Annex 3.3

Validators Report 3 : Testing results

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1. The CWE Project and the task of the validators

The CWE project aims at coupling the 4 day-ahead markets of the CWE power exchanges, through a flow-based implicit capacity allocation mechanism.

The core of this mechanism will be an algorithm calculating the optimised market results (volumes and prices), from an input consisting of information from the PXs' order books and network parameters provided by the TSOs.

The CWE project has set up a workstream (the "Algorithm Design Workstream"), with the mission of designing the coupling algorithm. The main task of the Validators was to judge on the selection work done by the Algorithm Design Workstream, and to compare the proposed algorithms, both theoretically and based on the results of empirical testing performed by the candidates. This comparison also provides a list of advantages and disadvantages of each algorithm. The validators have to provide together one common report, comprising three parts:

Part I: Evaluation criteria and testing methodology.

Part II: Theoretical analysis of the algorithms.

Part III: Testing results for selection including their final recommendations.

The present report has been written by the validators and concerns the testing results. It formulates objective judgement on the quality of the results provided by the algorithm candidates. It gives an objective comparison on the strengths and weaknesses of both algorithms, and the final recommendation for the selection.

2. Material given to the validators for the evaluation of the solutions supplied by both algorithms

Both algorithms were tested on a large number of instances of the CWE Market coupling problem and the obtained results were supplied to the validators with the aim of estimating these two algorithms. The main results supplied to the validators concern the following criteria: utility, PRB, ΔP and solution time (see first column of Table 4). The results are presented, on one hand, under a synthetic form by various graphs and, on the other hand, by detailed excel tables.

All the instances are based on coupling of the markets served by Belpex, EEX, Powernext, and APX except HISRUN04b which is based on the market served by EEX solely. For the flow based instances the flow based input data from the R4CA is expanded from four weeks pseudo historical PTDF data to 52 weeks where each week stems from a season. The ATC input data from the TSOs is based on one year 2007 historical values for the borders FR-DE/DE-FR, BE-FR/FR-BE, NL-BE/BE-NL and DE-NL/NL-DE.

Instance name	**Flow based or ATC**	**Capacities network elements (vector b)**	**Market Input Data**
HISRUN01	Flow based	infinite	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times
HISRUN02	Flow based	limited	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times
HISRUN03	ATC	-	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times
HISRUN04a	ATC	-	Belpex, Powernext and APX : historical data, year 2007
HISRUN04b	-	-	EEX : One week from 2007
HISRUN05	Flow based	limited	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times ***Volume of each block order multiplied by 3***
HISRUN06	Flow based	limited	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times ***Number of block orders multiplied by 3***
HISRUN07	Flow based	limited	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times ***Capacities of all network element divided by 3***
HISRUN08	Flow based and ATC	limited	Artificially generated data coupling 15 markets Fill-or-kill constraint relaxed for the linked and flexible blocks
HISRUN10	Flow based	limited	Belpex, Powernext and APX : historical data, year 2007 EEX : one week copied 52 times ***Capacities of all network element multiplied by 3***

Table 1. Description of the instances

3. General comments on both algorithms

A major difference in the design of COSMOS and MLC is that COSMOS is based on an exact solution approach while MLC is based on a heuristic approach. Both these approaches are very often used in Combinatorial Optimization.

In a heuristic approach, a fast algorithm is run in order to compute a feasible solution. A set of locally clever choices are done during the algorithm in order to finally provide a “good” solution in regards with the criteria to be optimized. If no feasible solution exists, the heuristic algorithm cannot provide any solution. However, especially for hard optimization problems, it can happen that feasible solutions exist and the algorithm is unable to find any.

Exact solution approaches are usually based on a branch-and-bound algorithm. The principle is to implicitly enumerate the set of potentially feasible solutions in order either to prove that no feasible solution exists or to provide a feasible solution that is optimal for the given criterion. Total enumeration is avoided by a bounding procedure on the optimal solution value, allowing to discard branches of the enumeration tree. It can happen that the enumeration, even if it is limited, is too much large. In this case, the branch-and-bound algorithm takes a very long time to converge. Nevertheless, it is possible to stop its execution after a given duration and consider the best feasible solution computed so far.

From this general comparison between heuristic and exact solution approaches, we could expect that MLC would have difficulties from the quality of the computed solution point of view while COSMOS would have difficulties from the computation time point of view. The experimental tests show that none of the algorithms dramatically suffers from these drawbacks (see Tables 2 and 3).

