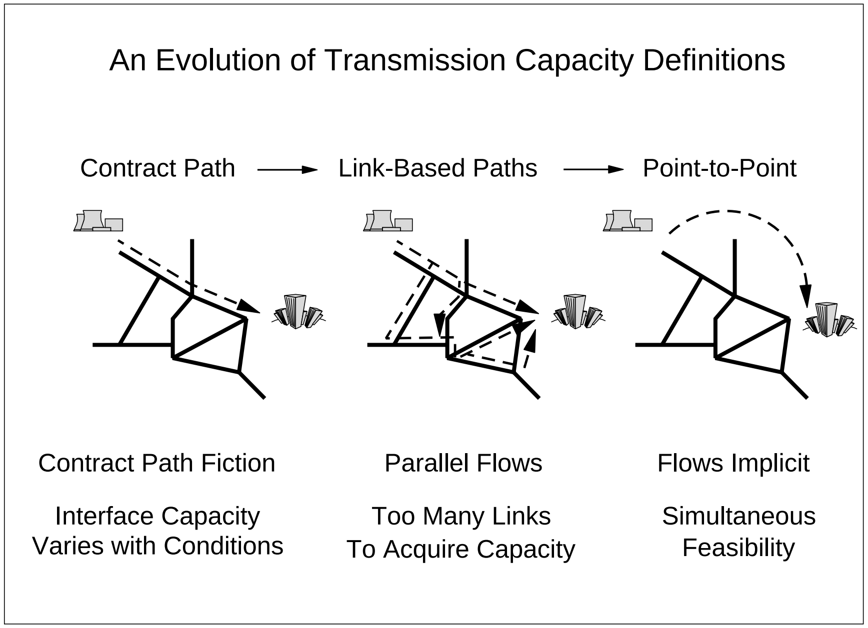
The challenge would be to identify how these results might be translated into a working system.

- Information exchange to include more than just congestion costs and net loads.
- Representation of networks using approximations of external systems.
- Settlement system for interregional redispatch costs.
- Design of regionally coordinated financial transmission right systems.
- Special algorithms that would exploit operator insight and experience.

The FERC CRT proposal was a critical innovation in moving to point-to-point rights in place of the contract path approach. This would connect with the settlements process among regions.

- **Point-to-Point Transmission Capacity Rights.** Abandoned contract path and link-based approaches for tradeable point-to-point rights. Handles all constraints

- **Physical vs. Financial Rights.** Industry response emphasized the difficulty of trading rights and matching with physical transmission use. Alternative interpretation emphasized financial contracts.



- **Coordinated Trading of Rights.** Transmission right trading requires coordination to respect network interactions. A role for the ISOs and Security Coordinators.

- **Northeast Implementation.** The CRT is alive and working in the PJM and New York implementations with financial transmission rights to receive congestion payments. Also found in FERC approved proposal for New England.

Supporting papers and additional detail can be obtained from the author. William W. Hogan is the Lucius N. Littauer Professor of Public Policy and Administration, John F. Kennedy School of Government, Harvard University and a Director of the Law and Economics Consulting Group in Navigant Consulting, Inc. This paper draws on work for the Harvard Electricity Policy Group and the Harvard-Japan Project on Energy and the Environment. The author is or has been a consultant on electric market reform and transmission issues for American National Power, British National Grid Company, Calpine Corporation, Commonwealth Edison Company, GPU Inc. (and the Supporting Companies of PJM), GPU PowerNet Pty Ltd, Duquesne Light Company, Electricity Corporation of New Zealand, Independent System Operator New England, National Independent Energy Producers, New England Power Company, New York Power Pool, New York Utilities Collaborative, Niagara Mohawk Corporation, PJM Office of Interconnection, San Diego Gas & Electric Corporation, Sempra Energy, TransÉnergie, Transpower of New Zealand, Westbrook Power, Williams Energy Group, and Wisconsin Electric Power Company. The views presented here are not necessarily attributable to any of those mentioned, and any remaining errors are solely the responsibility of the author. (For related papers, see http://ksgwww.harvard.edu/people/whogan).