Single Electricity Market

CONSULTATION ON THE RESULTS OF THE LR VS. MIP STUDY

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For attention of: All Parties and any interested parties

Responses to: mip_lr@sem-o.com

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Document References

Document	Date	Download Link
MIP v LR - Scope - DRAFT 7.pdf	15/06/2010	http://www.SEMO.com/Publications/General/MIP%20v%20LR%20-%20Scope%20-%20DRAFT%207.pdf
MIP_policy_V4 0 - Use of MIP for Determination of Market Schedules.pdf	15/06/2010	http://www.SEMO.com/Publications/General/MIP_policy_V4%200%20-%20Use%20of%20MIP%20for%20Determination%20of%20Market%20Schedules.pdf
Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming.pdf	09/11/2010	http://www.SEMO.com/Publications/General/Solver%20Choice%20in%20the%20SEM%20-%20A%20Comparative%20Study%20of%20Lagrangian%20Relaxation%20vs.%20Mixed%20Integer%20Programming.pdf
Market Incident Report - Increased Use of MIP as the Market Solver Sept 2010.pdf	16/12/2010	http://www.SEMO.com/Publications/General/Market%20Incident%20Report%20-%20Increased%20Use%20of%20MIP%20as%20the%20Market%20Solver%20Sept%202010.pdf
Solver Choice in the SEM - LR vs. MIP Ver 2.0.pdf	01/03/2011	http://www.SEMO.com/Publications/General/SEMO%20Solver%20Choice%20in%20the%20SEM%20-%20LR%20vs.%20MIP%20Ver%202.0.pdf

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1 PURPOSE OF THE CONSULTATION

This document has been compiled to seek feedback from Participants and other interested parties on the question of solver choice in the SEM. This issue has been discussed at a number of Market Operator User Group (MOUG) meetings and two Market Operator Special Topic (MOST) meetings. It has been the subject of a significant study completed by SEMO which formed the basis of a major paper published last year. SEMO has also produced a follow up paper on some of the issues identified.

The supporting documents which can inform input into this consultation are available on the SEMO Website. Links can be found in the Document References section. Any queries or comments on the documents should be forwarded to SEMO at mip_lr@sem-o.com.

After the end of the comment phase of the consultation, SEMO will review responses received and compile a report for the Regulatory Authorities. This will summarise the responses and will make a recommendation to the SEM Committee with regards to what changes, if any, are proposed. Subject to Regulatory Authority approval, SEMO will publish an information paper and implement the approved actions.

2 BACKGROUND

The SEM is the wholesale electricity market covering the island of Ireland and has been operational since November 1st 2007. The market was designed as a centrally dispatched Gross Mandatory Pool model with a single System Marginal Price. This design requires the use of Unit Commitment software which must optimise the available generation portfolio to achieve the best economic dispatch of generators. This is done on economic merit order, working with the objective of minimising generator production costs in the market.

To solve unit commitment problems in power systems and markets, sophisticated mathematical optimisation software is used to determine the least cost production schedule. This software is largely seen as “black box” technology where commercial and technical data of participating generators is input and market schedules and prices are output. There are many optimisation techniques available; however, because of the non-convex nature of the unit commitment problem, more sophisticated methods are required.

Optimisation science was developed as part of the field of Operations Research during the 1940s and 1950s using Linear Programming to solve convex problems but this could not be easily applied to unit commitment problems due to the integer nature of the problem. The Lagrangian Relaxation (LR) method, which is now commonly applied to unit commitment problems, was first successfully developed in 1970. This has become the most commonly used technique for unit commitment in electricity markets around the world. Mixed Integer Programming (MIP) was also developed around this time but, due to computational requirements of this approach, its application was largely limited to academic circles. It has only been in the last ten years that improvements in computer processing power and memory and developments to the algorithms have meant that MIP has become viable for use in commercial markets.

During the development of the Central Market Systems for use in the SEM, the MSP software was designed with the option of using either an LR or MIP solver. At that time, because LR was still considered the most reliable commercial standard solver this was selected for use in the SEM; however, the MIP solver was also included and retained for use as a back up.

On a number of occasions during the first months of the SEM, due to issues with the outputs of the LR solver, SEMO made use of the back up solver for determining the Market Schedules and System Marginal Prices. SEMO hosted a MOST (Market Operator Single Topic meeting) in August 2008 to explain to Participants the high-level workings of the solvers and the process adopted by SEMO around the use of MIP in the SEM.

