# IASM2223T-4

## Interim Auction Solution Methodology

***This Interim Auction Solution Methodology provides information relating to Sections M.4 and M.6 of the Capacity Market Code for the Capacity Auction for the Capacity Year 2022/2023, which is expected to be held on 28th March 2019. The auction will be referred to within this document as the 2022/2023 T-4 Capacity Auction.***

***In accordance with D.1 of the Capacity Market Code, the Capacity Year commences at 23:00 on 30th September 2022 and ends at 23:00 on 30th September 2023. The Capacity Year will be referred to in this document as the 2022/2023 Capacity Year.***

***All information set out in this document relates solely to the 2022/2023 T-4 Capacity Auction.***

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# Contents

# 1 Background

The Capacity Market for Ireland and Northern Ireland centres around annual Capacity Auctions that take place approximately four years in advance of delivery (T-4 auction) and approximately one year in advance of delivery (T-1 auction). These auctions match offers from Participants in respect of their Capacity Market Units against a Demand Curve set by the Regulatory Authorities. The auction is combinatorial in nature as it seeks to maximise Net Social Welfare subject to satisfying various constraints including inflexibility constraints (where offers can be all or nothing) and Locational Capacity Constraints (where a certain predetermined quantity of capacity must clear in particular areas of Ireland and Northern Ireland).

In accordance with the SEM Committee decision SEM-16-081, the Capacity Market Code (in F.8.5.1) provides for the enduring auction solution methodology of Auction Format D, a combinatorial optimisation approach based on Mixed Integer Programming. In the interim, in accordance with the SEM Committee decision SEM-18-155, the Capacity Market Code (in M.4 and M.6 as modified by CMC_01_19) provides for Auction Format C, which maximises social welfare subject to locational capacity constraints. Auction Format C differs from Auction Format D primarily in that it limits the number of combinations considered to ensure solution times within the Allowed Timeframe.

Auction Format C is referred to here as the Interim Auction Solution Methodology as it combines M.4 (Interim Auction Solution) and M.6 (Alternative Auction Solution Methodology) of the Capacity Market Code. M.4 relates to tie-breaking rules used in the determination of the Auction Clearing Price and M.6 relates to the rules-based alternative to a mixed integer programming approach that is used to deal with inflexibility constraints and locational capacity constraints.

The Interim Capacity Auction Methodology is subject to a set of requirements in M.6.1.7 of the Capacity Market Code. In particular, in accordance with M.6.1.7.(d), the Interim Auction Solution Methodology, “shall provide for limits, specified by the System Operators, on the number of combinations of solutions for Inflexible price-quantity pairs the subject of Capacity Auction Offers considered…so as to allow the methodology to reach a solution within the Allowed Timeframe”. Under the Interim Auction Solution Methodology described here, when seeking to maximise Net Social Welfare, a subset of inflexible offers not cleared is considered (rather than all inflexible offers not cleared) in order to ensure that the auction can solve within the Allowed Timeframe.

The subset of offers considered is governed by a set of parameters for each level of Locational Capacity Constraints and for the final Net Social Welfare maximisation. These parameters are referred to here as N_<Level>_<Direction>. There are three levels, 0, 1 and 2 (where Level 0 refers to the overall auction level) and two directions – Up and Down – from the base solution.

The Interim Auction Solution Methodology set out in this document implements the requirements of the Capacity Market Code set out in F.8 as modified by the Interim Auction Solution set out in M.4 and the Alternative Auction Solution Methodology set out in M.6 (as modified by CMC_01_19).

# 2 Interim Auction Solution Methodology

## 2.1 Determination of Auction Clearing Price

The System Operators determine the Auction Clearing Price in accordance with Section F.8.3. Taking all price-quantity pairs as flexible and scheduling offers in order of increasing price, the Price Setting Offer shall be the price-quantity pair:

a) Whose quantity, in whole or in part, together with the cumulative quantity of all previously scheduled price-quantity pairs, is equal to the quantity on the Demand Curve; and
b) Whose price is equal to or lower than the price corresponding to that quantity on the Demand Curve.

