Single Electricity Market Operator – Training Module

Physical Market Processes

May 2007

DISCLAIMER

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Scope of the Physical Market Course

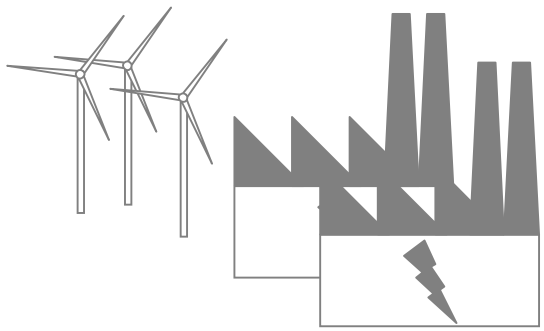
Physical Market Scope

You should leave this course having some understanding of:

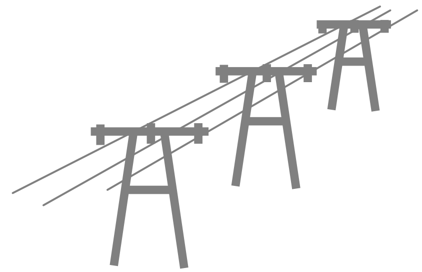
Element	Done?
Key elements of the Physical Market	q
Key data submitted by different Units	q
How Units are scheduled by the MSP Software	q
Data used for the Ex Ante Indicative MSP Run	q
How SMP is calculated	q
What the Operations Schedule is	q
How Instruction Profiling works	q
Data used for the Ex Post Indicative MSP Run	q
Data used for the Ex Post Initial MSP Run	q