SEMO undertook to complete a comparative study of the two solvers. The paper “Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming” represents the results of that study. The intent of the study is to provide comparative analysis to Participants in the SEM and the Regulatory Authorities. It is hoped that this would provide assurance to Participants with regard to the issue of solver choice in the SEM and may inform future decisions and developments in this area.

2.1 FINDINGS OF THE PAPER

A total of 154 Ex-Post Initial study cases and 16 Ex-Ante Indicative study cases were completed for this study. In each case, the original base case from SEM operations was used as a starting point but to ensure consistency of comparison, the latest version of the software was used. This means that the study cases completed with the LR program used later versions than that used in SEM operations. As a result, the LR solutions used in this study may differ from historical data published in the SEM.

Timeout settings were used on the MIP program where its execution would be terminated after five minutes, ten minutes and thirty minutes as appropriate.

Schedule analysis was to be completed under the following broad headings -

- MSP Production Costs,
- System Marginal Price,
- Revenue (based on non-loss adjusted Energy Payments to generators as a proxy for Consumer Costs),
- Scheduling of Energy Limited Generators (Hydro stations),
- Unit commitment relative to fuel and station technology type, and
- Constraint Payments.

During the course of the study, we extended the scope to cover

- Timeout settings of the MIP solver, and
- Internal software parameters.

A key observation, which is apparent, not just from the studies we completed but also from academic literature that we reviewed, is that while the LR algorithm is known to converge to sub-optimal solutions, using MIP may not provide a global optimal solution to the SEM either. This is because the use of timeout settings and a convergence tolerance mean that the MIP solver may terminate prematurely before reaching optimality. As a result, we must be clear that we are always comparing sub-optimal solutions.

We noted that in over 83% of study cases, the MSP Production Costs were observed to be lower in the MIP solutions than in those from the LR. A key observation when reviewing the changes in the unit commitment outputs was the increased use of Energy Limited or Hydro stations. Using the MIP solver, we observed that full Energy Limits were more frequently used with significantly higher quantities of their Energy Limit being scheduled whereas this was not the case with respect to the LR results. Other fuel and station technology types did not appear to be significantly impacted by the solver choice in terms of unit commitment decisions while their final schedule quantities were affected.

When we reviewed System Marginal Prices and Consumer Costs, we noted that the MIP solver produced higher results in over 57% of cases. This was despite an observed reduction in peak prices. Constraint Costs were also observed to increase in our study cases; however, as the Dispatch Production Cost is a static value across all studies, when one solver reduces the MSP Production Cost this will increase the Constraint Costs.

Detailed observations can roughly be summed up as follows -

- Using MIP rather than LR will more frequently lead to reduced MSP Production Costs;
- Using MIP rather than LR has demonstrated increased use of Energy Limited Generators;
- Using MIP with the five minute timeout setting provides best value of solution in terms of optimality, production costs and solution time;
- MIP schedules more frequently produced higher System Marginal Prices;
- MIP schedules more frequently produced higher Consumer Costs;
- MIP schedules more frequently produced higher Constraint Costs (as a consequence of the reduced MSP Production Costs);

Considering that the objective of the MSP software is to minimise the aggregate MSP Production Costs across the Optimisation Time Horizon, this would mean that the MIP solver appears to better implement the requirements of the Trading & Settlement Code (T&SC); however, consideration should be given to our observations with regard to increasing total Consumer Costs.

We should also note the finding that the MSP Production Costs for most LR solutions are comparable to the sub-optimal solutions found using MIP with the current timeout and convergence tolerance settings.

3 QUESTIONS FOR CONSULTATION

Following on from the paper on the solvers published last year, and the workshop provided by SEMO on March 1st 2011, we are now proposing three questions for the industry and interested parties.

3.1 SHOULD SEMO ADOPT THE MIXED INTERGER PROGRAMMING ALGORITHM AS THE "SOLVER OF CHOICE" FOR THE SEM?

Based on the evidence presented in the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming" and as noted in the subsequent paper "Increased Use of MIP as the Market Solver", it would appear that the MIP program is better at delivering the objective to minimise MSP Production Costs as required by the T&SC and that the LR algorithm in some particular cases has difficulty solving the commitment decisions for the SEM, which can lead to, in our view, inefficient pricing outcomes.

We would ask respondents to comment on whether the presentations and papers provided by SEMO demonstrate that the MIP algorithm should be adopted as the "solver of choice" for the SEM.

We would ask respondents to consider issues here with relation to the following points -

- The observed impacts on MSP Production Costs as noted in the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming",
- The observed impacts on System Marginal Price as noted in the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming",
- The noted limitations of the LR algorithm in dealing with certain aspects of the SEM design as noted in the paper "Increased Use of MIP as the Market Solver".