		Number PRBs		Average ΔP		Max ΔP	
		av	max	av	max	av	max
HISRUN01	C	1.417	11	0.12	9	0.167	9
	M	1.660	12	0.11	2.04	0.152	2.04
HISRUN02	C	2.504	14	0.244	6.95	0.456	15.13
	M	2.936	16	0.252	6.95	0.475	16.85
HISRUN03	C	2.294	15	0.202	3.68	0.349	6.98
	M	2.702	19	0.226	3.74	0.397	6.98
HISRUN04a	C	2.297	15	0.320	14.34	0.607	31.14
	M	2.696	20	0.311	5.85	0.55	25.12
HISRUN05	C	7.308	31	0.749	5.431	1.99	31.30
	M	10.01	57	1.038	8.535	2.91	31.30
HISRUN06	C	12.59	70	0.307	2.23	0.869	11.63
	M	20.04	155	0.54	6.45	1.614	27.15
HISRUN07	C	4.071	24	0.481	31.84	1.465	142.68
	M	4.559	23	0.586	49.07	1.452	150.92
HISRUN08	C						
	M	10.47	26	4.76	48.2	15.76	161.96
HISRUN10	C	2	10	0.190	6.96	0.292	6.96
	M	2.449	15	0.187	6.96	0.302	6.96

Table 2. Comparison daily Number of PRBs, average ΔP and Max ΔP for different sets of instances, each representing one year

		Net Utility	Number iterations	Duration(1)		
		Av	Av	feas.	best	end
HISRUN01	C	25302801	120	2.9	7.47	53
	M	25302776	55			15.6
HISRUN02	C	24874385	387	3.4	11.05	105
	M	24874251	65			18
HISRUN03	C	25029492	379	2.55	6.73	75.8
	M	25029383	64			15.7
HISRUN04a	C	22938577	332	0.89	3.93	32.96
	M	22927444	59			26.78
HISRUN05	C	63969090	1115	5.64	59	342
	M	63963981	77			32.6
HISRUN06	C	63970731	1095	9.33	54	409
	M	63967798	68			32.8
HISRUN07	C	24460206	688	3.65	25.66	187.39
	M	24459661	72			20
HISRUN08	C					
	M	54629110	85			178
HISRUN10	C	25010818	221	3.47	8.58	79.9
	M	25010781	60			16.21

(1)with no scaling

Table 3. Performances comparison for different sets of instances, each representing one year

4. Comparison of the algorithms criterion by criterion

Table 4 gives some elements of comparison of both algorithms for the main criteria.

Criteria	Comments
PRB turnover loss	For almost all the tested instances the PRB turnover loss associated with the solution given by MLC is greater than the turnover loss associated with the solution given by COSMOS. For example for HISRUN04a the total PRB turnover loss of MLC minus the total PRB turnover loss of COSMOS is equal to 107934 euros. For HISRUN10 this difference is equal to 49023 euros.
Δ Utility *vs* sumΔP	The utility of the solution given by COSMOS is always greater than the utility given by MLC, except for very few cases, and, generally, the value of sumΔP is lower for COSMOS than for MLC. For example, for HISRUN04a the average utility obtained by COSMOS minus the average utility obtained by MLC is equal to 11113 and the average sumΔP of COSMOS is equal to 1.19 while the average sumΔP of MLC is equal to 1.60. However, the value of sumΔP is sometimes smaller for MLC.
sumΔP	For almost all the tested instances the value of sumΔP associated with the solution given by MLC is greater than the value of sumΔP associated with the solution given by COSMOS.
Δ turnover *vs* Δ Utility	Turnover loss and utility are better in the COSMOS solution than in MLC for most instances. Moreover, it seems from the results that the turnover loss is highly correlated with a loss in the welfare.

Number of PRBs	For almost all the tested instances, the number of PRBs associated with the solution given by MLC is greater than the number of PRBs associated with the solution given by COSMOS. For many instances, COSMOS slightly outperforms MLC. For example, for HISRUN04a, the total number of PRB of MLC minus the total number of PRBs of COSMOS is equal to 979-834=145. For HISRUN10, this difference is equal to 889-726=163. However, for difficult instances, this difference may be more important. So, for HISRUN06 this difference is equal to 7278-4573=2705.
Max ΔP	For this criterion and for many instances the behaviour of both algorithms is comparable. For example, for HISRUN04a the sum of Max ΔP is equal to 221 for COSMOS and to 201 for MLC. Conversely, for HISRUN10, the sum of Max ΔP is equal to 106 for COSMOS and to 110 for MLC. However, for difficult instances, the sum of Max ΔP may become substantially larger for MLC compared to COSMOS. So, for HISRUN06, the sum of Max ΔP is equal to 315 for COSMOS and to 586 for MLC.
Average ΔP	For many instances, the value of this criterion is almost the same for COSMOS and MLC. For example, for HISRUN04a, the cumulative average ΔP of MLC is equal to 113 and the cumulative average ΔP of COSMOS is equal to 116. For difficult instances, COSMOS may produce better solutions for this criterion than MLC. For example, for HISRUN06, the cumulative average ΔP of MLC is equal to 196 while the cumulative average ΔP of COSMOS is equal to 118.
Solution time (with no scaling)	The computational time required by MLC to obtain a "good" feasible solution is generally smaller than the computation time required by COSMOS to obtain a (proven) optimal solution. For example, for HISRUN04a, the average time required to obtain the optimal solution by COSMOS is equal to 33 seconds but the standard deviation is important since it is equal to 120 seconds ; for MLC the average time required for obtaining the solution is equal to 27 seconds but the standard deviation is small (8.3 seconds). For HISRUN10, the average time required to obtain the optimal solution by COSMOS is equal to 80 seconds with a standard deviation of 184 seconds; for MLC the average time required for obtaining the solution is equal to 16.2 seconds with a standard deviation of 4.2 seconds.