SEMO Recap

Electricity Market Recap



Generation



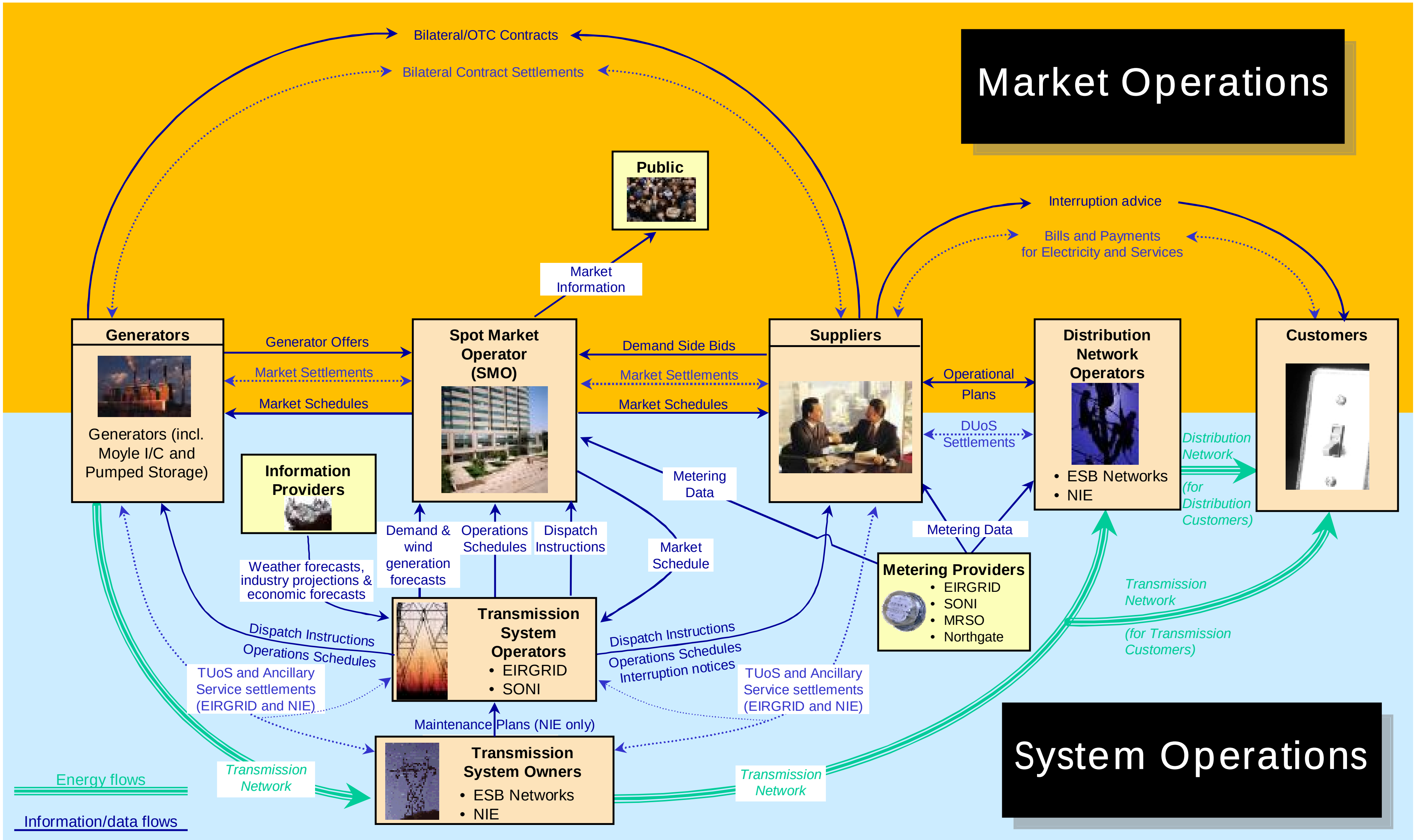
Transmission & Distribution

Demand

System and Network Operators & Market Operator

Market

Markets vs. System Operations



SEM Recap

Gross mandatory pool

All island

Global SMP

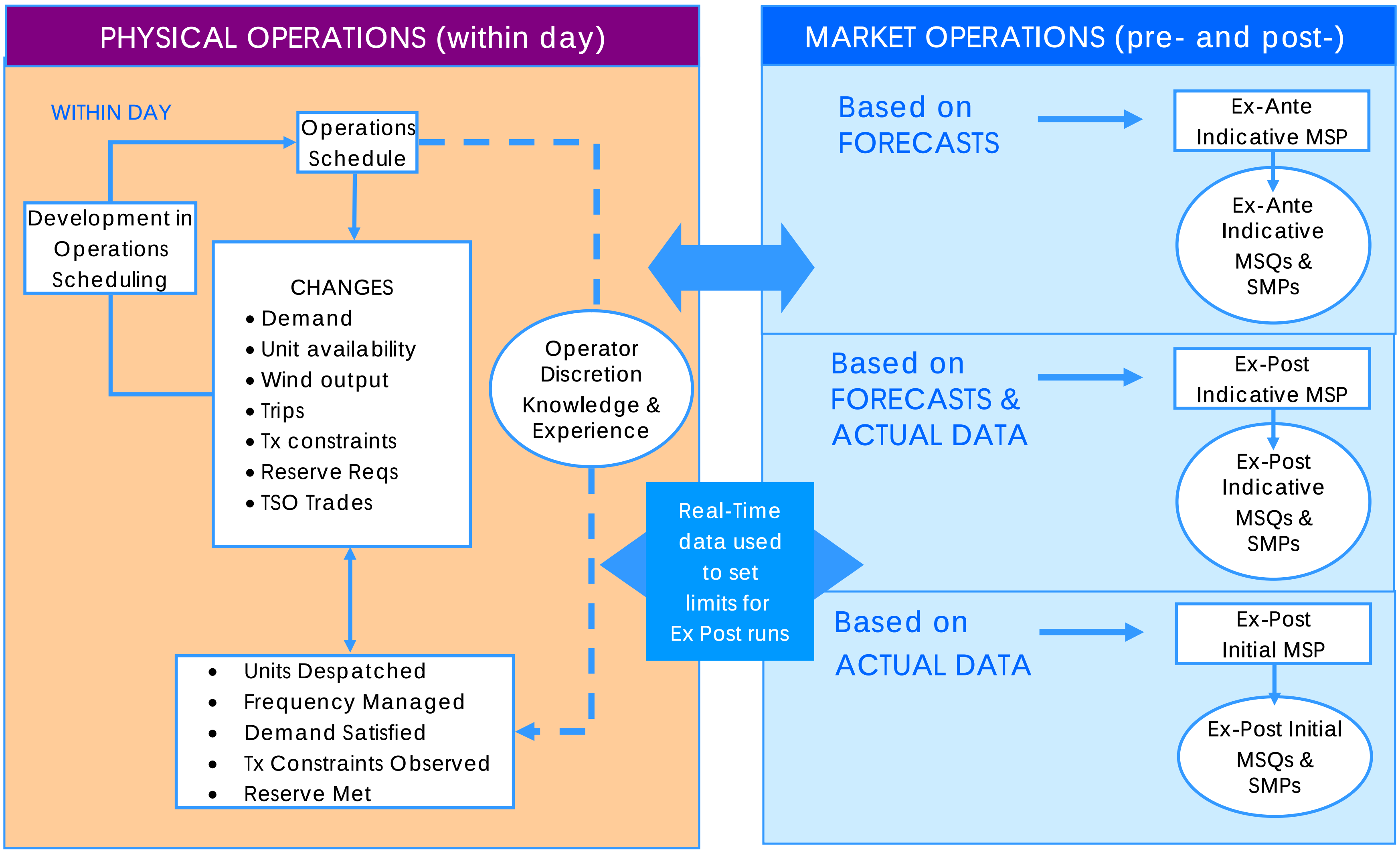
Half hour intervals

Optimisation Horizon

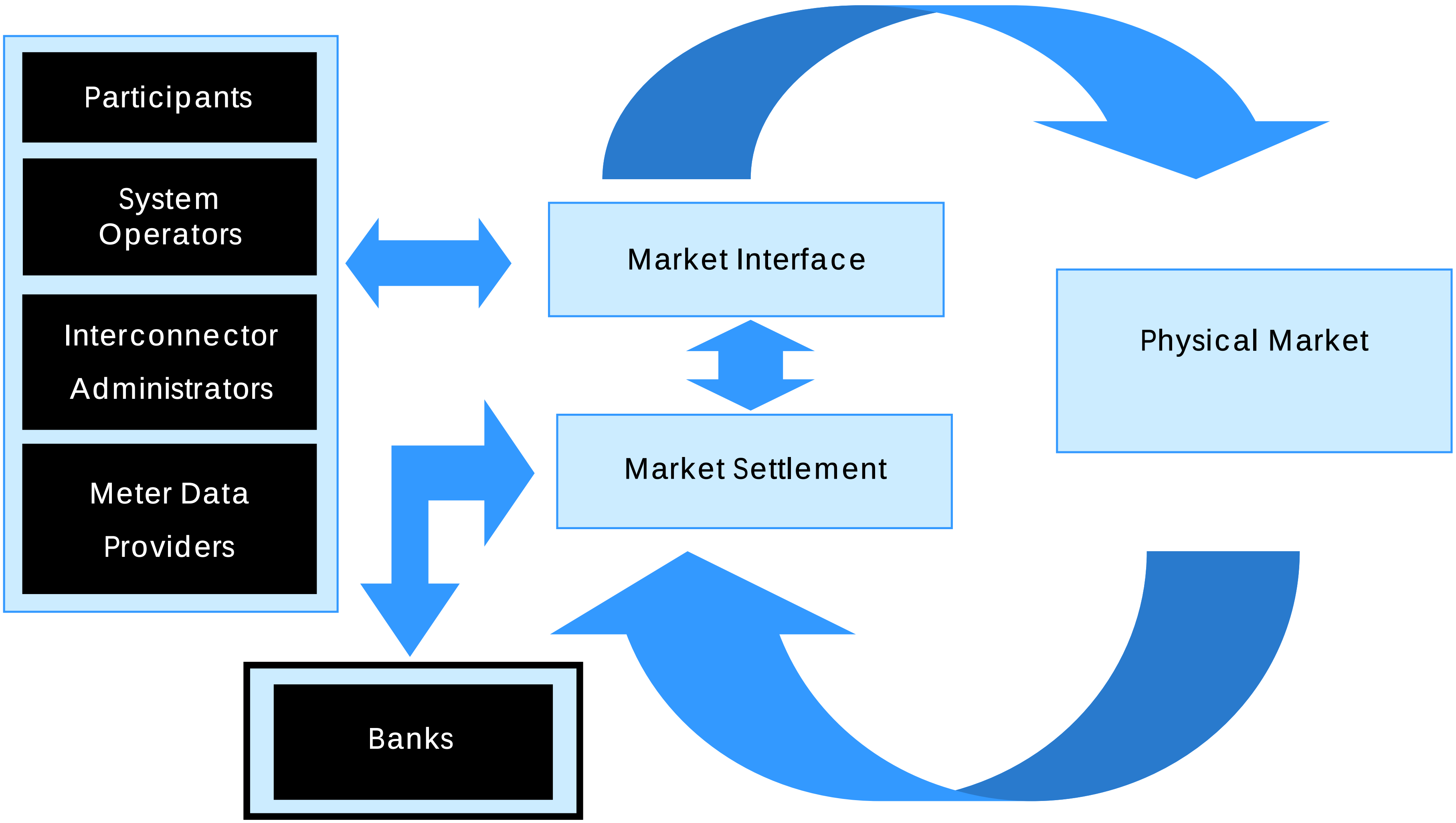
Daily clearing

Ex-Post Settlement

Market versus Physical Operations

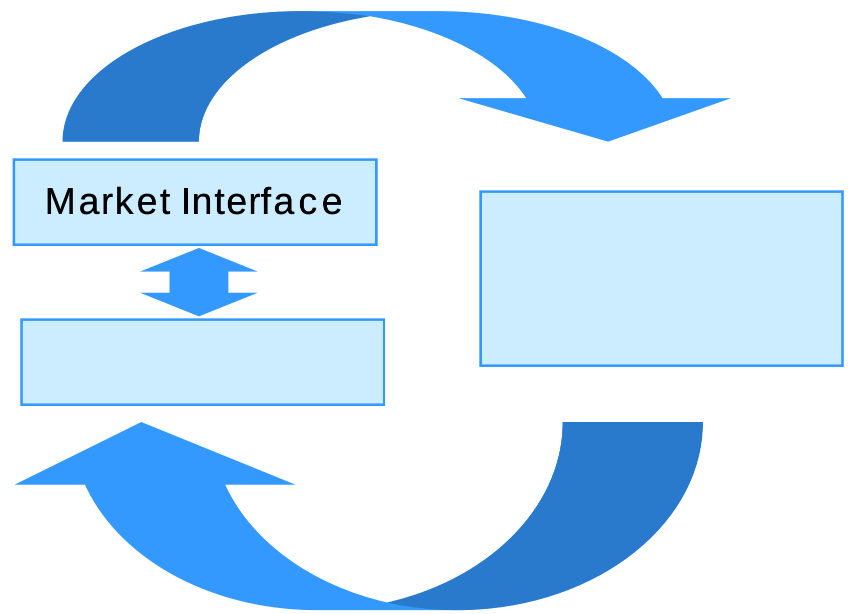


SEMO Systems Overview



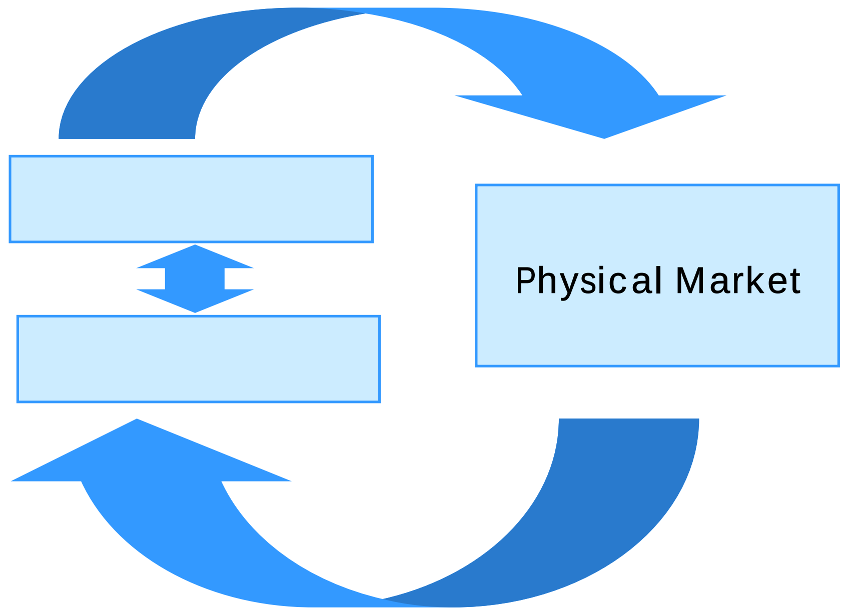
SEMO System Components - 1

- Market Participant Registration
  - Parties, Participants, Units
- Market Participant Interface
  - Registration data, Commercial Offer Data (COD) and Technical Offer Data (TOD)
- Event Manager
  - Manages market timescales



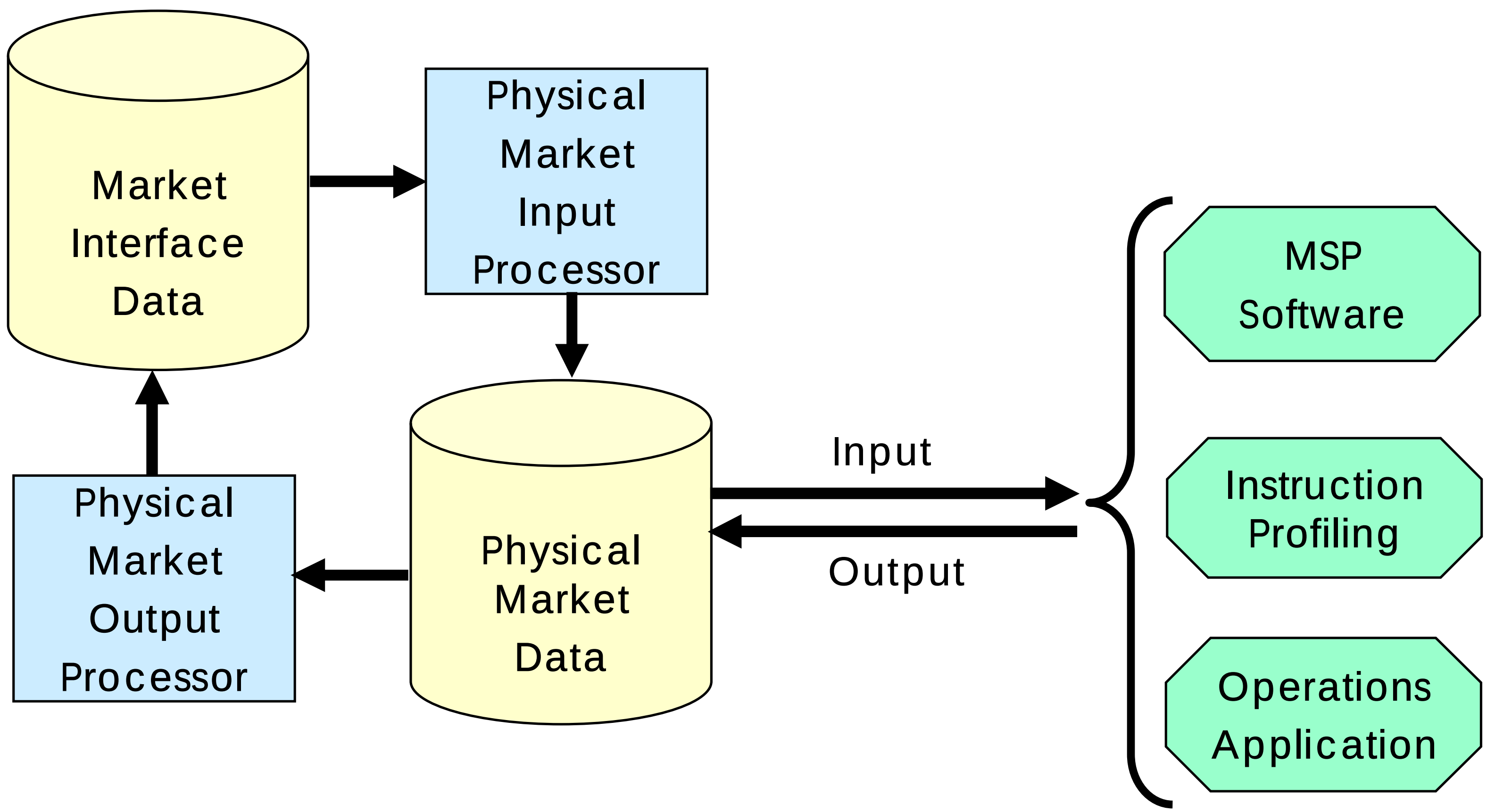
SEMO System Components - 2

- Physical Market
  - Input Data for all Market Scheduling and Pricing (MSP) Runs
  - Ex-Ante Indicative MSP Runs
  - Calculation of System Marginal Price (SMP)
  - Operations Scheduling
  - Instruction Profiling
  - Ex-Post Indicative MSP Runs
  - Ex-Post Initial MSP Runs
  - Posting of information



SEMO System Components - 2

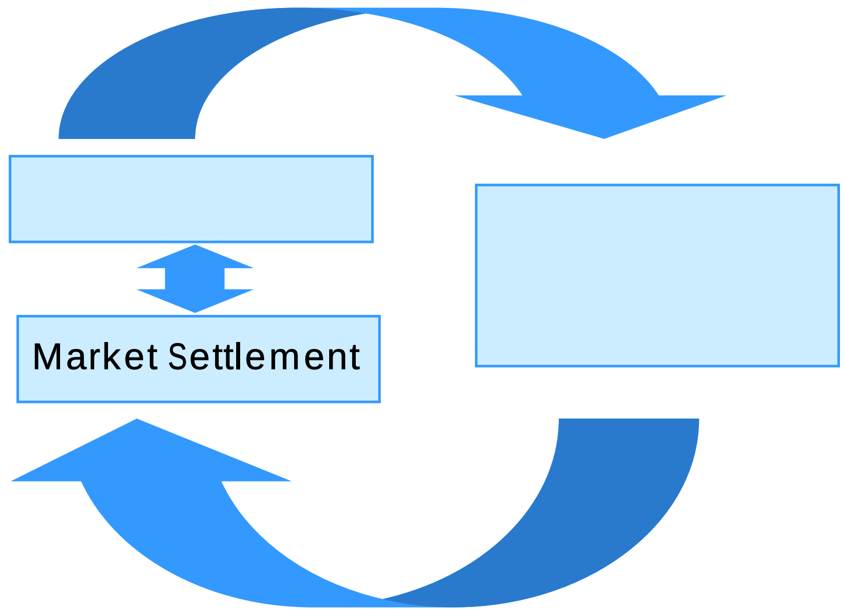
- Physical Market has a number of key components