Where no price-quantity pair satisfies the above criteria, the Price Setting Offer is the last price-quantity pair scheduled once all price-quantity pairs have been scheduled to their respective maximum quantities.

In accordance with paragraphs M.4.1.3 to M.4.1.5 (which apply), where a tie exists for the Price Setting Offer, the offers will be scheduled in the following order of priority: Clean, higher Net Social Welfare, lower Maximum Duration and finally randomly.

## 2.2 Initial Clearing

Price quantity pairs with prices higher than the Auction Clearing Price and an offered capacity duration greater than one year that are not exempt under F.4.1.9 are cleared at zero MW.

Exempt Price Quantity Pairs, as defined in CMC_03_19, are not cleared for Locational Capacity Constraints or Net Social Welfare purposes until all applicable price quantity pairs with an offered capacity duration of one year have been cleared.

In addition, an Exempt Price-Quantity Pair and a price-quantity pair with offered capacity durations of one Capacity Year shall not be considered as tied price-quantity pairs for the purposes of paragraph F.8.4.6.

In accordance with F.8.4.4.c, all scheduled price quantity pairs with a price below the Offer Price Clearance Ratio of the Auction Clearing Price in accordance with section F.4 – Capacity Auction Clearing are cleared. The current Offer Price Clearance Ratio is 0%.

## 2.3 Locational Capacity Constraints

Figure 1 illustrates a set of offers that contribute to satisfying a Level 1 Locational Capacity Constraint. The same approach would apply for a Level 2 Locational Capacity Constraint. Some of these offers may already be cleared by the Initial Clearing Process based on a non-zero Offer Price Clearance Ratio. The following process is applied to identify a set of feasible solutions involving different combinations of inflexible offers to be considered further.

For each Locational Capacity Constraint that is not satisfied (starting with Level 2 and then Level 1), the following steps are followed for all feasible solutions already determined in that Locational Capacity Constraint:

1. Determine the base solution (the marginal offer that meets the requirements of the constraint when inflexibility constraints are relaxed). In Figure 1, this is offer J, which is a flexible offer. This can also be an inflexible offer.

2. Where two or more offers have the same price (i.e. there is a tie), schedule[1] offer pairs in the following order: clean, flexible, quantity (lesser quantities first), duration (shorter durations first), random.

3. Where available, select next N_<Level>_Up[2] inflexible offers not cleared above base solution (inclusive). Where available, select next N_<Level>_Down inflexible offers not cleared below base solution (inclusive). These offers represent the subset of inflexible offers not cleared to be considered further[3]. Where a tie exists, the approach in step 2 applies. In Figure 1, N_L1_Up = 2 and N_L1_Down = 2 (shown in the diagram simply as N = 2) and the subset of offers to be considered is G, I, K and M.

