Day-ahead Market Clearing Software Performance Improvement

FERC Technical Conference on Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

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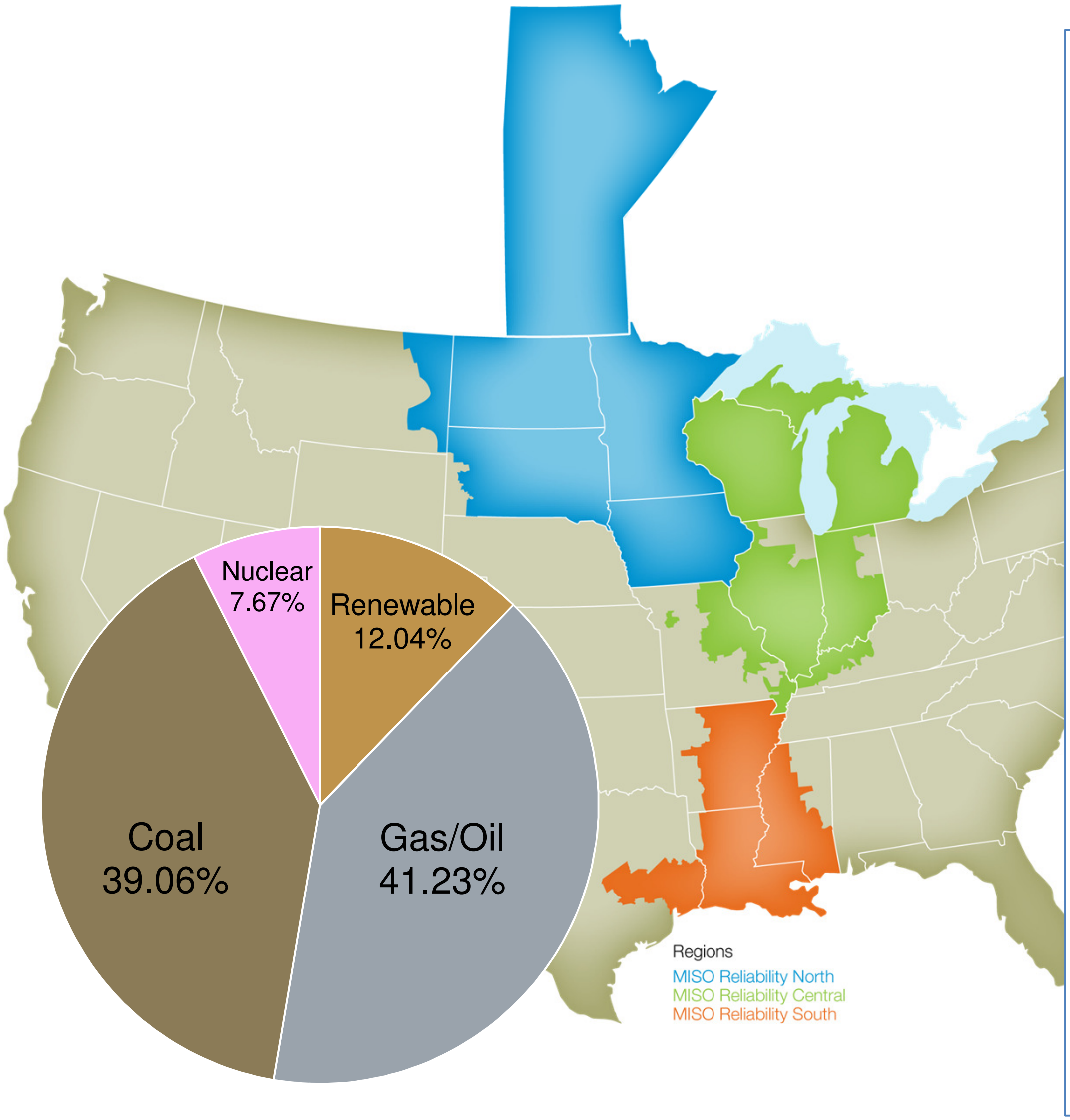
MISO Region