SEMO System Components - 3

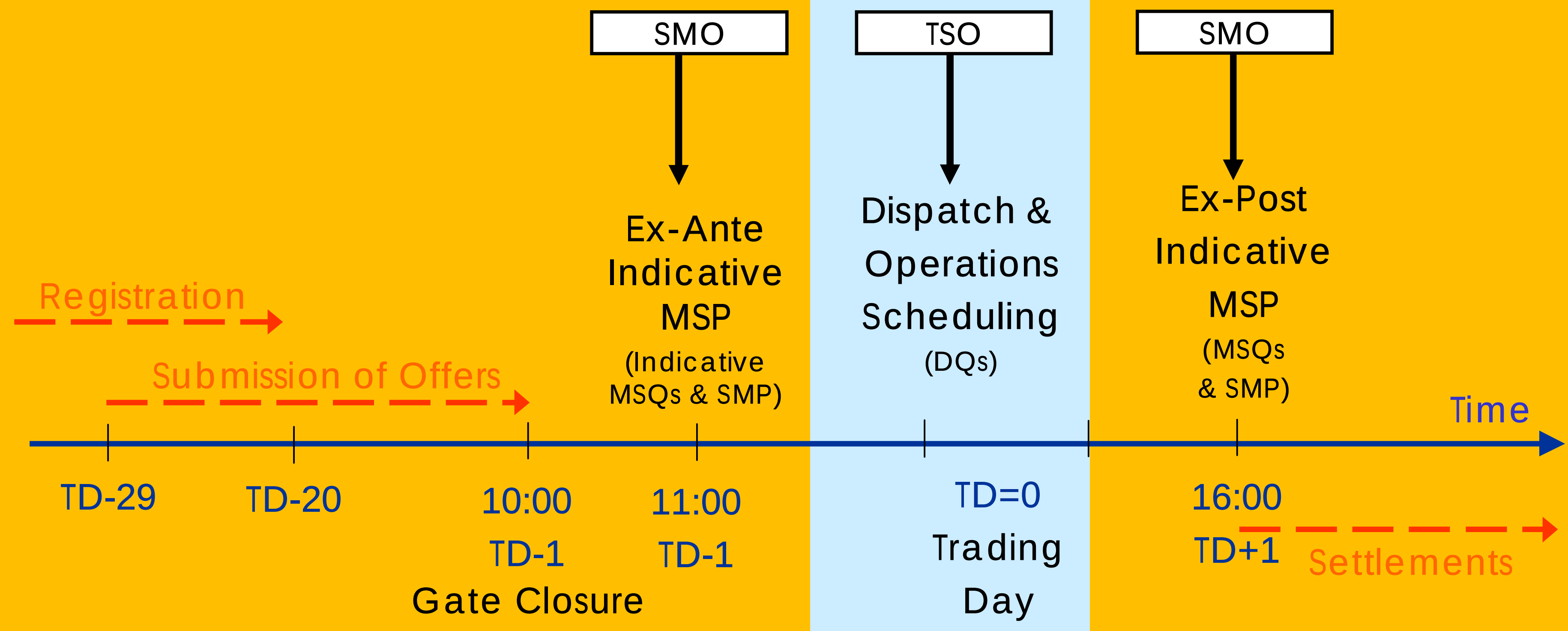
- Market Settlement
  - Calculation of Payments and Charges
  - Billing and Invoicing
  - Meter Data Management
  - Credit and Risk Management