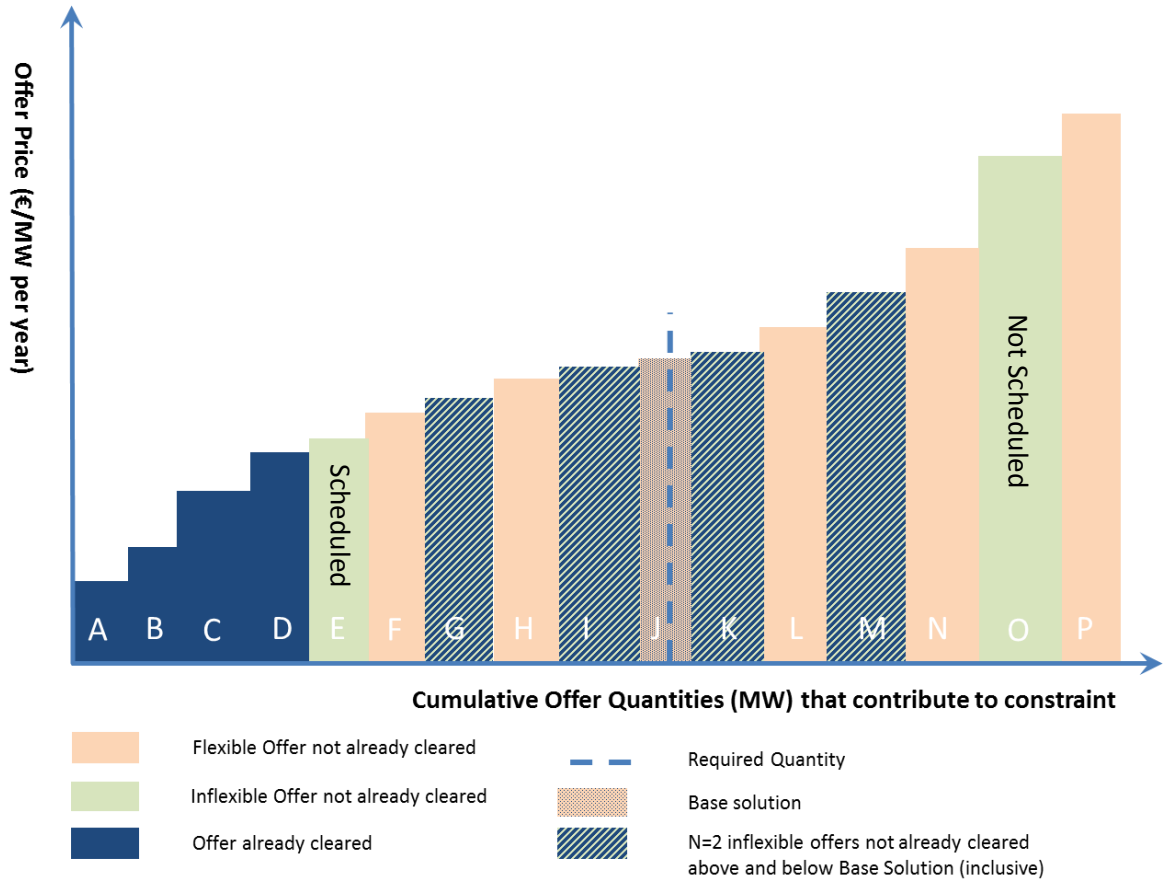


**Figure 1 - Identifying feasible solutions based on subset of inflexible offers not cleared for N=2**

[1] Throughout, the term 'schedule' refers to processing of offers for the purposes of determining Net Social Welfare of a particular solution whereas the term 'clear' refers to the final acceptance of the offer.

[2] N_<Level>_Up or N_<Level>_Down are parameters used in the Interim Auction Solution Methodology to reduce the number of combinations to be considered. <Level> refers to whether the parameter applies to Level 2, Level 1 or the whole auction, which is referred to as Level 0. There are six parameters in total. See Section 3.

4. Inflexible offers not cleared below this subset are scheduled. Inflexible offers not cleared above this set remain not scheduled. In Figure 1, offer E is scheduled and offer O remains not scheduled on this basis.

5. Determine allowed solutions for every combination of subset of inflexible offers not cleared subject to offers on same CMU being scheduled in order. Based on offers set out in Figure 1, 16 combinations of the four inflexible offers are possible. They are G, I, K, M, GI, GK, GM, IK, IM, KM, GIK, GIM, GKM, IKM, GIKM and “none”.

6. For each allowed solution, schedule allowed flexible offers not cleared in order of increasing price as required to cover any remaining shortfall. Based on offers set out in Figure 1, combination GIKM would not require any flexible offers to be scheduled, whereas the combination of none of the inflexible offers would require F, H, J, L and N (partially).