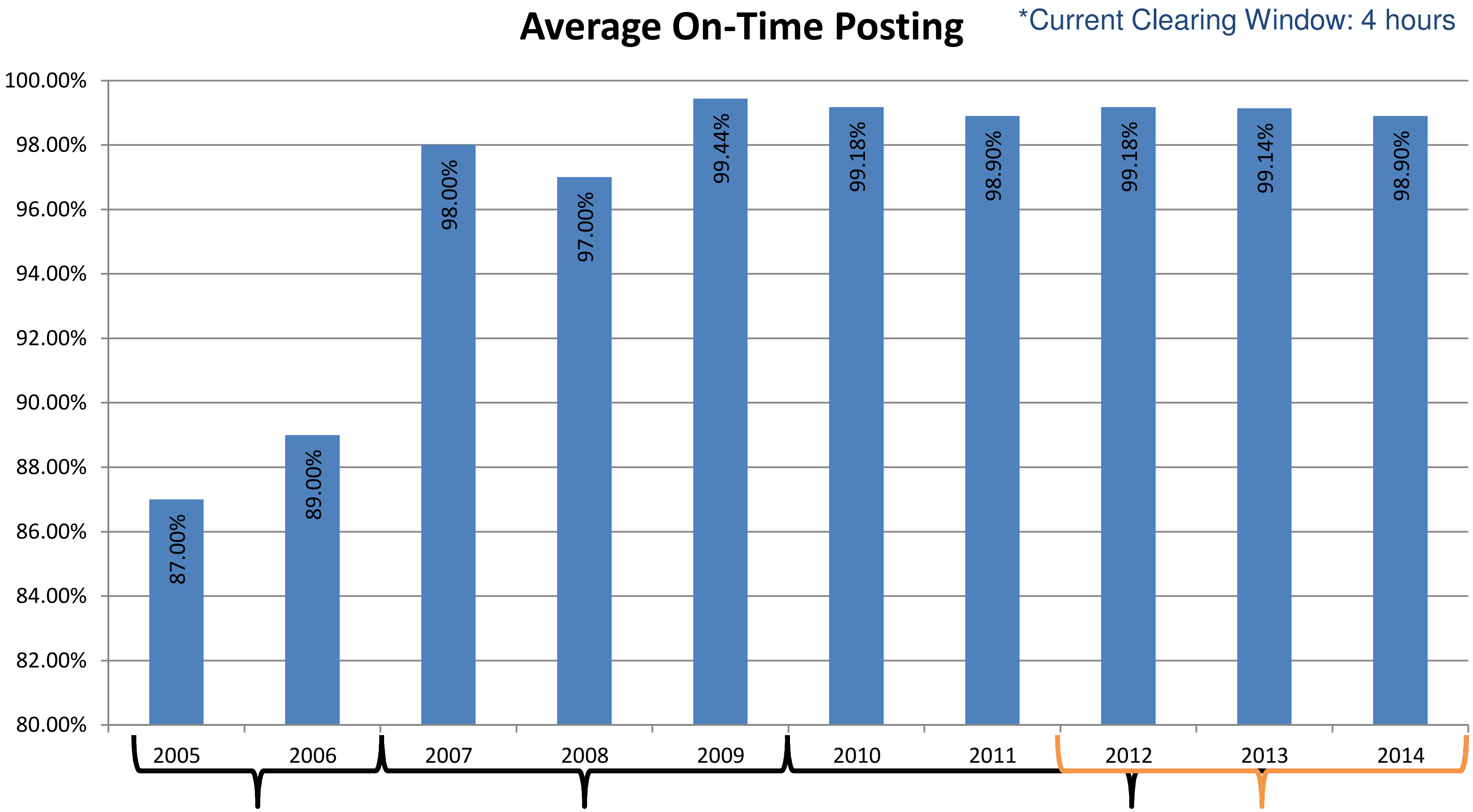
Key Statistics

Market Participants	408
MWs of Generating Capacity (Mkt)	179,514
Peak Load (MW)	133,181
Generating Units	1,401
Network Buses	45,098
Miles of Transmission Lines	65,800
Square Miles of Territory	900,000
States Served	15 Plus Manitoba Province, Canada
Millions of People Served	42

Unique Challenges of MISO Market System

Large network and market model with diverse resources and equipment types	• 45,098 network buses • 1,401 generating units with 179,514 MW capacity (market) • Large number of transmission constraints: ~200/h in DA case • Phase shifters, HVDC, combined cycles, storages, ……
Large number of pricing nodes and market activities	• 2446 pricing nodes • Virtual transaction volumes tripled in the past few years
Managing higher level of uncertainties	• Wind capacity: 2005 - 500MW 2015 - 13,726MW • Loop flows and transactions
Tight market clearing window	• Suggestion to reduce day-ahead clearing window from 4 hours to 3 hours for better gas-electricity coordination

Day-Ahead Market performance is a continual focus



Average On-Time Posting

*Current Clearing Window: 4 hours

6 hour clearing window

5 hour clearing window

4 hour clearing window

11 late postings 2012-14; Late by 00:30:44 on average

Improvements to maintain on-time performance within current clearing window are constantly being sought

2013

Hardware, architecture, software

Jan 2014*

Observed small percentage of cases with challenges

- Cold weather with more transmission constraints
- Large numbers of financial activities with newly integrated system

Jan-June 2014

Worked with SCUC and MIP solver vendors to investigate issues and potential solutions

- Some promising directions/no silver bullet solution

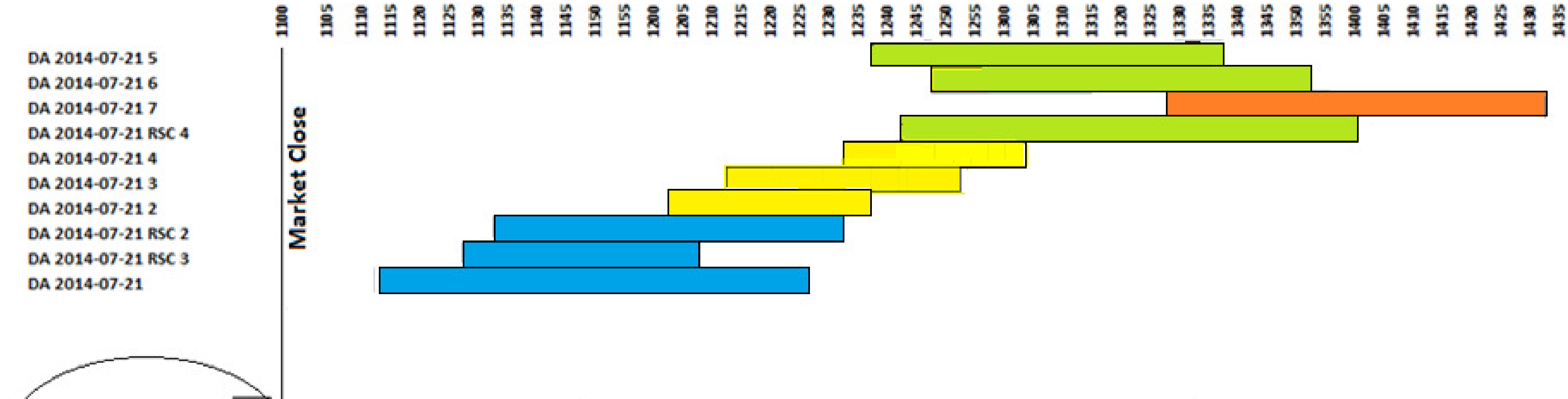
June 2014

MISO creates internal strategy team to

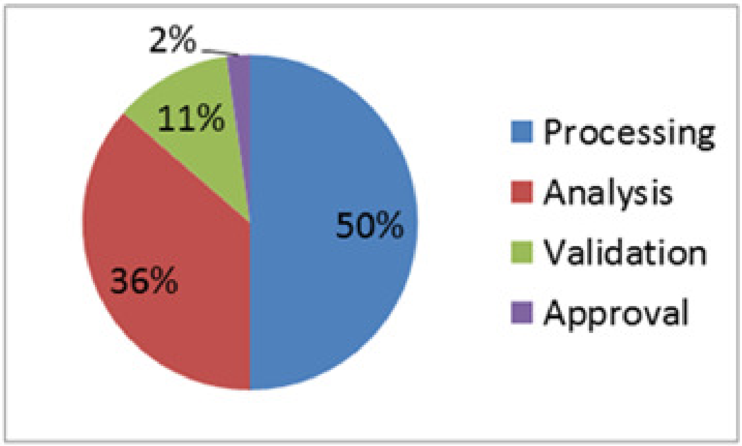
- Improve current engine stability, quality and reliability
- Improve process flexibility and efficiency
- Consider impact of market enhancements, regulatory changes, and other external factors on these efforts