NOTE: Settlement will be covered in a separate course

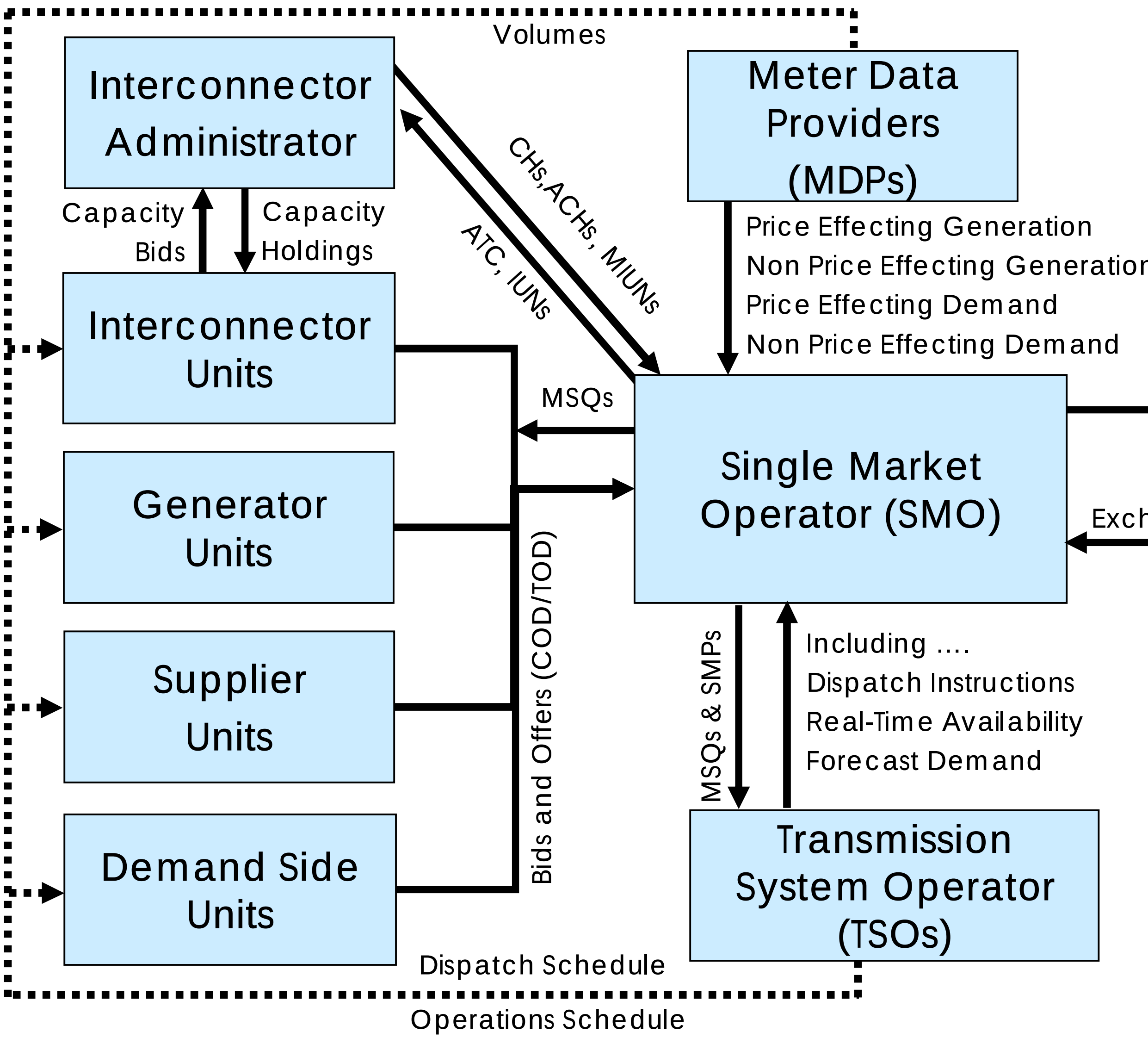


Physical Market Overview

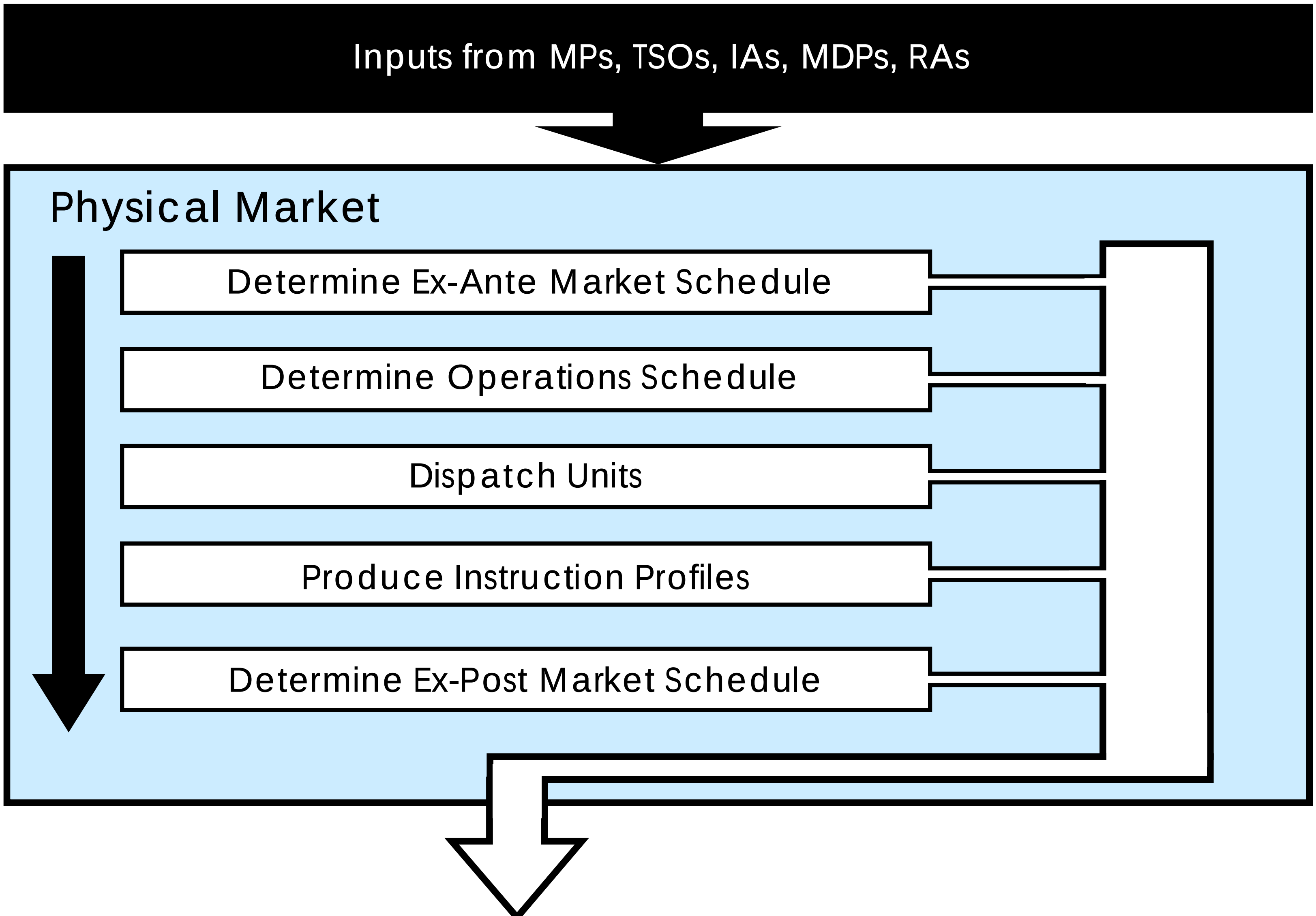
Sequence of PM Processes



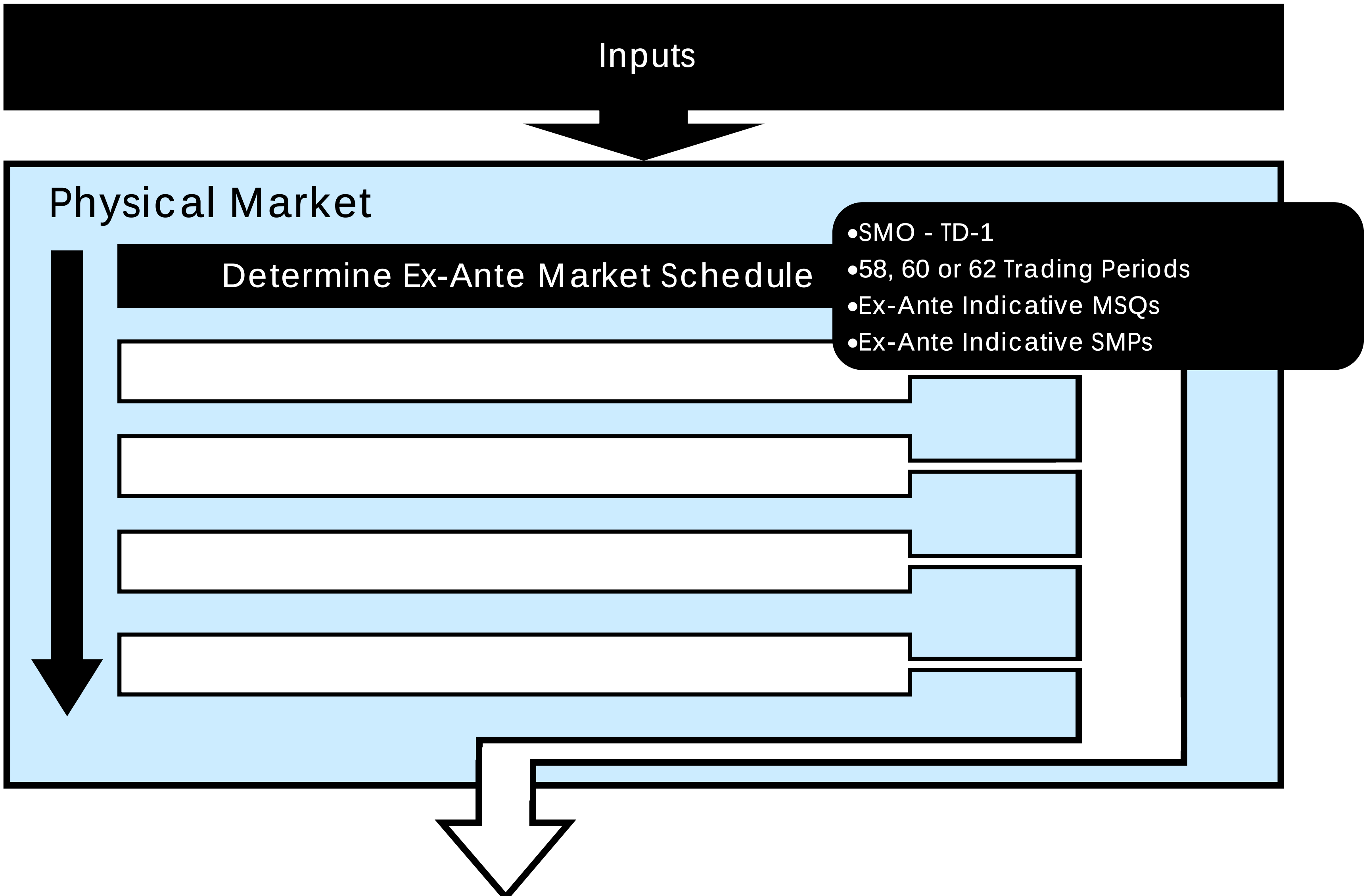
Physical Market – Trading Interactions



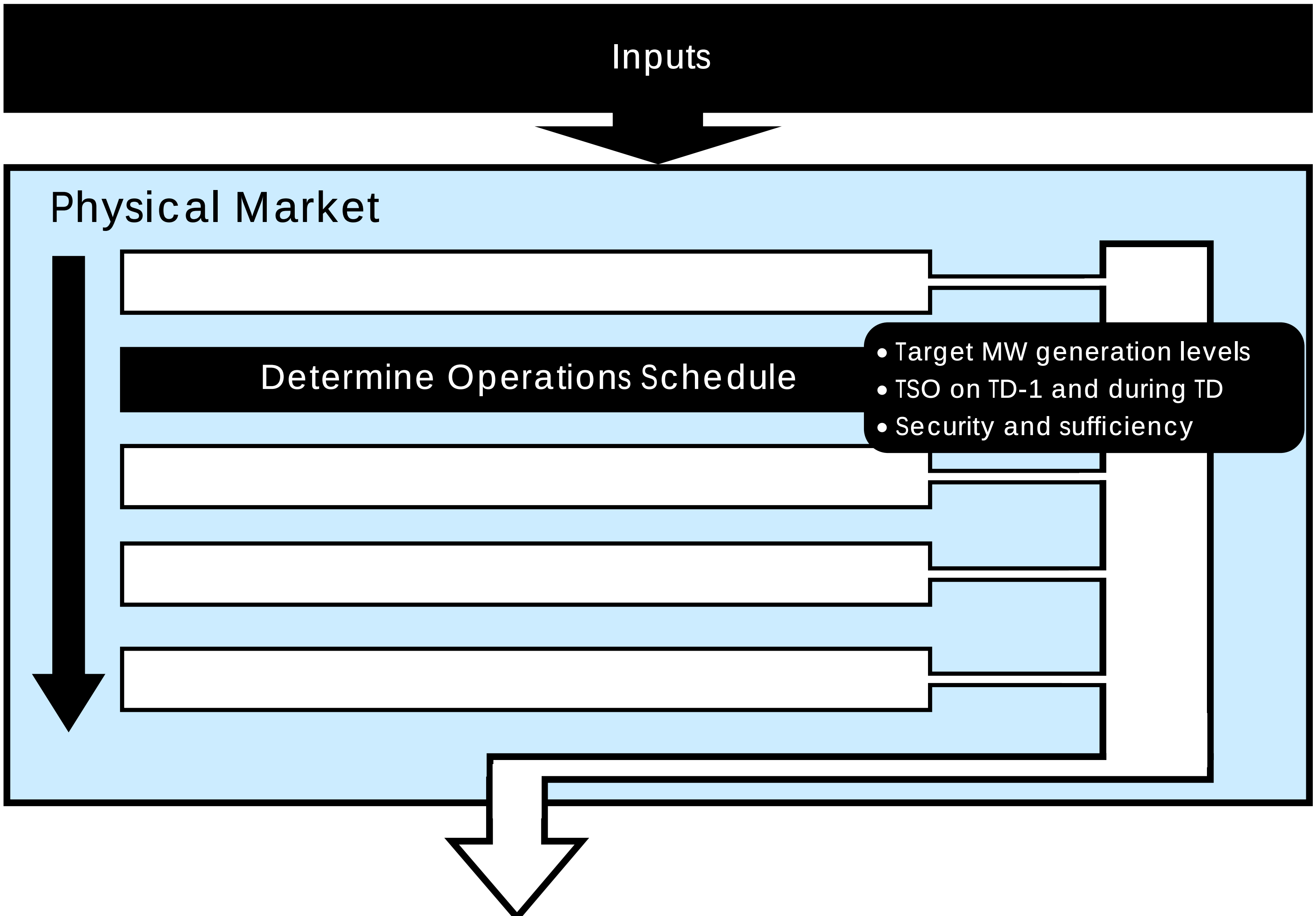
Physical Market Components



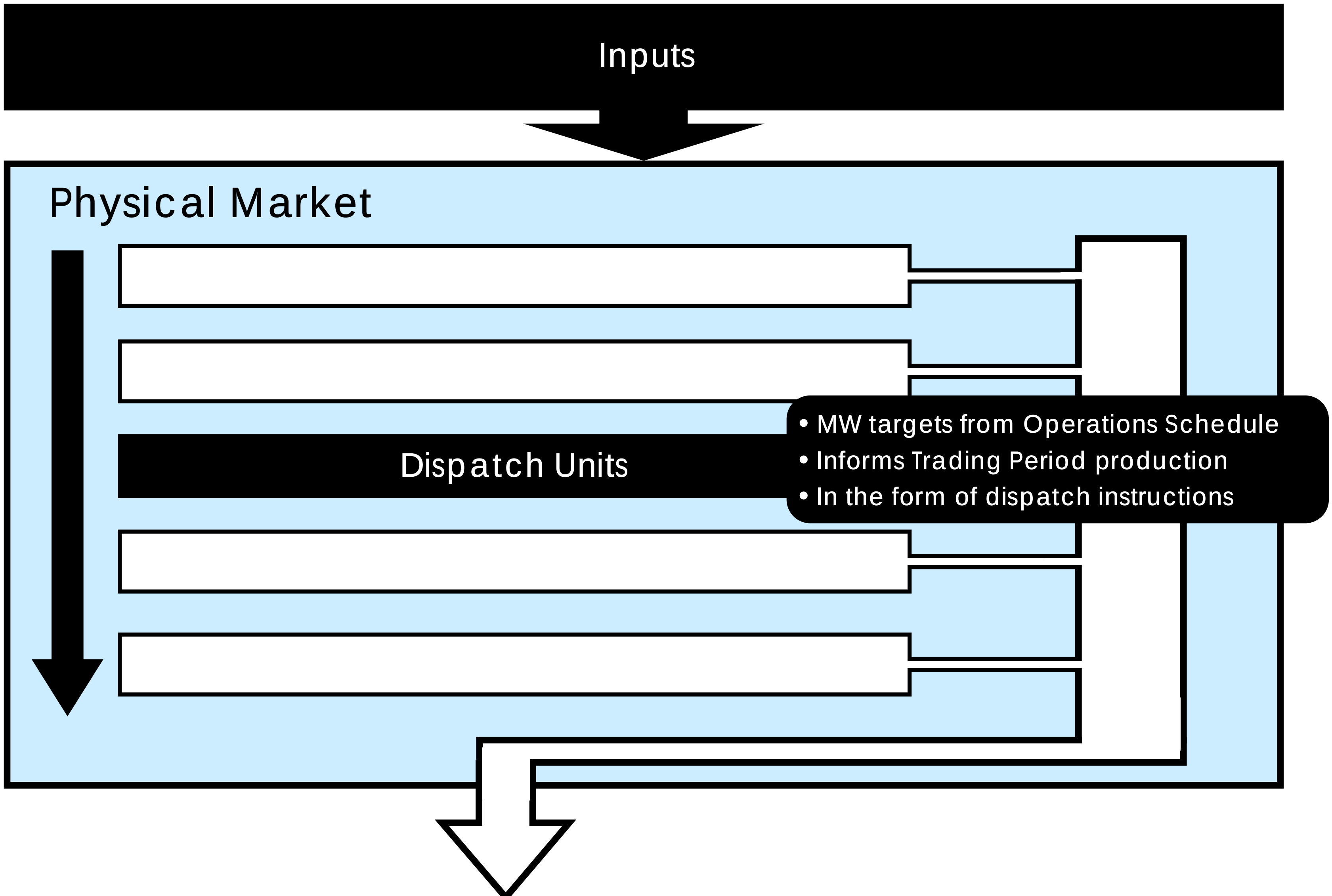
Physical Market Components



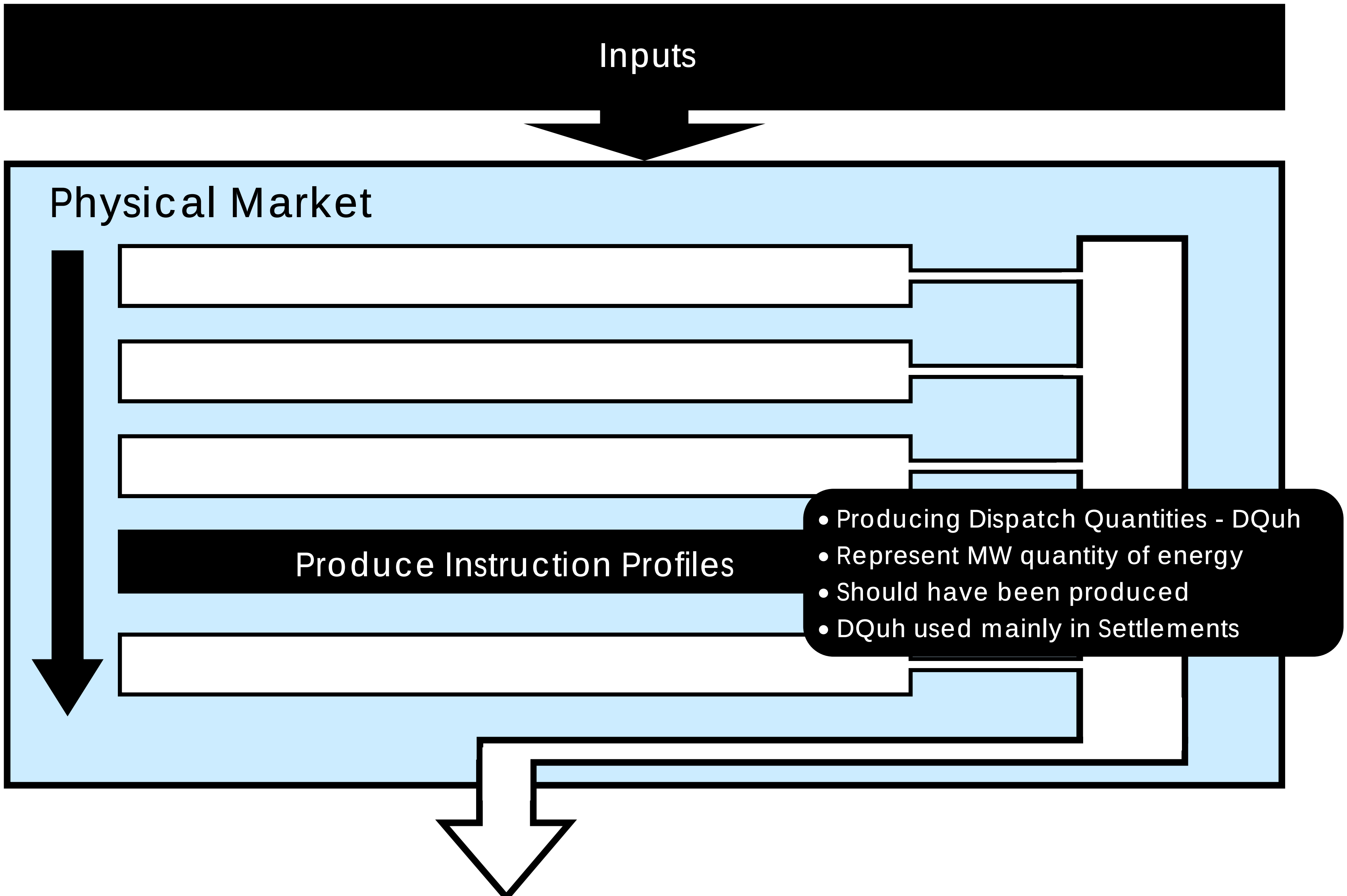
Physical Market Components



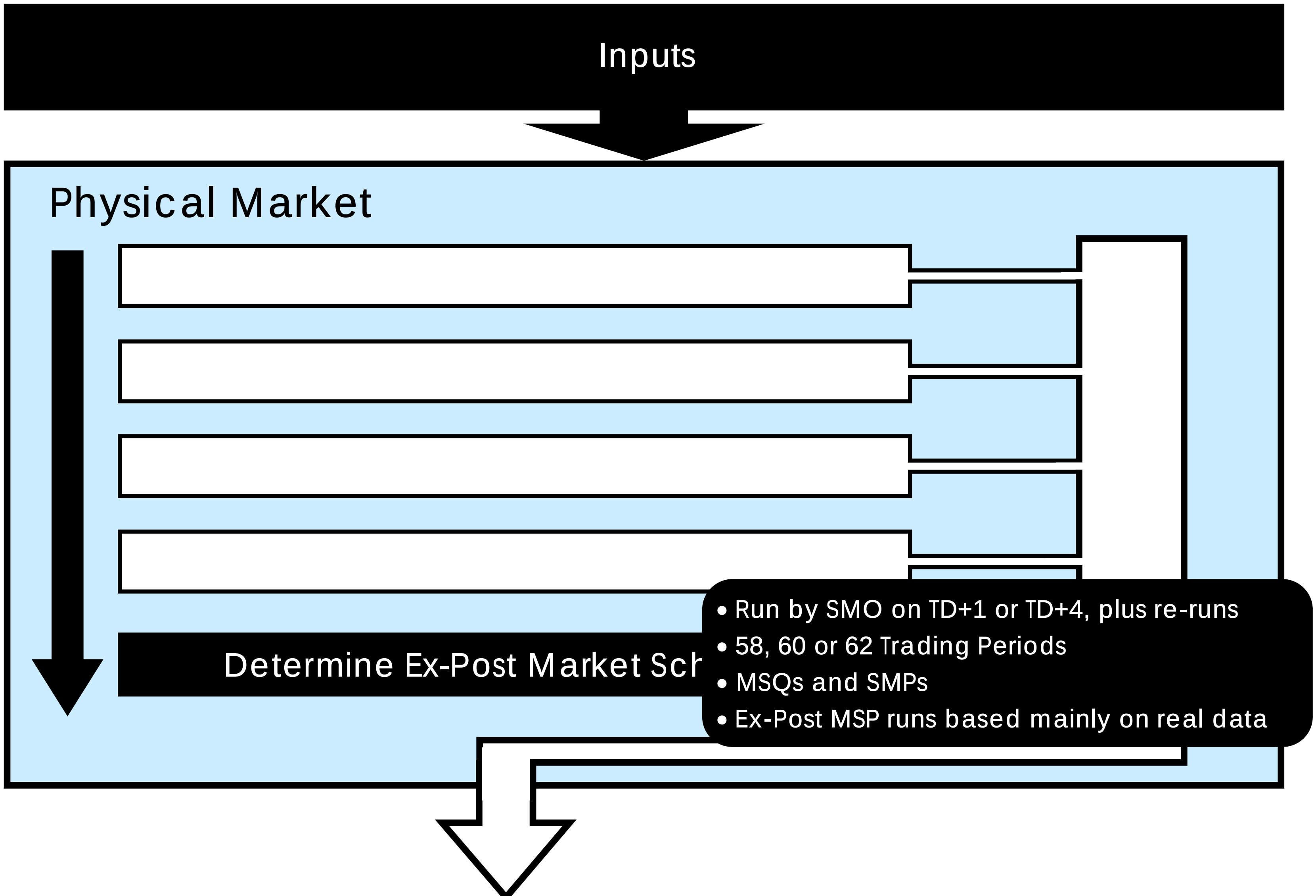
Physical Market Components



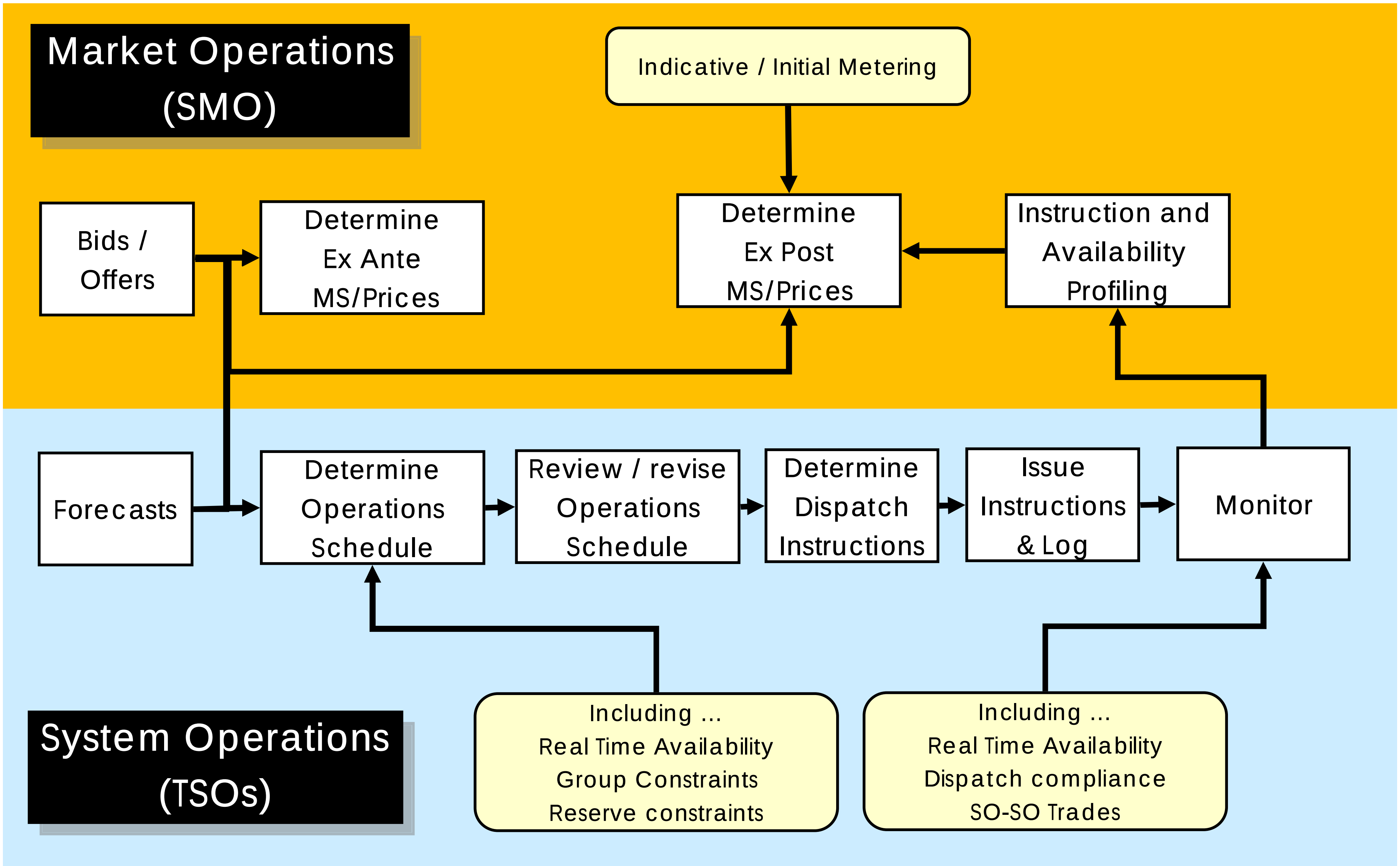