7. Check feasibility of allowed solution: (a) it meets the Required Quantity and (b) it does not exceed the Required Quantity by more than an entire offer quantity. Based on offers set out in Figure 1, all combinations would be feasible.

8. Record feasible solutions to take forward to processing next step of auction.

## 2.4 Inflexibility Constraints and Final Solution

Once a set of feasible solutions that satisfy all the Locational Constraints has been identified, associated offers are scheduled for each feasible solution and the Net Social Welfare of each feasible solution is calculated.

For each feasible solution, an approach similar to Section 2.3 is applied to determine if the Net Social Welfare can be improved as follows:

1. Determine the base solution (the marginal offer that meets the requirements of the constraint when inflexibility constraints are relaxed).

2. Where available, select next N_L0_Up inflexible offers not cleared above base solution (inclusive). Where available, select next N_L0_Down inflexible offers not cleared below base solution (inclusive). These offers represent the subset of inflexible offers not cleared to be considered further. Where a tie exists, the approach in step 2 applies.

3. Inflexible offers not cleared below this subset are scheduled. Inflexible offers not cleared above this set remain not scheduled.

4. Determine allowed solutions for every combination of subset of inflexible offers not cleared subject to offers on same CMU being scheduled in order.

5. For each allowed solution, schedule allowed flexible offers not cleared in order of increasing price where they increase the Net Social Welfare of the allowed solution.

6. The feasible solution is updated with the allowed solution with greatest Net Social Welfare. Where there is no allowed solution with a greater Net Social Welfare, the feasible solution is not updated.

The feasible solution (updated accordingly as set out above) with the highest Net Social Welfare from the set of feasible solutions identified in section 2.3 (as modified by this section) is cleared. Where there is a tie between offers cleared in accordance with F.8.4.6 of the Capacity Market Code, the relevant offers are cleared in accordance with F.8.4.7 of the Capacity Market Code.

# 3 Auction Parameters

## 3.1 Allowed Timeframe

In accordance with paragraph F.8.5.2 of the Capacity Market Code:

The "Allowed Timeframe" shall be 24 hours from the program run being initiated or such shorter period as is determined from time to time by the System Operators.

The Allowed Timeframe for the 2022/2023 T-4 Capacity Auction is 24 hours.

## 3.2 Number of Inflexible Offers Not Cleared considered (N)

The values of N to be applied in the 2022/2023 T-4 Capacity Auction are set out in Table 1.

**Table 1 - Values of N to be used in 2022/23 T-4 Capacity Auction**

| Parameter | Value |
|---|---|
| **N_L0_Up** | 4 |
| **N_L0_Down** | 4 |
| **N_L1_Up** | 4 |
| **N_L1_Down** | 4 |
| **N_L2_Up** | 4 |
| **N_L2_Down** | 4 |

The values in Table 1 represent a reasonable trade-off between reaching an optimal solution and solving the auction within the allowed timeframe of 24 hours, which is the maximum permissible under the Capacity Market Code. The rationale for these values is set out in following section.

## 3.3 Rationale for Value Chosen

The reason for adopting the Interim Auction Solution Methodology relates to the tractability of the mathematical problem being solved. Where values of N are equal as above[4], each Locational Capacity Constraint and the Final Step will result in a maximum of 2N inflexible offers not cleared being considered, each of which results in $2^{2N}$ combinations for each Locational Capacity Constraint and for the Final Step. Table 2 sets out the max number of solutions to be considered for different values of N and different numbers of Locational Capacity Constraints.

Table 3 and Table 4 set out theoretical times to solve and memory requirements for the same values of N and numbers of Locational Capacity Constraints. These values represent the maximum requirements and while it is unlikely that these maximum requirements would be reached, it is not possible to predict with certainty the amount of time required to solve the problem and memory requirements.

[4] This can be generalised where they are not equal such that the number of combinations of 2 to the power of the sum of the N_<Level>_Up and N<Level>_Down for each binding constraint.