*Post South Region Integration

Typical Day-Ahead Clearing Run – 3Hrs 40Min

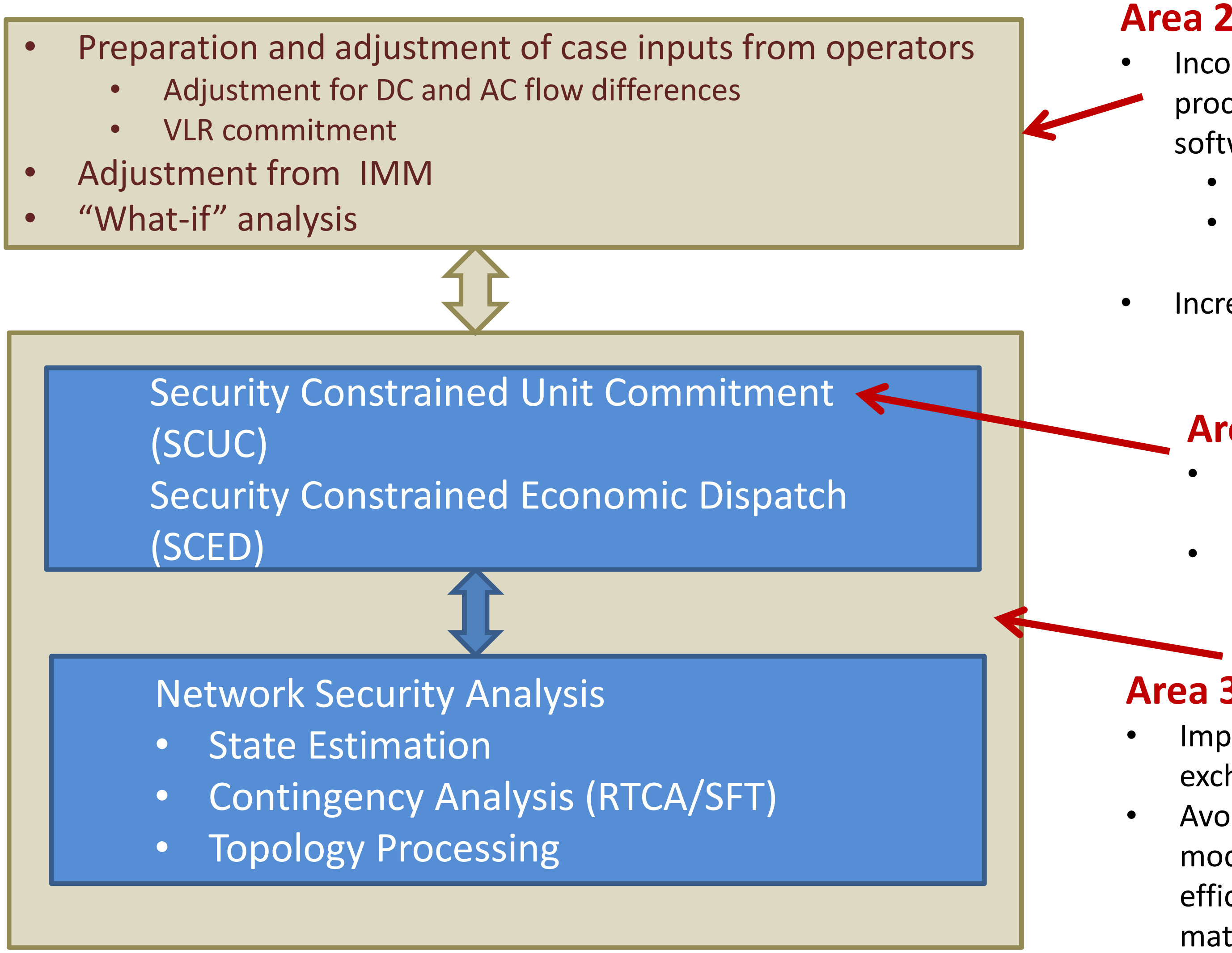


Cases ran from 0700-1100 with the best available data for preparation



	%	Time
Processing	50%	110
Analysis	36%	80
Validation	11%	25
Approval	2%	5

Day ahead (DA) Market Clearing Process



- Preparation and adjustment of case inputs from operators
    - Adjustment for DC and AC flow differences
    - VLR commitment
- Adjustment from IMM
- “What-if” analysis

Security Constrained Unit Commitment (SCUC)
Security Constrained Economic Dispatch (SCED)

Network Security Analysis
- State Estimation
- Contingency Analysis (RTCA/SFT)
- Topology Processing

Area 2

- Incorporate pre- and post-processes into clearing software
    - Commit reason
    - Polishing for non-zero MIP gap
- Incremental solve capability