Physical Market Components



Physical Market Components



Markets vs. System Operations



Introduction: Optimisation

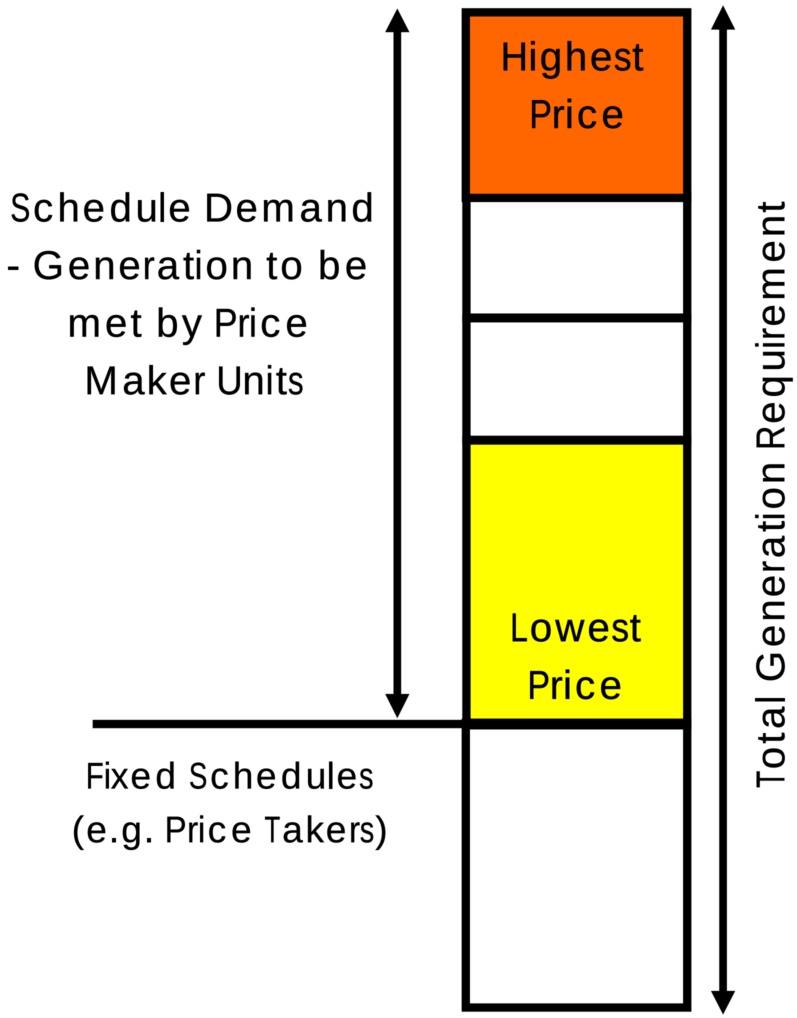
- The MSP Software calculates MSQs (scheduled output) for Generator Units to meet Schedule Demand and the resulting prices of meeting a further 1MW of Schedule Demand (the "variables")

- It does this with the goal of minimising the cost of production of meeting the Schedule Demand and other constraints (the "Objective Function")

- In the SEM, the SMP is then calculated to ensure that Generator costs are recovered.