If responding in support of adopting the MIP algorithm, we would also welcome comments from respondents in relation to the following -

- The policy with regard to future re-pricing of historical days (that is, should SEMO re-price with the newly adopted algorithm or, in keeping with normal international market practice, should the policy be that historical days are re-priced with the software that was in use for the original Ex-Post Initial MSP run?)
- Any requirements for parallel running of the market solvers during any changeover period.
- The timeout settings to be used in the operation of MIP, taking note of the findings in section 3 of the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming"..

3.2 SHOULD SEMO CONTINUE TO USE THE LAGRANGIAN RELAXATION ALGORITHM AS THE "SOLVER OF CHOICE" FOR THE SEM?

Based on the evidence presented in the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming", while the MIP program is better at achieving the objective of the Trading & Settlement Code to minimise MSP Production Costs, in a high number of cases it was observed that the variance in MSP Production Costs between the solutions of the two programs was within 1% of each other. This led to the conclusion that the LR solutions are very good relative to the solutions found using MIP with the current timeout and convergence tolerance settings.

We would ask respondents to comment on whether the evidence presented demonstrates that the LR algorithm should be retained and that the MIP algorithm should not be adopted as the normal default solver.

It is noted in detail within the paper "Solver Choice in the SEM - A Comparative Study of Lagrangian Relaxation vs. Mixed Integer Programming" that with the LR program there is frequent under-utilisation of the energy available from Energy Limited Generators. As the energy from these generators is bid at €0 price, further use of this energy in the schedules will further reduce the MSP Production Costs, leading to closer alignment to the current requirements of the Trading & Settlement Code. However, as also noted in the paper, an unforeseen consequence of Energy Limited Generators being run to their full limit is a constrained Shadow Price calculation which has led to some increases in System Marginal Price and Consumer Costs observed when using the MIP algorithm.

In responding to this question on retaining the LR algorithm, we would invite respondents to consider what action, if any, should be taken with regard to the commitment of Energy Limited Generators by the LR program? Respondents should note that this issue has been considered under modification 37_10 at the Modifications Committee.

We would also welcome comments with regard to what changes are required to the Trading & Settlement Code to permit SEMO to make use of an algorithm which may be seen as not best fulfilling the obligations to minimise MSP Production Costs set out therein?

3.3 SHOULD SEMO ADOPT A POLICY OF ONLY USING ONE ALGORITHM?

The policy adopted by SEMO with regard to extreme price events from the LR algorithm includes the potential to make use of the MIP program. This approach is not in keeping with standard international practice where only one algorithm is used for all publications.

We would ask respondents to comment on whether SEMO should adopt a policy more in line with international practice and only use one algorithm, regardless of the schedule outcomes with the exception of extreme circumstances, such as the chosen algorithm completely fails to produce a schedule. Note, that by this comment, we consider an infeasible solution still constitutes a schedule output and is not covered as an extreme circumstance.

Should both solvers fail to produce a schedule output, this would be classed as "MSP Failure" as defined under the T&SC and actions as set out therein will follow.

In respect of this issue, we would invite respondents to consider the following additional questions when formulating their response.

3.3.1 WHAT ACTION SHOULD SEMO TAKE IN FUTURE WITH RESPECT TO EXCEPTIONAL PRICE EVENTS IN THE SEM?

Should respondents agree that SEMO should only use one algorithm, what action, if any, should be taken with respect to exceptional price outcomes in the SEM?

We would ask respondents to consider issues of publication timing requirements as set out in the T&SC, potential resource requirements to meet suggested actions, and also what value constitutes an exceptional price event in the SEM.

3.3.2 WHAT ACTION SHOULD SEMO TAKE IN THE FUTURE WITH RESPECT TO INFEASIBLE SCHEDULES IN THE SEM?

Should respondents agree that SEMO should only use one algorithm, what action, if any, should be taken should the solver produce an infeasible solution?