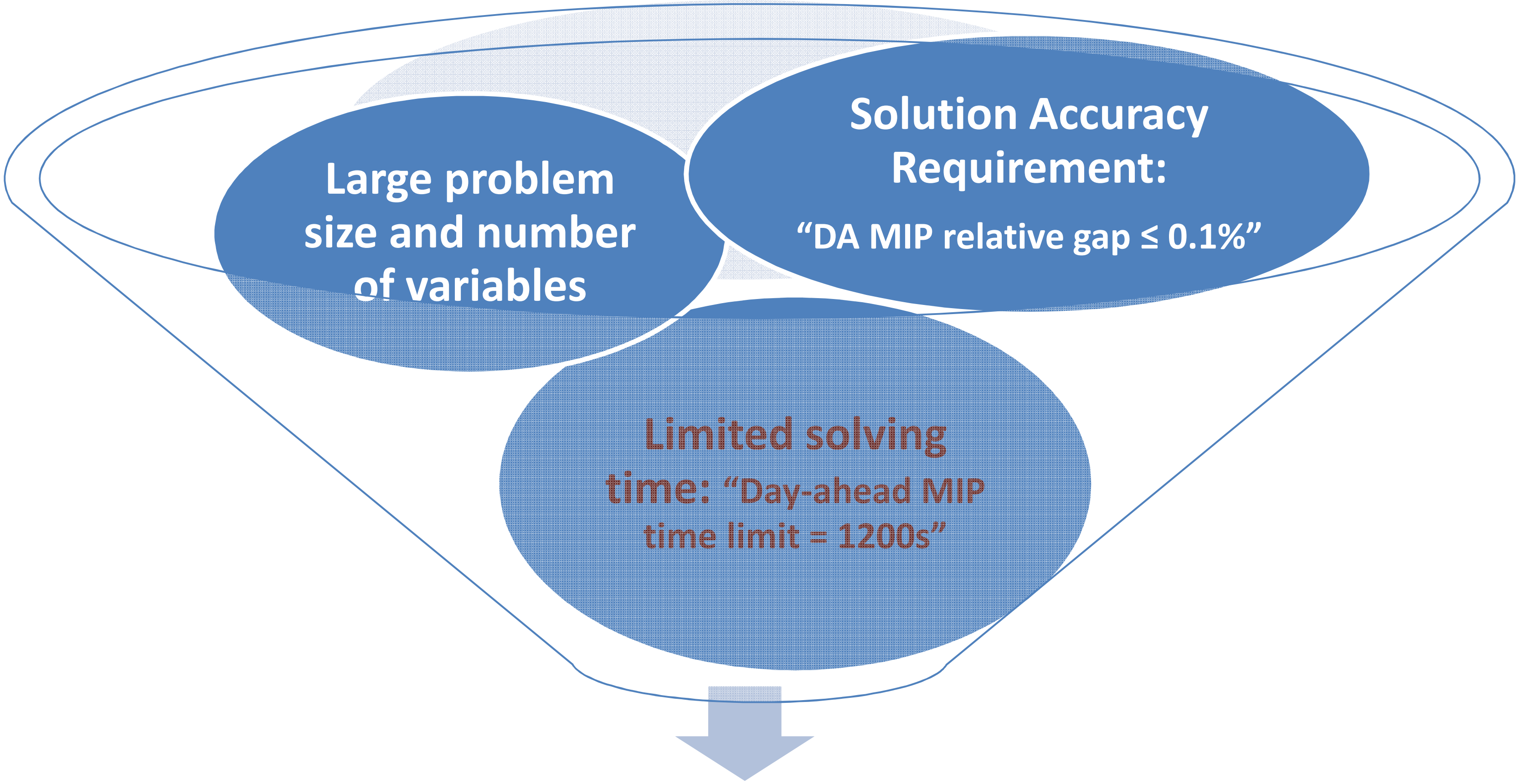
Area 1

- MIP performance under dense matrix
- Incorporate user knowledge

Area 3

- Improve efficiency on data exchange
- Avoid putting large network model in CPLEX (not very efficient in processing spare matrix)

Challenge for MIP Solvers



Large problem size and number of variables

Solution Accuracy Requirement:

“DA MIP relative gap ≤ 0.1%”

Limited solving time: “Day-ahead MIP time limit = 1200s”

Small percentage of DA cases solved with large MIP gaps

Primarily driven by large number of **transmission constraints** and **virtuals**

Experience from MISO DA SCUC

Number of binaries:

Not the single contributor of performance challenges

- Without transmission constraints, MISO DA cases can solve in ~100s

Very dense matrices from **transmission constraints** and **continuous virtual variables** can drive performance challenge

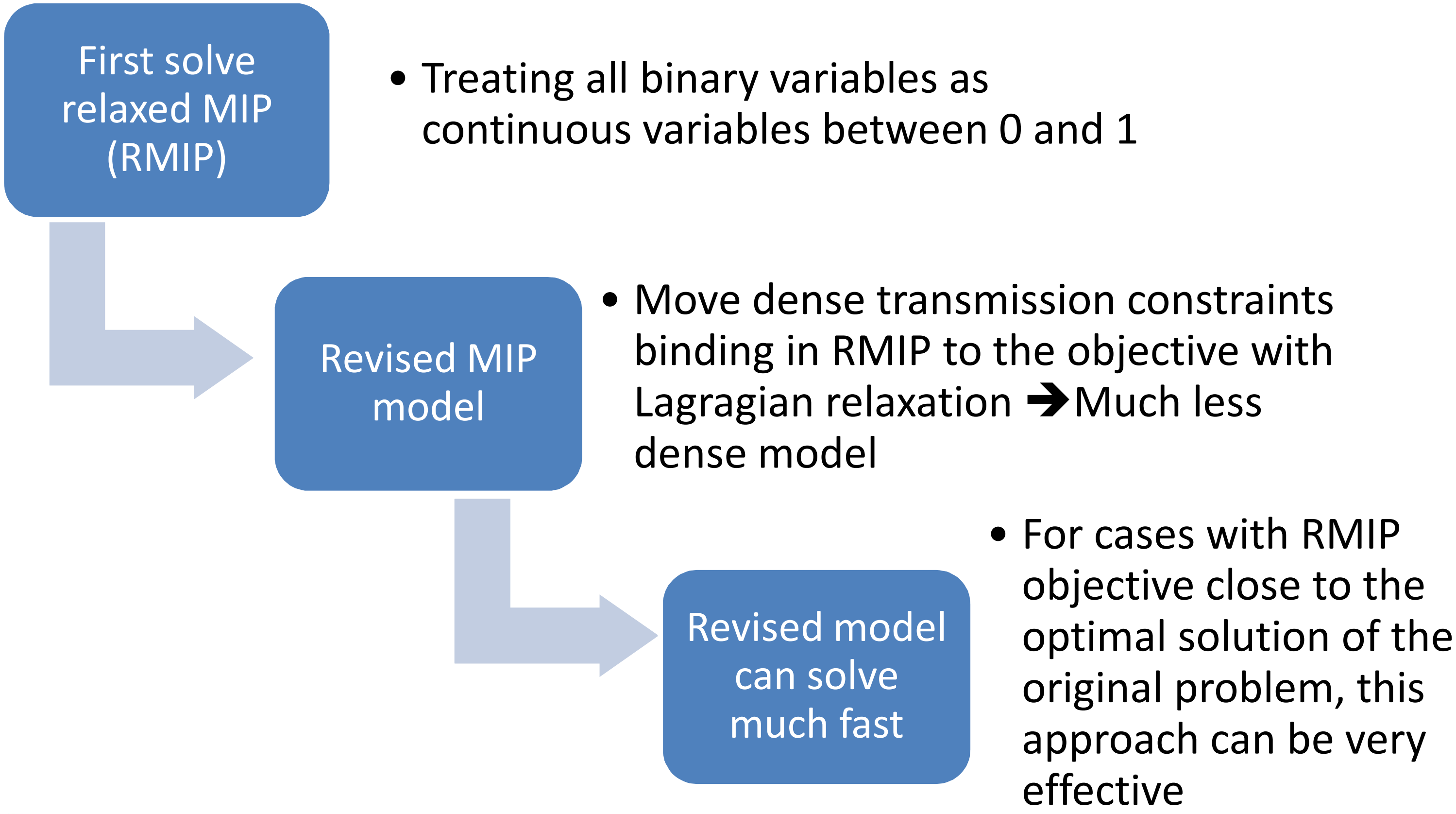
- Bad performance cases happened under a large number of virtuals and transmission constraints

MIP may not solve faster even if it is fed with a better initial solution

- Does not work well when multiple iterations are required
- Need to develop algorithm to solve SCUC incrementally in order to improve DA clearing process

Exploring New Heuristics

- Solve revised MIP models to find upper bounds faster
  - “IBM_LR”: Lagragian Relaxation on dense transmission constraints (suggested by IBM research)



First solve relaxed MIP (RMIP)

- Treating all binary variables as continuous variables between 0 and 1

Revised MIP model

- Move dense transmission constraints binding in RMIP to the objective with Lagragian relaxation ➔Much less dense model

Revised model can solve much fast

- For cases with RMIP objective close to the optimal solution of the original problem, this approach can be very effective

Exploring New Heuristics (Cont.)