- It does this subject to a number of key constraints:
  - Sum of MSQs for Price Maker Units = Schedule Demand
  - MSQ must be less than or equal to its availability
  - MSQ must be greater than or equal to Minimum Stable Generation
  - Change in output across time must obey ramp limits
  - Interconnector flow must be within limits (i.e. max, min, ramp rate)
  - Energy scheduled from pump storage units over time must keep the reservoir level within allowable limits
  - Energy limits on Units must be observed

Creating a Market Schedule - Basics



Units scheduled in price order, subject to technical limits:

- Operating Limits
- Time constraints (e.g. warmth dependent start times, min off and min on times)
- Operating modes of units
- Energy costs, including pumped storage
- Resource constraints

Physical Market Optimisation

Determining market schedules – three stages

1. Unit Commitment
   - Determine which units will be committed
   - Determine unit energy schedules
   - Use a least cost approach to meeting Schedule Demand over a fixed Optimisation Time Horizon, given the technical characteristics of Generating Units

2. Economic Dispatch
   - Optimise the unit energy schedules given the unit commitment & set shadow prices

3. System Marginal Price
   - Determine settlement prices which recover start-up and no-load costs
   - Shadow Price + UPLIFT = SMP

The Objective Function

Unit Commitment

- Minimise sum over all periods of:
  - Start Up Costs
  - No Load Costs
  - Generator and Interconnector usage costs
  - Cost of slack variables

Economic Dispatch

- Minimise sum over all periods of:
  - Generator and Interconnector usage costs (based on bids)
  - Cost of slack variables

Cost of slack variables

- Cost of slack variables which allow constraints to be violated if no feasible solution exists. These costs are operator set and will be approved by the Regulators. They apply to:
  - Energy Balance
  - Energy Limits
  - Reservoir Limits
  - Interconnector Ramp Rates

Losses – Transmission and Distribution

Distribution Losses

- Account for pre-submission by all Parties
  - No account of Distrubution Loss Factors taken in SEM systems

Transmission Losses

- Not applied at all in Physical Markets processes
  - MSP Software : Market Schedule Quantities (MSQuh)
  - MSP Software : Price Effecting Metered Generation and Demand (MGuh and MDvh)
  - Instruction Profiling : Dispatch Quantities (DQuh)

- If applied, then MSP Software would be more complex, as bid/offer quantities would have to be by Trading Period, to account for loss factors

- Quantities (MGuh, MDvh, DQuh, MSQuh) in settlement calculations will be loss-adjusted
  - Payments and charges will account for loss factors

Key Data Submission by Price Makers

Inputs depend on Resource Type

Units Categories:

1. Predictable Price Maker
2. Variable Price Maker
3. Predictable Price Taker
4. Variable Price Taker
5. Autonomous Price Taker

Special rules relating to inputs for:

6. Interconnector Units (Predictable Price Makers)
7. Pumped Storage Units (Predictable Price Makers)
8. Energy Limited Units (Variable Price Makers or Variable Price Takers)
9. Wind Power Units (Variable Price Makers or Variable Price Takers)
10. Demand Side Units (Predictable Price Makers)
11. Units Under Test (may not be Pumped Storage Units, Autonomous Generator Units, Interconnector Units, Interconnector Error Units and Interconnector Residual Capacity Units)

Technical Offer Data

Data	EA	EP	N/A
Minimum On-Time	Y	Y	
Maximum On-Time	Y	Y	
Minimum off Time	Y	Y	
MAXGEN			Y
MINGEN			Y
Forecast Availability Profile (Ex-Ante)	Y		
Forecast minimum Stable Generation (Ex-Ante)	Y		
Forecast minimum Output Profile (Ex-Ante)	Y		
Real-Time Availability (Ex-Post)		YP	
Minimum Stable Generation (Ex-Post)		YP	
Minimum output (Ex-Post)		YP	
Start of restricted loading ranges A and B			Y
Firm Access Quantity for Trading Site		YP	
Registered Firm Capacity		YP	
Non-Firm Access capacity		YP	
Non-Firm Access Quantity		YP	
Fixed Unit Load		YP	
Unit Load Scalar		YP	
Priority Dispatch Flag	YP	YP	
Hot Cooling Down Time Boundary	Y	Y	
Warm Cooling Down Time Boundary	Y	Y	
TLAF			Y
Synchronous Start-Up Times (Cold, Warm, Hot)	Y	Y	
Block Load Flag	YP	YP	
Loading Rates 1, 2 and 3 (Cold, Warm, Hot)			Y
Loading up Break Point 1 and 2 (Cold, Warm, Hot)			Y

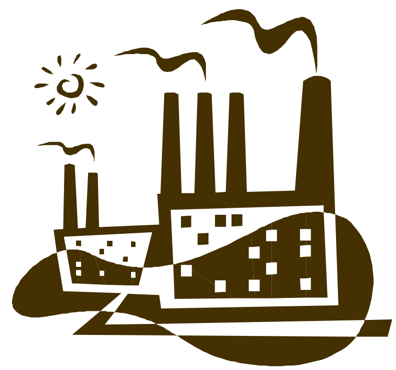
Data	EA	EP	N/A
Soak Times 1 and 2 (Cold, Warm, Hot)			Y
Trigger points 1 and 2 (Cold, Warm, Hot)			Y
End Point of Start-Up Period			Y
Ramp Up Rates 1, 2, 3, 4 and 5	YP	YP	
Ramp Up Break Points 1, 2, 3, 4 and 5	YP	YP	
Ramp Up Rates 1, 2, 3, 4 and 5	YP	YP	
Ramp Down Break Points 1, 2, 3, 4 and 5	YP	YP	
Deloading Rates 1 and 2			Y
Deload Break Pont			Y
Dwell Times 1, 2 and 3	YP	YP	
Dwell Times Trigger Point 1, 2 and 3	YP	YP	
Droop (%)			Y
Short-Term Maximisation Capacity			Y
Reserve			Y
Number of Starts			Y
Number of Run Hours			Y
Following Data for Pump Storage Units Only			
Operational Reservoir Capacity Energy Limit	Y	Y	
Minimuim Reservoir Capacity	Y	Y	
Maximuim Reservoir Capacity	Y	Y	
End Reservoir level	Y	Y	
Pumping load Capacity	Y	Y	
Pumped Storage Cycle Efficiency	Y	Y	
Modes Of Operation			Y
Pumped Storage Target Reservoir Level	Y	Y	
% Pumped Storage Target Reservoir Level	YP	YP	
TSO Reservoir max/min, levels and periods			Y

Note

- "EA" indicates Ex Ante UUC
- "EP" indicates Ex Post UUC
- "N/A" indicates data is not used in the UUC
- "Y" indicates that the data falls into the category.
- "YP" indicates that the data is pre-processed into a new form before being used.

1. Predictable Price Makers

PREDICTABLE PRICE MAKERS submit :



PQ pairs

- Up to 10 per Trading Day
- Strictly monotonically increasing
- Same PQ pairs used in last 6 hours of the Optimisation Time Horizon

Start Up Costs

- Must be 1, up to 3 allowed
- Starting up in hot, warm and cold states
- Will be in £ or €

No Load Cost

- Cost of running at 0MW
- Submitted in £ / € per hour

2. Variable Price Makers

VARIABLE PRICE MAKERS submit :

PQ pairs

- Up to 10 per Trading Day
- Strictly monotonically increasing
- Same PQ pairs used in last 6 hours of the Optimisation Time Horizon

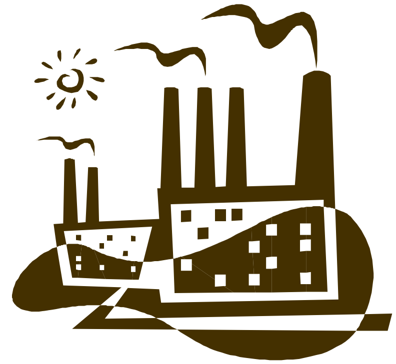
Start Up Costs

- Must be 1, but up to 3 allowed
- Represent costs of starting up in hot, warm and cold states
- Will be in £ or €

No Load Cost

- Cost of running at 0MW
- Submitted in £ per hour or € per hour

3. Predictable Price Takers



PREDICTABLE PRICE TAKERS submit :

Nomination Profile (NQuh)

- The MSP software will set MSQs at the minimum of Min (Nom Avail) and Forecast Availability in Ex Ante
- In Ex Post, based on real-time availability & Actual Output

Decremental Price (DECPuh)

- Must be submitted as zero for each Trading Period

PQ pairs, Start Up Costs, No Load Cost

- Submitted for use in settlement when a unit is constrained up (i.e. when DQuh > MSQuh)

VARIABLE PRICE TAKERS submit :

Nomination Profile (NQuh)

- The MSP software will set MSQs at the minimum of Min (Nom Avail) and Forecast Availability in Ex Ante
- In Ex Post, based on real-time availability & Actual Output

Decremental Price (DECPuh)

- Must be submitted as zero for each Trading Period

Variable Price Takers do not submit PQ pairs, Start Up Costs, No Load Cost

- Variable Price Takers can only be constrained down, so this information is not required

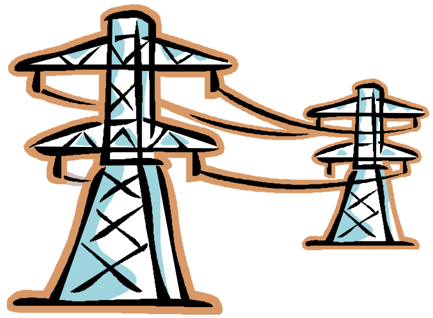
5. Autonomous Price Takers

AUTONOMOUS PRICE TAKERS submit :

No Technical or Commercial Offer Data

- Not scheduled in Ex-Ante Indicative MSP
- MSQ set to Actual Output in Ex-Post MSP
- Settled at Actual Output AOuh

6. Interconnector Units



INTERCONNECTOR UNITS submit :

PQ Pairs

- Up to 10 per Trading Period in the Trading Day
- Must be strictly monotonically increasing