**Table 2- Maximum Solutions Considered**

| Max Solutions Considered | | Number of Locational Capacity Constraints | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| N | 3 | 4.10E+03 | 2.62E+05 | 1.68E+07 |
| | 4 | 6.55E+04 | 1.68E+07 | 4.29E+09 |
| | 5 | 1.05E+06 | 1.07E+09 | 1.10E+12 |
| | 6 | 1.68E+07 | 6.87E+10 | 2.81E+14 |
| | 7 | 2.68E+08 | 4.40E+12 | 7.21E+16 |
| | 8 | 4.29E+09 | 2.81E+14 | 1.84E+19 |
| | 9 | 6.87E+10 | 1.80E+16 | 4.72E+21 |
| | 10 | 1.10E+12 | 1.15E+18 | 1.21E+24 |
| | 11 | 1.76E+13 | 7.38E+19 | 3.09E+26 |

**Table 3 - Maximum time to solve (hrs) on basis of 500 calculations per solution and $10^9$ calculations per second**

| Max Time to Solve (Hrs) | | Number of Locational Capacity Constraints | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| N | 3 | 1.42E-07 | 9.10E-06 | 5.83E-04 |
| | 4 | 2.28E-06 | 5.83E-04 | 1.49E-01 |
| | 5 | 3.64E-05 | 3.73E-02 | 3.82E+01 |
| | 6 | 5.83E-04 | 2.39E+00 | 9.77E+03 |
| | 7 | 9.32E-03 | 1.53E+02 | 2.50E+06 |
| | 8 | 1.49E-01 | 9.77E+03 | 6.41E+08 |
| | 9 | 2.39E+00 | 6.25E+05 | 1.64E+11 |
| | 10 | 3.82E+01 | 4.00E+07 | 4.20E+13 |
| | 11 | 6.11E+02 | 2.56E+09 | 1.07E+16 |

**Table 4 - Maximum memory requirements (GB) on basis of 20kB per solution**

| Max RAM requirements (GB) | | Number of Locational Capacity Constraints | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| N | 3 | 1.28E-04 | 8.19E-03 | 5.24E-01 |
| | 4 | 5.12E-04 | 1.31E-01 | 3.36E+01 |
| | 5 | 2.05E-03 | 2.10E+00 | 2.15E+03 |
| | 6 | 8.19E-03 | 3.36E+01 | 1.37E+05 |
| | 7 | 3.28E-02 | 5.37E+02 | 8.80E+06 |
| | 8 | 1.31E-01 | 8.59E+03 | 5.63E+08 |
| | 9 | 5.24E-01 | 1.37E+05 | 3.60E+10 |
| | 10 | 2.10E+00 | 2.20E+06 | 2.31E+12 |
| | 11 | 8.39E+00 | 3.52E+07 | 1.48E+14 |

The values in Table 4 reflect the requirement to store all the solutions associated with Locational Capacity Constraints in memory for consideration in the final step. The final step itself only replaces a solution where it can improve its Net Social Welfare and therefore does not increase memory requirements significantly. So whereas the time to solve is affected by the number of Locational Capacity Constraints and the final step, the memory requirements are driven primarily by the number of Locational Capacity Constraints.

These tables clearly demonstrate the need for limiting the value of N and give some guidance on prudent values to adopt. Note: while testing can give some degree of confidence regarding

ability to solve the problem within the timeframe, the number of solutions to be considered is quite dependent on the number of flexible and inflexible offers submitted.

There are three Locational Capacity Constraints to be considered in the 2022/2023 T-4 Capacity Auction:

- L2-1: Greater Dublin
- L1-1: Northern Ireland
- L1-2: Ireland

In previous auctions using Auction Format B, it was possible to assume that one Locational Capacity Constraints would not have been binding and therefore the $2^{2N}$ combinations needed to solve this constraint would not have been required. Therefore, it was possible to set N=5 and to achieve a solution within the Allowed Timeframe, on the basis of the number of binding Locational Capacity Constraints being two rather than three. This is not possible with Auction Format C as there is no automatic clearing of offers below the Price Setting Offer.