We would ask respondents to consider issues of publication timing requirements as set out in the T&SC, and potential resource requirements to meet suggested actions. Respondents should also consider the circumstances in which an infeasible solution is still a correct solution to deliver, such as with extreme load shedding events resulting in under-generation events

4 APPENDICES

4.1 MSP PRODUCTION COSTS FOR ALL MIP RUNS

Trade Date	*LR*	*MIP300*	*MIP600*	*MIP1800*
20-Dec-07	€ 6,461,011.26	€ 6,438,095.28	€ 6,434,366.19	€ 6,418,976.63
03-Jan-08	€ 7,550,550.00	€ 7,503,547.77	€ 7,501,996.47	€ 7,501,913.50
20-Jan-08	€ 6,757,324.61	€ 6,710,958.25	€ 6,709,066.77	€ 6,708,838.21
04-Feb-08	€ 7,732,607.10	€ 7,685,203.52	€ 7,676,619.81	€ 7,677,048.66
07-Feb-08	€ 6,414,549.08	€ 6,398,923.26	€ 6,396,531.00	€ 6,396,566.91
04-Mar-08	€ 8,017,073.52	€ 7,996,445.33	€ 8,003,365.84	€ 7,991,968.30
10-Mar-08	€ 7,225,844.06	€ 7,172,428.09	€ 7,172,423.96	€ 7,172,412.82
18-Mar-08	€ 7,723,503.18	€ 7,659,901.33	€ 7,659,784.23	€ 7,652,379.45
02-Apr-08	€ 7,347,856.45	€ 7,309,684.93	€ 7,309,372.47	€ 7,309,352.48
14-Apr-08	€ 8,433,771.68	€ 8,383,360.39	€ 8,383,559.67	€ 8,383,442.29
02-Jun-08	€ 6,846,433.75	€ 6,842,797.96	€ 6,842,795.57	€ 6,816,649.80
03-Jun-08	€ 7,783,521.59	€ 7,589,042.84	€ 7,572,916.96	€ 7,688,216.69
04-Jun-08	€ 8,694,965.56	€ 8,610,095.05	€ 8,572,162.45	€ 8,563,181.07
05-Jun-08	€ 8,560,471.07	€ 8,597,920.05	€ 8,625,339.65	€ 8,546,832.22
08-Jun-08	€ 7,106,365.00	€ 7,099,821.19	€ 7,099,811.80	€ 7,099,805.25
20-Jul-08	€ 6,078,985.09	€ 6,101,727.52	€ 6,101,271.20	€ 6,073,331.82
11-Aug-08	€ 6,963,003.82	€ 7,044,662.04	€ 7,047,135.33	€ 6,967,310.28
27-Aug-08	€ 6,732,240.05	€ 6,713,183.44	€ 6,657,629.20	€ 6,657,550.89
29-Aug-08	€ 7,287,617.02	€ 7,249,537.42	€ 7,249,590.43	€ 7,249,598.28
03-Sep-08	€ 8,166,425.96	€ 8,002,439.74	€ 8,002,393.22	€ 7,866,200.96
04-Sep-08	€ 8,143,320.41	€ 8,022,033.02	€ 8,022,013.95	
16-Sep-08	€ 8,566,615.08	€ 8,479,755.19	€ 8,481,603.80	€ 8,435,708.31
12-Oct-08	€ 5,859,552.44	€ 5,904,936.81	€ 5,841,593.12	
13-Oct-08	€ 7,918,250.28	€ 7,901,776.47	€ 7,885,385.36	€ 7,885,393.27
14-Oct-08	€ 7,825,723.73	€ 7,786,440.88	€ 7,785,467.93	€ 7,770,098.14
19-Oct-08	€ 4,490,508.79	€ 4,501,143.05	€ 4,476,701.17	
22-Oct-08	€ 6,224,607.90	€ 6,180,562.31	€ 6,180,504.78	€ 6,180,226.15
02-Nov-08	€ 7,123,060.47	€ 7,132,908.53	€ 7,130,384.75	€ 7,106,977.50
23-Nov-08	€ 5,169,035.72	€ 5,156,356.83	€ 5,156,135.43	€ 5,153,829.99
24-Nov-08	€ 6,529,391.20	€ 6,526,532.48	€ 6,526,574.34	€ 6,477,638.31
21-Dec-08	€ 4,906,836.02	€ 4,898,631.54	€ 4,898,594.53	€ 4,891,173.01
22-Dec-08	€ 5,938,174.72	€ 5,887,240.16	€ 5,887,186.04	€ 5,877,370.18
07-Jan-09	€ 7,561,787.94	€ 7,582,562.74	€ 7,573,635.06	
10-Jan-09	€ 4,780,378.67	€ 4,755,059.60	€ 4,733,399.79	
11-Jan-09	€ 5,378,226.46	€ 5,345,380.63	€ 5,343,968.13	€ 5,343,645.50
03-Mar-09	€ 4,375,284.52	€ 4,416,061.13	€ 4,416,067.10	€ 4,357,222.30
04-Mar-09	€ 4,784,022.60	€ 4,852,087.49	€ 4,850,779.26	€ 4,916,004.57
08-Mar-09	€ 3,328,483.32	€ 3,419,479.10	€ 3,416,397.90	€ 3,407,379.10
26-Mar-09	€ 3,616,719.17	€ 3,682,798.12	€ 3,682,949.94	€ 3,604,077.28
17-Apr-09	€ 3,572,958.95	€ 3,593,827.36	€ 3,593,520.78	€ 3,549,787.31