– “Binary_Reduction”:

Start from initial commitment solution

- Freeze binary variables in the SCUC problem and solve LP to get ***prices $\boldsymbol{\lambda_i}$ and primal profits $\mathbf{p_i^p}$*** for each resource

Solve profit maximization

under given prices $\boldsymbol{\lambda_i}$

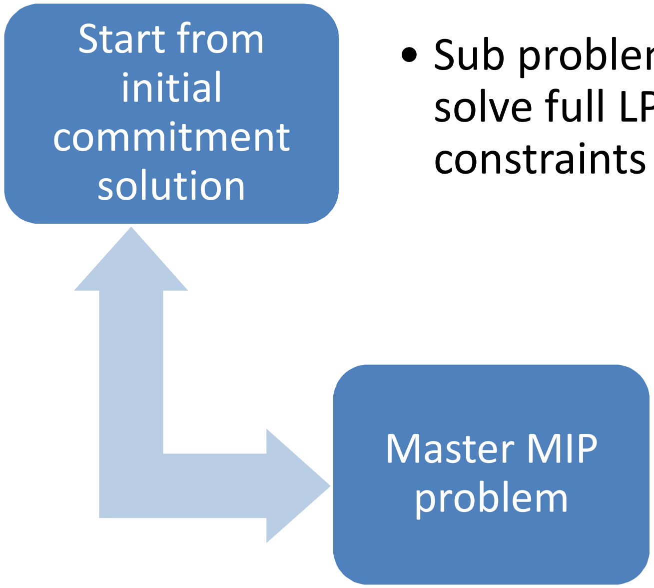
- $$\begin{cases} Max_{x,y}\,\{\lambda^T y - (c^T x + b^T y)\} \\ s.t.\ \ A_r x + B_r y \le g_r \quad \text{(Resource level constraints)} \\ x\colon binary\ variables; \quad y\colon continuous\ variables \end{cases}$$
- ➔$\boldsymbol{Maximum\ profit\ p_i^d\ under\ price\ \lambda_i}$

Solve SCUC with reduced number of binaries

- Freezing binary variables for resources with $p_i^p = p_i^d$ (“in the money”)
- Solving reduced MIP with binary variables for “out-of-money” resources (with p_i^p<p_i^d); *about 100~200 resources*

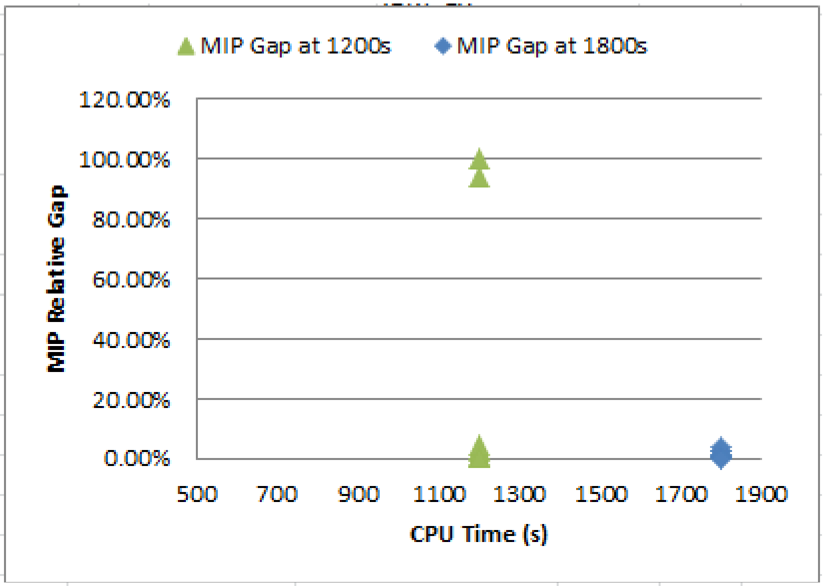
Exploring New Heuristics (Cont.)

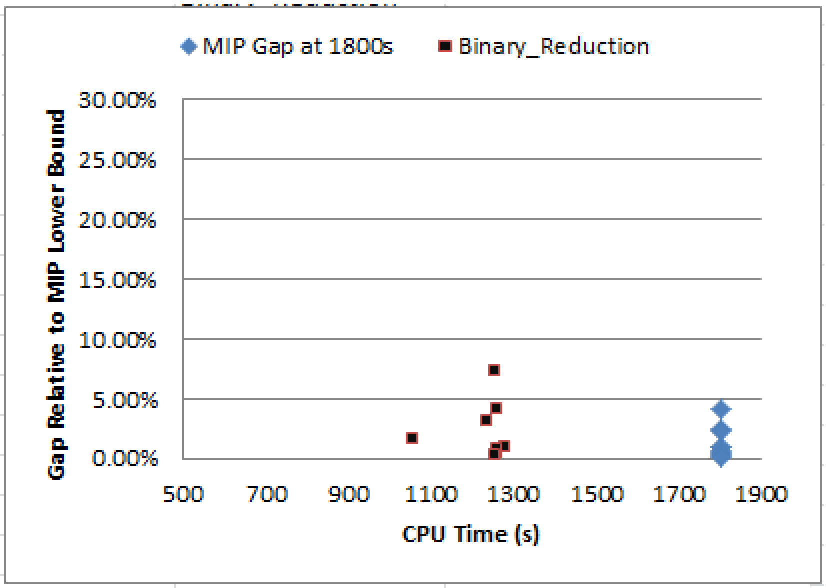
- "Decomposition"