Maximum Import Capacity

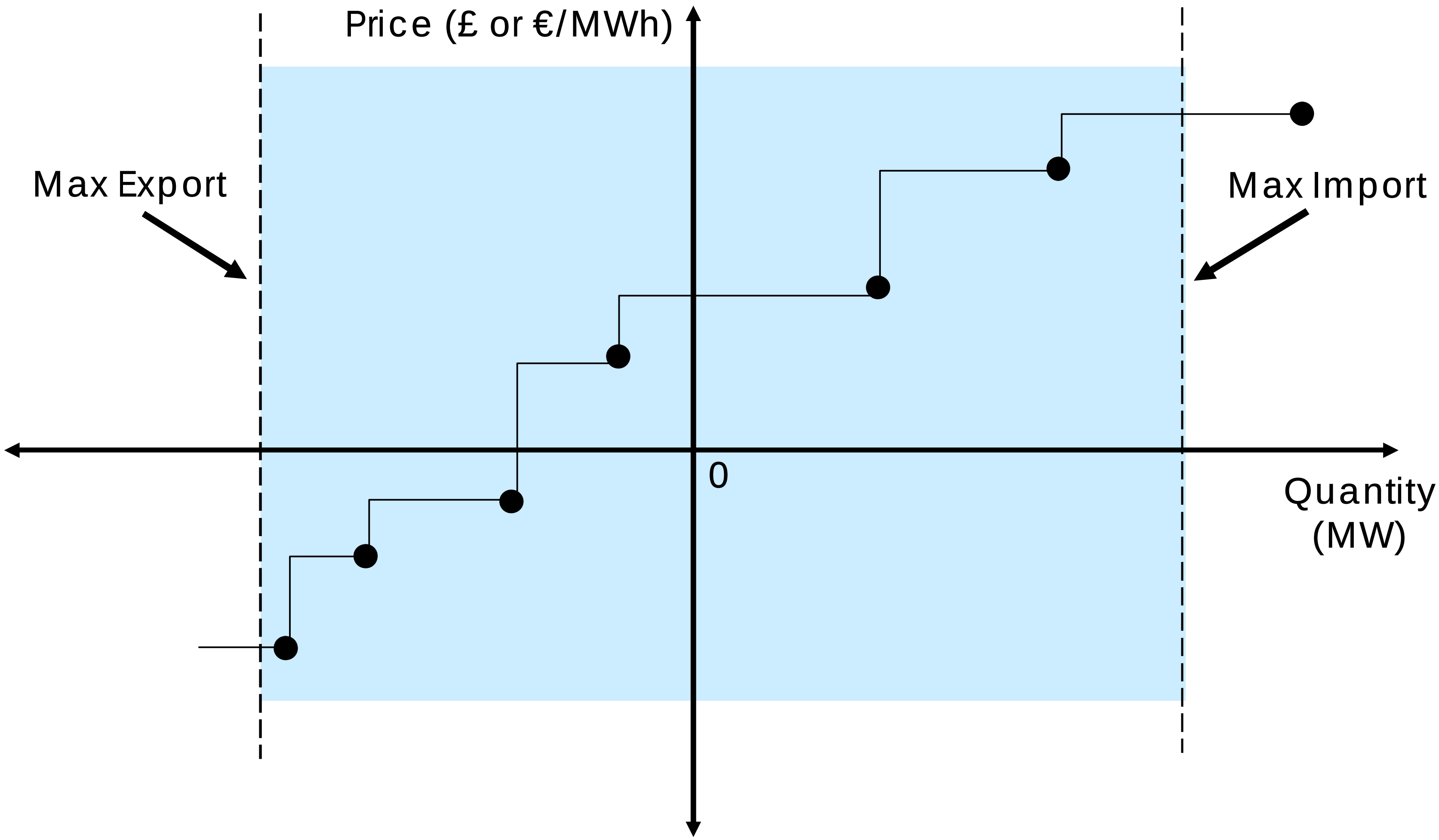
Maximum Export Capacity

- Amount the Interconnector User wishes to trade via an interconnector
- Must be within the bounds of the Active Interconnector Capacity Holdings

Note:

Interconnector Units are "virtual", in that the unit is not registered as such. Instead, the Participant is registered as an interconnector user, then bids on a relevant interconnector, using the above data and subject to its capacity holdings.

6. Interconnector Unit Bid Format – Ex Ante



- These are the price, quantity points specified in the participant's bid

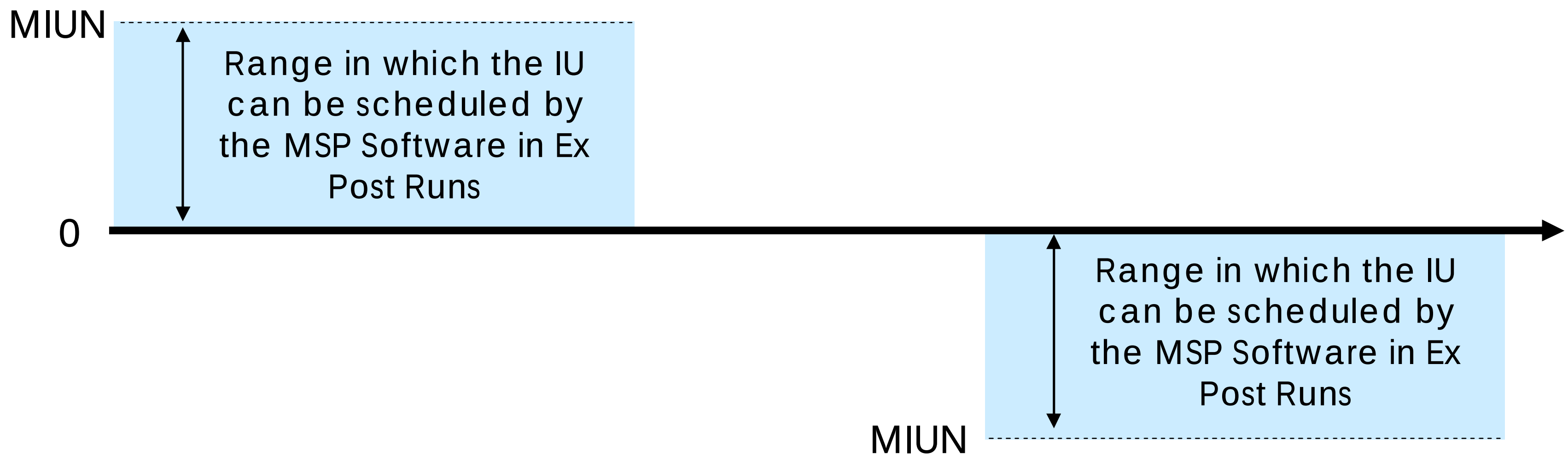
6. Interconnector Unit Bid Format – Ex Post Limits

SCENARIO 1:

If latest MIUN >=0 then …

SCENARIO 2:

If latest MIUN < 0 then …

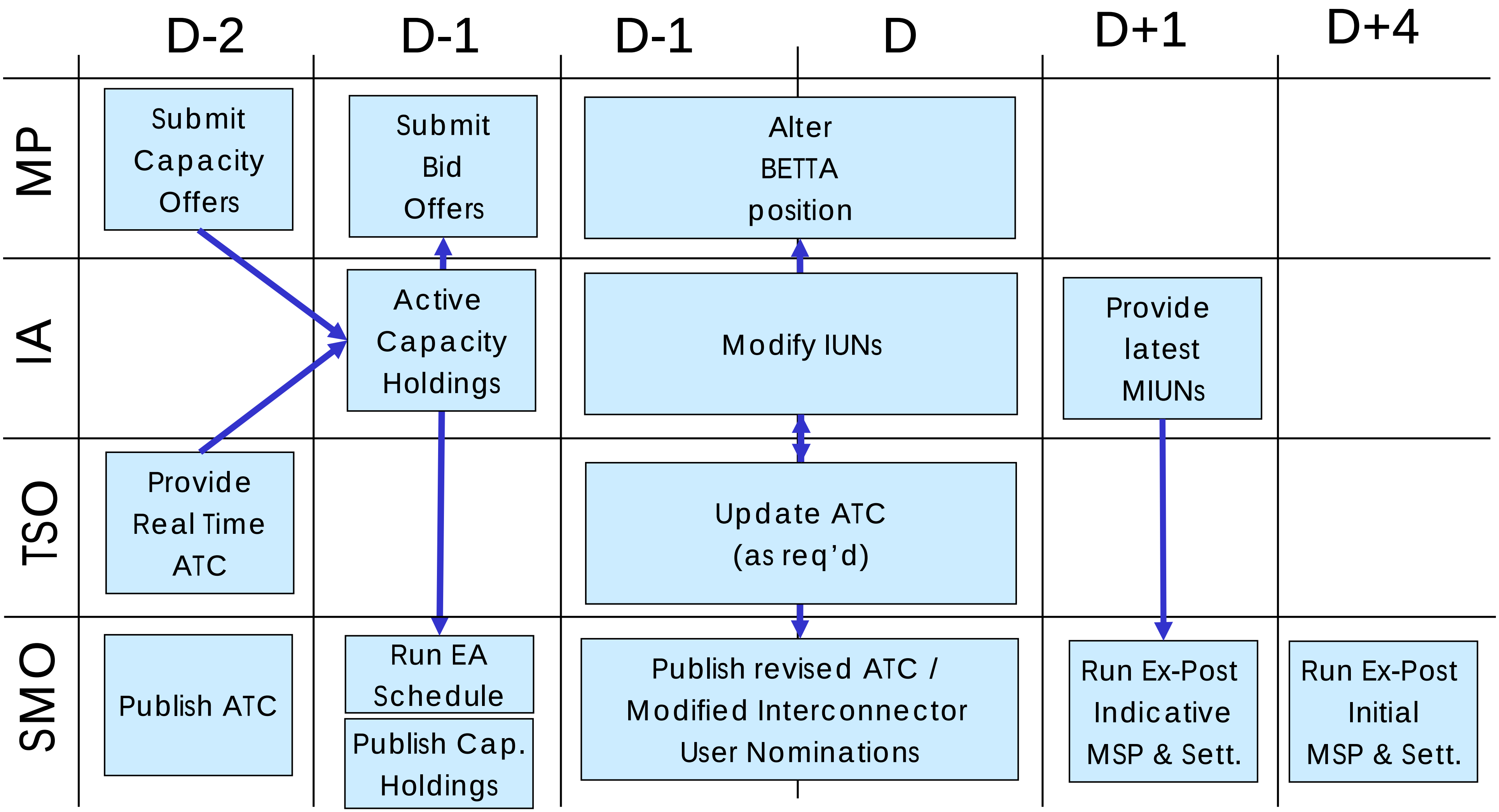


6. Interconnector Roles

Interconnector Users (I/U) are also impacted with various factors which are not directly related to the MSP software:

- I/U cannot be scheduled by the MSP software if no capacity on interconnector
- Capacity Auctions managed and operated by the Interconnector Administrator
- Interconnector Units are scheduled by the MSP software between:
  - Minimum (Active Import Capacity Holding , Maximum Import Capacity) and
  - Minimum in absolute terms (Active Export Capacity Holding, Maximum Export Capacity)

6. High Level Interconnector Process



7. Pumped Storage Units – key inputs

PUMPED STORAGE UNITS submit :

- Maximum Reservoir Capacity
- Minimum Reservoir Capacity
- Target Reservoir Level
- Target Reservoir Level Percentage
- Operational Reservoir Capacity (MWh)
- Pumped Storage Cycle Efficiency (PSCEuh)

Pumped Storage stations offer cycle efficiency and target energy levels.
Note: *Participants may submit the reservoir level from the previous day*

8. Energy Limited Unit

ENERGY LIMITED UNITS submit :

Energy Limit
- Max limit for accumulated MWh energy output
- For a Trading Day based on limitation of fuel source

Energy Limit Period
- Energy Limit Period per Trading Day
- Applies in respect of an Energy Limited Generator Unit
- Start and stop times to be submitted with the bid/offer data to define the period within which that Energy Limited Unit is eligible to run

Energy Limit Factor
- Portion of the Energy Limit for the Trading Day that is applied to determine the Energy Limit for the last six hours of the Optimisation Horizon. The default value is 0.25.

Within the Trading Day, TSOs can accept a single re-declaration.