Trade Date	*LR*	*MIP300*	*MIP600*	*MIP1800*
27-Apr-09	€ 3,636,896.33	€ 3,625,921.08	€ 3,611,657.62	€ 3,598,430.95
29-Apr-09	€ 3,855,590.66	€ 3,895,486.49	€ 3,895,487.07	€ 3,816,969.15
05-May-09	€ 3,169,615.00	€ 3,175,059.61	€ 3,175,260.90	€ 3,106,205.63
02-Jun-09	€ 4,003,059.03	€ 3,986,964.05	€ 3,986,051.46	€ 3,954,442.74
09-Jun-09	€ 3,882,023.53	€ 3,860,654.48	€ 3,861,674.37	€ 3,860,111.38
15-Jun-09	€ 3,746,655.07	€ 3,703,126.26	€ 3,713,404.32	€ 3,711,466.31
22-Jun-09	€ 3,777,562.92	€ 3,737,566.35	€ 3,717,836.35	€ 3,726,847.74
26-Jul-09	€ 2,239,168.21	€ 2,193,564.31	€ 2,186,972.51	
25-Aug-09	€ 2,527,710.37	€ 2,582,212.57	€ 2,497,391.76	€ 2,495,691.01

4.2 MIP GAP FOR ALL MIP RUNS

Trade Date	*MIP300*	*MIP600*	*MIP1800*
20-Dec-07	1.60%	1.50%	0.97%
03-Jan-08	1.27%	1.24%	1.21%
20-Jan-08	1.25%	1.21%	1.16%
04-Feb-08	1.38%	1.26%	1.22%
07-Feb-08	1.27%	1.01%	0.98%
04-Mar-08	1.19%	1.18%	0.98%
10-Mar-08	1.23%	1.09%	1.00%
18-Mar-08	1.70%	1.63%	1.14%
02-Apr-08	1.09%	1.08%	1.04%
14-Apr-08	1.01%	0.99%	0.98%
02-Jun-08	1.22%	1.21%	0.81%
03-Jun-08	1.81%	1.59%	2.17%
04-Jun-08	2.53%	1.91%	1.72%
05-Jun-08	0.97%	1.43%	0.67%
08-Jun-08	1.71%	1.70%	1.38%
20-Jul-08	1.87%	1.82%	1.20%
11-Aug-08	4.60%	4.64%	3.40%
27-Aug-08	2.86%	2.00%	1.70%
29-Aug-08	2.03%	1.14%	0.88%
03-Sep-08	3.67%	3.65%	1.75%
04-Sep-08	1.74%	0.97%	
16-Sep-08	1.90%	1.87%	1.19%
12-Oct-08	1.66%	0.58%	
13-Oct-08	1.62%	1.39%	1.33%
14-Oct-08	1.15%	1.09%	0.86%
19-Oct-08	1.17%	0.63%	
22-Oct-08	1.41%	1.39%	1.09%
02-Nov-08	1.26%	1.23%	0.90%
23-Nov-08	1.91%	1.72%	0.95%
24-Nov-08	2.12%	2.13%	1.37%
21-Dec-08	1.96%	1.92%	1.73%
22-Dec-08	1.93%	1.91%	1.61%
07-Jan-09	1.10%	0.98%	
10-Jan-09	1.10%	0.65%	
11-Jan-09	1.96%	1.93%	1.89%
03-Mar-09	1.57%	1.55%	0.21%
04-Mar-09	1.22%	1.17%	1.89%
08-Mar-09	1.33%	1.24%	0.97%
26-Mar-09	2.99%	3.01%	0.82%
17-Apr-09	3.71%	3.71%	2.47%
27-Apr-09	1.85%	1.44%	0.98%
29-Apr-09	2.54%	2.53%	0.53%
05-May-09	3.12%	3.12%	0.95%

Trade Date	*MIP300*	*MIP600*	*MIP1800*
02-Jun-09	2.46%	2.43%	1.57%
09-Jun-09	1.21%	1.21%	1.09%
15-Jun-09	0.82%	1.09%	0.98%
22-Jun-09	3.06%	2.53%	2.38%
26-Jul-09	1.05%	0.75%	
25-Aug-09	4.90%	1.69%	1.47%