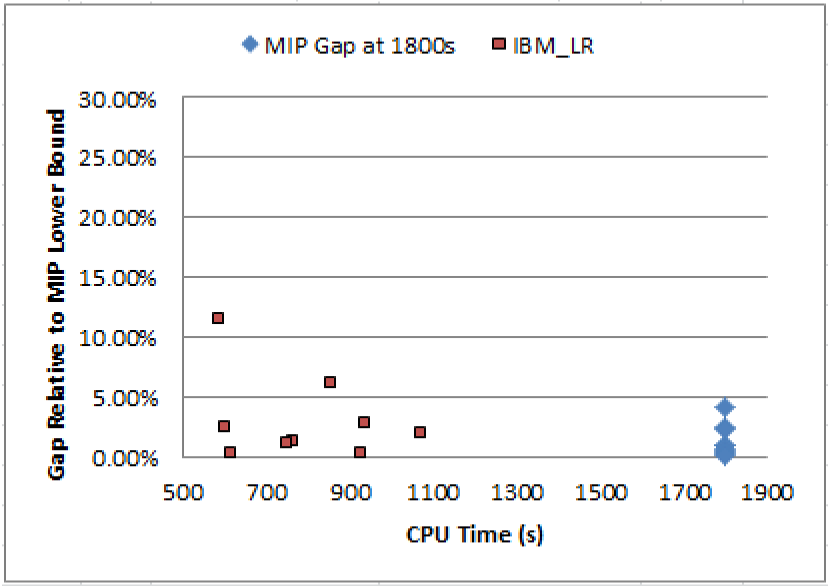


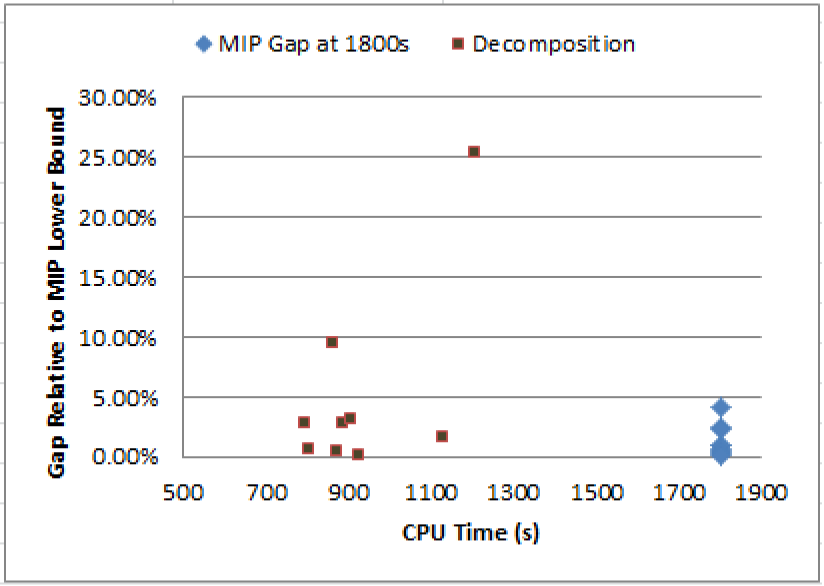
- Sub problem: freeze all binaries and solve full LP with all transmission constraints
- Solve MIP with only binding or near binding transmission constraints

Results from Test Set I (difficult cases)





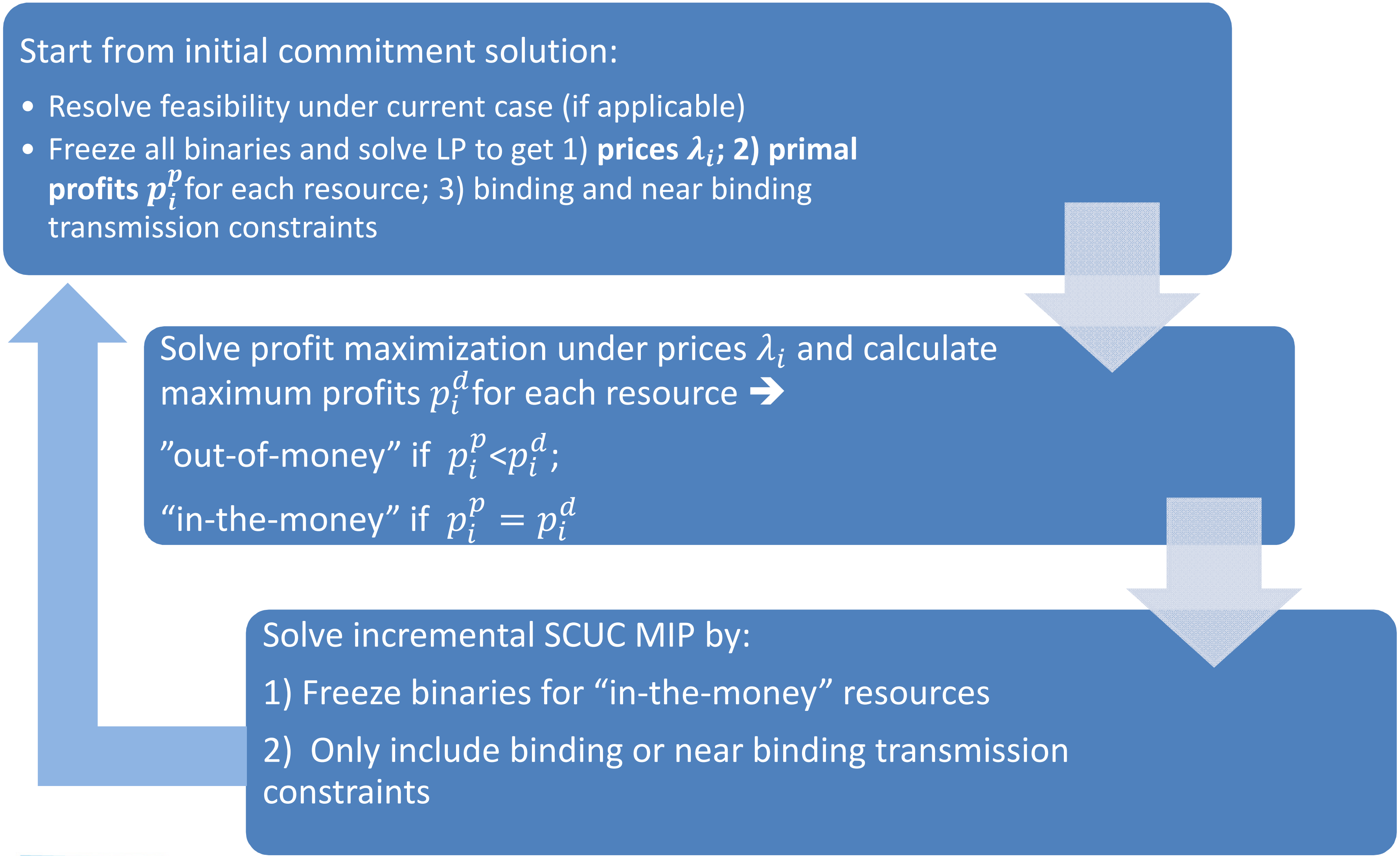




Applying the New Heuristics

- Two ways to use the new heuristic methods
  - As backup solving methods:
    - Does not expect to be triggered often since MIP solver can generally solve better
  - To improve incremental solve and post analysis capability
    - Expect to improve the efficiency of the DA clearing process
      - Allow more incremental SCUC iterations to reduce manual adjustment
      - Incorporate pre- and post-processes into clearing software
        - Commit reason identification
        - Polishing for non-zero MIP gap