Therefore, based on three Locational Capacity Constraints and an Allowed Timeframe of 24 hours, a value of N=4 is considered prudent on the basis that N=5 would potentially breach the Allowed Timeframe. It is also important to consider the memory requirements of the auction in terms of number of solutions. As can be seen in Table 4, the maximum memory requirements for N=5 would be of the order of 2 TB whereas for N=4, the requirements are 34 GB. Based on tests conducted using the updated algorithm, we have encountered cases where using N=5 resulted in performance issues where the algorithm is not able to solve in the Allowed Timeframe due to memory issues. As such, we consider that setting N=4 is prudent and ensures that the auction can be solved in the Allowed Timeframe.

# 4 Capacity Market Code Requirements (including CMC_01_19)

## 4.1 Section M.6

In accordance with M.6.1.7 of the Capacity Market Code, the Interim Auction Solution Methodology must reflect the following principles:

(a) **the starting cleared quantity for each priced-quantity pair the subject of a Capacity Auction Offer shall be the minimum value required to be cleared under paragraph F.8.4.4(c);**

F.8.4.4 (c) states that offers below the Offer Price Clearance Ratio of the Auction Clearing Price shall be cleared. In accordance with section F.8.3 - Determination of the Auction Clearing Price, where a tie exists for the Price Setting Offer, the offers will be scheduled in the following order of priority: Clean, higher Net Social Welfare, lower Maximum Duration and finally randomly (in accordance with paragraphs M.4.1.3 to M.4.1.5). As the Offer Price Clearance Ratio is 0%, no offers will be cleared under paragraph F.8.4.4 (c).

(b) **the methodology shall, as required, determine additional quantities to clear from price-quantity pairs the subject of Capacity Auction Offers so as to ensure that each Locational Capacity Constraint is satisfied, or if this is not possible, that the shortfall is minimised;**

See approach set out in section 2.3.

(c) **the methodology shall determine additional quantities to clear from price-quantity pairs the subject of Capacity Auction Offers if this will result in a higher Net Social Welfare under paragraph F.8.4.2;**

See approach set out in section 2.4.

(d) **the methodology shall provide for limits, specified by the System Operators, on the number of combinations of solutions for Inflexible price-quantity pairs the subject of Capacity Auction Offers considered under sub-paragraphs (b) and (c) so as to allow the methodology to reach a solution within the Allowed Timeframe;**

Due to the combinatorial nature of this calculation, the number of solutions increases rapidly with N. In order to ensure that the Capacity Auction will solve in the Allowed Timeframe of 24 hours, values of N set out in Table 1 have been chosen based on a trade-off between optimality and practicality.

(e) **if a solution can be found within the Allowed Timeframe without imposing the limits described in sub-paragraph (d), then the solution that maximizes the Net Social Welfare under paragraph F.8.4.2 applies; and**

Where all constraints are satisfied by flexible offers, it is possible that the optimal solution can be found within the Allowed Timeframe; however, due to the combinatorial nature of the calculation, and that we are operating on the basis of the Interim Auction Solution, set out in M.4 of the CMC, unless the base solutions for all Locational Capacity Constraints and for the final step are flexible offers, it will be necessary to impose the limits described in sub-paragraph (d).

(f) **to reduce solution time, the methodology may exclude exploring combinations of solutions that are likely to be inferior to other combinations of solutions and the exclusion of which will not conflict with the principle in sub-paragraph (e).**

Prior to the implementation of the enduring solution, in most cases, it would not be possible to identify a solution as being optimal (due to the combinatorial nature of the calculation); however, the approach set out here is considered to be more likely to identify more optimal solutions on the basis that solutions based on offer combinations beyond N are more likely to be inferior due to their more expensive price.