Table 4. Elements of comparison of COSMOS and MLC for the main evaluation criteria

5. Comments on the results with respect to the evaluation criteria

5.1 Optimality and quality of the solution

5.1.1 Optimality of the solution

The optimality of the solution is defined in terms of total utility. In almost all instances, COSMOS finds the best total utility, and often proves the optimality of the solution. MLC did better only in a very few cases where COSMOS was not able to find the optimal solution.

5.1.2 Quality of the solution in terms of market aspects

From the testing results, it appears that other market aspects (turnover loss, Max ΔP, number of PRBs) are strongly correlated with total utility. Therefore, COSMOS performs also substantially better on these criteria. However, due to the design of the algorithm, there exist a few pathological cases for which the COSMOS solution ends up with very large MaxΔP. Note that this also happens for MLC although the parameter DP should try to keep the sum of ΔPs small. We could think that it is due to a too aggressive increase of DP on these instances. The examination of the results obtained on HISRUN05 with a tuned version of MLC shows that it is not the case. Indeed, on this instance the average value of Max ΔP goes up from 2.91 to 3.37 while the computation time increases from 32.6 to 139.2 seconds. As regards the criterion number of PRBs, the tuned version of MLC slightly improves the “standard” version but the number of PRBs obtained by the tuned version remains greater than the number of PRBs associated with the first feasible solution found by COSMOS.

		Number PRBs		Average ΔP		Max ΔP	
		av	max	av	max	av	max
HISRUN05	C	7.308	31	0.749	5.431	1.99	31.30
	C*	7.419	34	0.824	5.431	2.197	31.30
	M	10.01	57	1.038	8.535	2.91	31.30
	M*	9.78	48	0.993	10.38	3.37	273.82

Table 5. C*: COSMOS first feasible solution
M*: MLC with a better tuning

		Net Utility	Number iterations	Duration[1]		
		Av	Av	feas.	best	end
HISRUN05	C	63969090	1115	5.64	59	342
	C*	63988028	9			7
	M	63963981	77			32.6
	M*	63963593	437			139.2

[1]with no scaling

Table 6. C*: COSMOS first feasible solution
M*: MLC with a better tuning

5.2 Performance

In all tests, both algorithms provide a feasible solution well before the time limit is reached. For COSMOS however, we have no indication at this time on the quality of this solution. Nevertheless, COSMOS uses the available computing time to improve the solution and prove optimality. In all cases, it leads to very good solutions before the time limit. In MLC, only one solution is provided. This solution is found very quickly (within 30 seconds for most instances).

5.3 Scalability

The impact on the instance size is clearly under control for both algorithms, as a feasible solution is always found quickly. The impact on the time limit is not an issue for MLC as convergence occurs well before the limit is reached. However, for difficult instances, the quality of the solutions provided by MLC is degraded. We can wonder if a proper tuning of the parameters could improve that situation. The results of Table 5 show that it is not the case, at least on the considered instances. Moreover, we noticed that, on all the instances, the first feasible solution found by COSMOS is more quickly obtained than the heuristic solution given by MLC (See Tables 1 and 2). Moreover, for HISRUN05, the first feasible solution of COSMOS is already better than the solution of COSMOS (See Table 5).

5.4 Data sensitivity of the parameters setting

The only tunable parameter of COSMOS is the time limit. For MLC, the parameters forcing convergence and setting the increase rate of DP could be tuned, but first results indicate that tuning the parameters increases the computing time without a clear benefit in terms of solution quality.

6. Conclusion

The analysis of the computational results shows that both algorithms allow to handle the CWE Market coupling problem in a completely satisfactory way on the numerous considered instances. They indeed supply good quality solutions towards all the important criteria and the computation time required to obtain these solutions is generally much lower than the fixed limit.

However, most of the time the solutions obtained by COSMOS are slightly better than those obtained by MLC and that is true for all the criteria chosen by the Algorithm Design Workstream for the evaluation of the algorithms. On the difficult instances, the superiority of COSMOS is more clear. An important advantage of COSMOS is that it supplies generally the optimal solutions from the total utility point of view contrary to MLC. The fact that MLC is faster than COSMOS does not compensate for this inconvenience because the computation time required by COSMOS respects widely the fixed time limit. Moreover, the first solution found by COSMOS appears faster than the solution provided by MLC and, on HISRUN05, the COSMOS solution is better than the MLC one.