Incremental solve (“binary_reduction” + ”decomposition”)



Start from initial commitment solution:

- Resolve feasibility under current case (if applicable)
- Freeze all binaries and solve LP to get 1) **prices $\boldsymbol{\lambda_i}$; 2) primal profits $\boldsymbol{p_i^p}$** for each resource; 3) binding and near binding transmission constraints

Solve profit maximization under prices λ_i and calculate maximum profits p_i^d for each resource ➔

”out-of-money” if $p_i^p < p_i^d$;

“in-the-money” if $p_i^p = p_i^d$

Solve incremental SCUC MIP by:

1) Freeze binaries for “in-the-money” resources

2) Only include binding or near binding transmission constraints

Commit Reason Identification and Further Solution Polishing

- Operators spend a long time analyzing “out-of-money” resources
  - An indication of solution quality
  - Potential dispute from market participants

- SCUC MIP solution usually results in a set of resources “out-of-money” for two reasons:
  - Non-convexity
    - e.g. only requires partial commitment in an hour to relieve congestion, but has to be committed and dispatched at EcoMin for several hours due to binary constraints.
    - Usually marginal resources for some system-wide or zonal constraints
    - **Commitment reason identification to identify this set of resources**
  - Non-zero MIP gap
    - e.g. not committing a small wind with zero offers since its impact on the objective is much less than MIP gap tolerance
    - **Further polishing to improve commitment for this set of resources**

Commit Reason Identification

- Identify "out-of-money" resources from a commitment solution
- Freeze binaries for "in-the-money" resources and solve relaxed MIP (RMIP) with simplex method
  - Binary variables for "out-of-money" resources are treated as continuous variable between 0 and 1 (i.e. an LP problem) and may be fractional from RMIP solution
- Calculate sub-gradient for RMIP solution on the **basis matrix** with respect to an incremental change on system-wide or zonal constraints
  - Power balance
  - Reserve requirements (system-wide or zonal)
  - Transmission constraints
- A resource is considered marginal for a system-wide or zonal constraint if its dispatch result changes with an incremental change on that constraint from the sub-gradient solution

Further Solution Polishing

- Further polishing for “out-of-money” resources that are not identified as marginal
  - Approach 1: Solve MIP with much smaller set of binaries and tighter MIP gap tolerance
    - May still require longer than affordable time
  - Approach 2: Solve LP to check whether profit maximization commitment is better
    - Heuristic single path search
    - Sufficiently good to adjust commitment for small resources

Test Results on Normal Cases

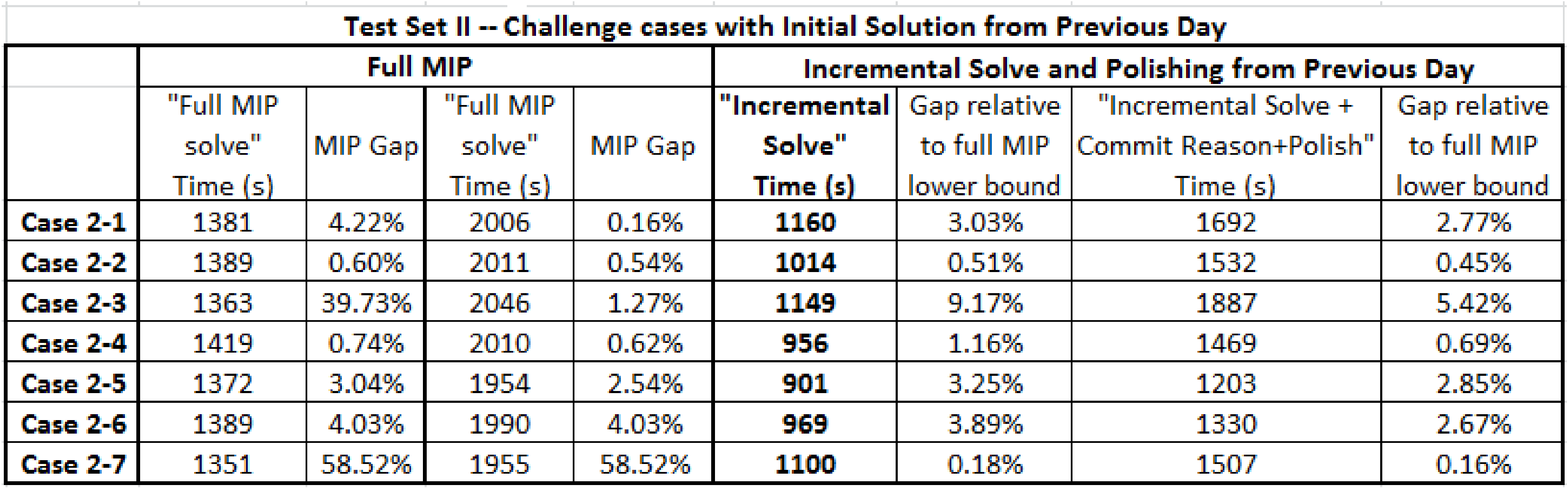
- Incremental solve can reach solution much faster with good quality
- Total time for “incremental solve + commit reason + polish” is similar to or less than full MIP solving time
- Can be used to improve the analysis and validation process and potentially allow more iterations

Test Set III -- Normal cases with good Initial solution

	Full MIP		**Incremental Solve and Polish from Initial solution from case solved the same day before market close**			
	"Full MIP solve" Time (s)	MIP Gap	**"Incremental Solve" Time (s)**	Gap relative to full MIP lower bound	"Incremental Solve + Commit Reason+Polish" Time (s)	Gap relative to full MIP lower bound
Case 3-1	1391	0.30%	**1087**	0.44%	1467	0.38%
Case 3-2	698	0.01%	**349**	0.03%	606	0.02%
Case 3-3	563	0.03%	**356**	0.05%	570	0.05%
Case 3-4	975	0.10%	**425**	0.05%	640	0.04%
Case 3-5	982	0.08%	**428**	0.10%	697	0.08%
Case 3-6	711	0.03%	**447**	0.08%	633	0.07%
Case 3-7	756	0.07%	**376**	0.21%	703	0.09%

Test Results on Challenge Cases

- Incremental solve is more stable at 1200s compared to full MIP
- Solution time and accuracy from “incremental solve + commit reason + polish” is similar to full MIP with 1800s time limit



Test Set II -- Challenge cases with Initial Solution from Previous Day

	Full MIP				**Incremental Solve and Polishing from Previous Day**			
	"Full MIP solve" Time (s)	MIP Gap	"Full MIP solve" Time (s)	MIP Gap	**"Incremental Solve" Time (s)**	Gap relative to full MIP lower bound	"Incremental Solve + Commit Reason+Polish" Time (s)	Gap relative to full MIP lower bound
Case 2-1	1381	4.22%	2006	0.16%	**1160**	3.03%	1692	2.77%
Case 2-2	1389	0.60%	2011	0.54%	**1014**	0.51%	1532	0.45%
Case 2-3	1363	39.73%	2046	1.27%	**1149**	9.17%	1887	5.42%
Case 2-4	1419	0.74%	2010	0.62%	**956**	1.16%	1469	0.69%
Case 2-5	1372	3.04%	1954	2.54%	**901**	3.25%	1203	2.85%
Case 2-6	1389	4.03%	1990	4.03%	**969**	3.89%	1330	2.67%
Case 2-7	1351	58.52%	1955	58.52%	**1100**	0.18%	1507	0.16%

Voltage and Local Reliability (VLR) Commitment

- Significant amount of work on manual commitment for load pockets with **complicated operational rules**
  - Capacity requirement for N-1-G-1 and voltage
    - Current operational approach: Look-up commitment requirement table based on different forecasted zonal load level (…>L6>L5>…>L1)
  - Introduced binary constraints for each interval based on forecast zonal load
    - e.g. if zonal forecast load is between L5 and L6: one of the commitment highlighted in yellow needs to be satisfied

$W5+W6>=1 \text{ and } W5+W6+U4+U5>=2 \text{ and}$

$\{ (U3+(U1+U2)/2=2 \text{ and } W5+W6=1 \text{ and } U4+U5=1) \text{ or}$

$(U3+(U1+U2)/2>=1 \text{ and } W5+W6=1 \text{ and } U4+U5=2) \text{ or}$

$(U3+U1+U2>=3 \text{ and } W5+W6=2 \text{ and } U4+U5=0) \text{ or}$

$(U3+U1+U2>=1 \text{ and } W5+W6=2 \text{ and } U4+U5=1\} \text{ or}$

$(U3+U1+U2>=-1 \text{ and } W5+W6=2 \text{ and } U4+U5=2\}$

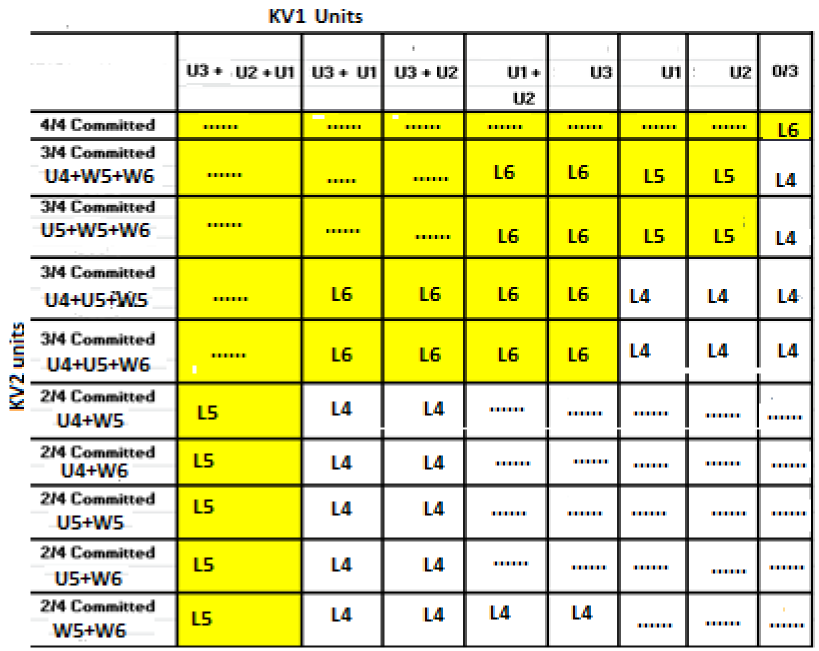
Convert to binary constraints to be enforced in SCUC:

$W5+W6>=1$ and

$W5+W6+U4+U5>=2$ and

$W5+W6+U4+U5+U3+(U1+U2)/2>=4(2-W5-W6)$ and

$U1+U2+U3+2(U4+U5)>=3(W5+W6-1)$



KV1 Units

KV2 units

	U3 + U2 + U1	U3 + U1	U3 + U2	U1 + U2	U3	U1	U2	0/3
4/4 Committed	......	......	......	......	......	......	......	L6
3/4 Committed U4+W5+W6	......	......	......	L6	L6	L5	L5	L4
3/4 Committed U5+W5+W6	......	......	......	L6	L6	L5	L5	L4
3/4 Committed U4+U5+W5	......	L6	L6	L6	L6	L4	L4	L4
3/4 Committed U4+U5+W6	......	L6	L6	L6	L6	L4	L4	L4
2/4 Committed U4+W5	L5	L4	L4	......	......	......	......	......
2/4 Committed U4+W6	L5	L4	L4	......	......	......	......	......
2/4 Committed U5+W5	L5	L4	L4	......	......	......	......	......
2/4 Committed U5+W6	L5	L4	L4	......	......	......	......	......
2/4 Committed W5+W6	L5	L4	L4	L4	L4	......	......	......

VLR commitment – Open Issues

- Alternative solutions to incorporate into SCUC/SCED
  - Short term
    - Interface proxy
    - new reserve product and constraints
    - Zonal reserve requirement or post-zonal reserve deployment constraints
  - Long term
    - AC OPF (???)

- Pricing of VLR commitment
  - Long lead units usually dispatched at EcoMin
  - Currently compensated by high make-whole-payment

- Commit reason

Future work

- Work with optimization solver side
  - Provide information for MIP solver to incorporate in the searching
    - Initial binary solution to start with
    - Hint of constraints to focus on (e.g. lazy constraint)
    - Hint of binary variables to focus on
  - The goal is to combine custom heuristics with MIP solver
- Improve software efficiency with better architecture and parallelization
- Long term R&D collaboration
  - Distributed SCUC
  - High performance computing
  - Combine Lagrangian Relaxation with branch-and-cut

Importance of Improving the Software Performance

- The percentage of bad performance DA cases is very small and can mostly be addressed with longer solving time
- Future market development and industry evolution may require a more complicated SCUC model and tighter solving time
  - Gas electricity coordination
    - Request from participants to reduce DA clearing time to 3 hours
  - Multi-day DA commitment to better commit base load long lead units
  - Configuration based combined cycle modeling
  - More distributed variables (virtuals, DER/DR, etc)
  - Flow control devices