Note:
Energy Limit Period must be submitted as the entire Trading Day
Energy Limit Factor must be submitted as 0.25

9. Wind Power Units : Price Maker, Price Taker and Autonomous

Relevant TSO will produce a forecast on a Trading Period basis. This information is used differently for each class of Wind Power Unit.

Price Maker wind generation units will submit exactly the same information as for other Variable Price Maker Generating Units:

- Wind forecasts for these units will be generated and submitted by the relevant TSO. However, this information is not used by the MSP software to generate the MSQs for these units.

Price Taker wind generation units:

- Wind forecasts will be used in the Ex-Ante Indicative MSP run, to calculate Schedule Demand. Min(Wind Forecast, Availability) will be used in the calculation of MSQs.

Autonomous wind generation units:

- Wind Forecasts will be used in the Ex-Ante Indicative MSP run, to calculate Schedule Demand. Autonomous Units will not have MSQs in the Ex-Ante Indicative Schedule.

10. Demand Side Units

- Price Quantity Pairs
- Shut-Down Cost
- Decremental Price
- Dispatchable Quantity (MW)
- Non-Dispatchable Quantity (MW)
- Minimum Down Time (h) and Maximum Down Time (h)
- Ramp Up / Down Rate

Note:

Demand Side Units are modelled as Generating Units (only the demand reduction is considered by the MSP software).

11. Units under Tests

- Units Under Test are identified via the UNDER_TEST_START_DATE and UNDER_TEST_END_DATE fields within the registration and technical data.
- On a daily basis a summary will be produced of the Units Under Test and those units which have applied to be under test.
- Those identified as "under test" that are Variable Price Makers are treated like Variable Price Takers
- For those identified as "under test" that are Predictable Price Makers are treated like Predictable Price Takers

This temporary classification will be applied in the MSP software and has special rules for settlement.

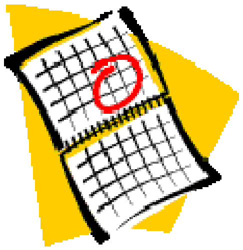
Note:

Pumped Storage Units, Autonomous Units, Netting Generator Units and all types of Interconnector Unit are not permitted to be Under Test.

Market Scheduling

The MSP software determines unconstrained schedules:

- Ex Ante Indicative MSP: TD-1
- Ex Post Indicative MSP: TD+1
- Ex Post Initial MSP: TD+4
- Plus re-runs as required



Note:

- *The MSP Software works the same way for ex ante and ex post runs*
- *The only changes are with respect to how input data is prepared*

- *Calculations required by the T&SC which are performed before or after the MSP Software is solved are not discussed here.*

Scope of the MSP Optimisation

Optimisation Time Horizon

- 6 AM on Trading Day to noon the next day
- 58, 60 or 62 half-hour Trading Periods
- First 46, 48 or 50 Trading Periods are the Trading Day
- Last 6 hours are the 2nd day of the Optimisation Time Horizon

Unit Types Included

- Only considers Price Maker units
- All other unit types have nominations or availability netted from demand (Ex Ante) or are not included (Ex Post, based on metering)

Demand

- Ex Ante
- Ex Post
- The demand is calculated prior to the MSP software being run

Daylight Savings

Short Day (23 hours / 46 Trading Periods)	6 hour Ending Overlap Optimisation Period
Normal Day (24 hours / 48 Trading Periods)	6 hour Ending Overlap Optimisation Period
Long Day (25 hours / 50 Trading Periods)	6 hour Ending Overlap Optimisation Period

Energy Balance and Shadow Prices

For each Trading Period

- Match scheduled supply (in MW) with the Schedule Demand
- Scheduled supply + Under-generation slack – Over-generation slack = Schedule Demand

Over-Generation and Under-Generation slack terms

- Slack terms have very high prices
- Under-generation: slack meets demand that cannot be supplied otherwise
- Over-generation: slack absorbs supply that exceeds demand

Transmission losses are not taken into account by the MSP Software

Shadow price

- MSP determines shadow prices for each period
- Used as an input to the SMP calculation

The Phases of the Problem

	Unit Commitment	Economic Dispatch	SMP Calculation
Purpose	Optimise which units will be committed and their energy schedules	Optimises the unit energy schedules given the unit commitment & sets shadow prices	Determines settlement prices which recover generator start-up and no-load costs.
Unit commitment	ü	Solution as input	Solution as input
Energy balance constraints	ü	ü	
Energy Limits	ü	ü	
Pump storage reservoir limits	ü	ü	
MW Schedules	ü	ü	Solution as input
Shadow Prices		ü	Solution as input
Settlement Prices			ü
Quality of solution	Local optima (may not be best solution)	Global Optima (given commitment)	Global Optima (given commitment)

How Different Types of Units Are Modelled

The MSP only models "generating units"

- "Normal Generators"
  - Start-up costs & no-load costs
  - 10 step bid curve
  - Unit commitment constraints
- Interconnector Units
  - No start-up or no-load costs
  - 10 step bid curves for each Trading Period
    - Can have positive and negative quantities
  - No unit commitment constraints on them
- Demand Side Units
  - "Normal Generators" but without no-load costs
  - Committing this generator is equivalent to curtailing the physical load
- Pump Storage Units
  - No start-up costs, no-loads costs or bids used in MSP Software
  - Positive (generating) or negative (pumping) output.
  - Subject to the normal unit commitment constraints, plus additional constraints

Types of Units

	Type	Scheduled based on
Thermal	PPMG	Bids and Availability
Thermal	PPTG	Nominations and Availability
Pumped Storage	PPMG	Cycle Efficiency and Target Reservoir Levels
Interconnector	PPMG	Bids, Active Capacity Holdings and Max Import/Export Capacities
Demand Side	PPMG	Bids and Availability
Wind Power	VPMG	Bids and Availability
Wind Power	VPTG	Wind Forecast and Availability
Autonomous Wind	APTG	Wind Forecast
Autonomous Non-Wind	APTG	Not Scheduled in Ex Ante MSQ=Actual Output in Ex Post

Bids Submitted by Generators, DSUs and I/C units

Offers can be submitted on any of the 29 days leading up to TD-1 at 1000

- Generator Units:
- Submissions are in the form of Price Quantity Pairs
- 10 Price Quantity Pairs per Trading Day
- Bids are based on short run marginal costs

Pi, Qi	Price	Quantity
1	15 Euro	10MW
2	20 Euro	20MW
3	25 Euro	30MW

Unit has 3 PQ pairs:

- *P1 applies from Q1 to Minimum Stable Generation*
- *P2 applies from Q1 to Q2 (excluding Q1)*
- *P3 applies from Q2 to Q3 (excluding Q2)*
- *P3 also applies up to Maximum Availability*

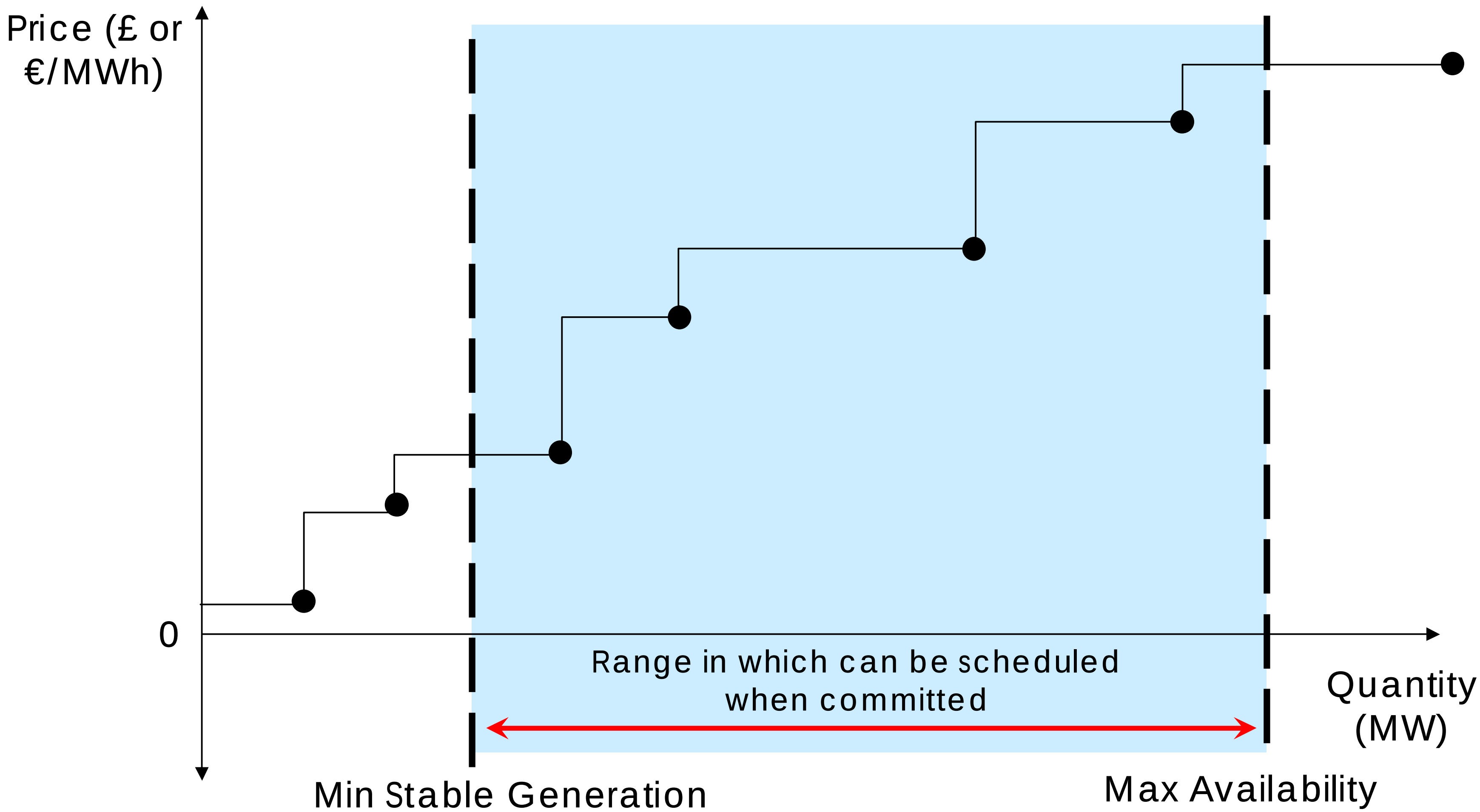
More to Bids and Offers than Price and Quantity

- Other factors which affect how a Unit will be scheduled by the MSP Software:

  - Technical Offer Data
    - Forecast Maximum Availability, Minimum Stable Generation and Minimum Output profiles
    - Energy Limits
    - Data identifying the technical capabilities of the unit
    - E.g. Min. & max. outputs, ramp rates, min. up & down times ....

  - Commercial Offer Data
    - Nomination Profiles for Price Takers or Price Makers under test
    - Decremental Price
    - No Load Costs
    - Start Up Costs

Scheduling Range – Most Units

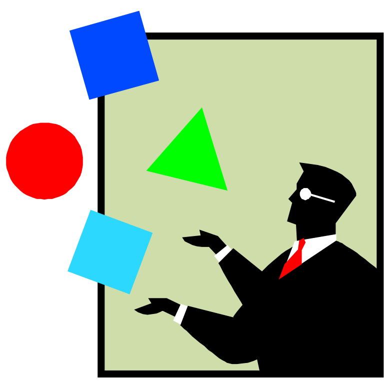


● *These are the price, quantity points specified in the participant's bid*

Tie-Breaking

The MSP Software is able to deal with ties in terms of Unit costs

- Generating and Demand-side Units with the Priority Dispatch flag set to ‘Yes’ will be scheduled
- In the event of a tie between two or more units with Priority Dispatch flag set to ‘Yes’, a random selection for the unit to be scheduled will be adopted.
- A similar process will apply for tied units where the Priority Dispatch flag is set to ‘No’.



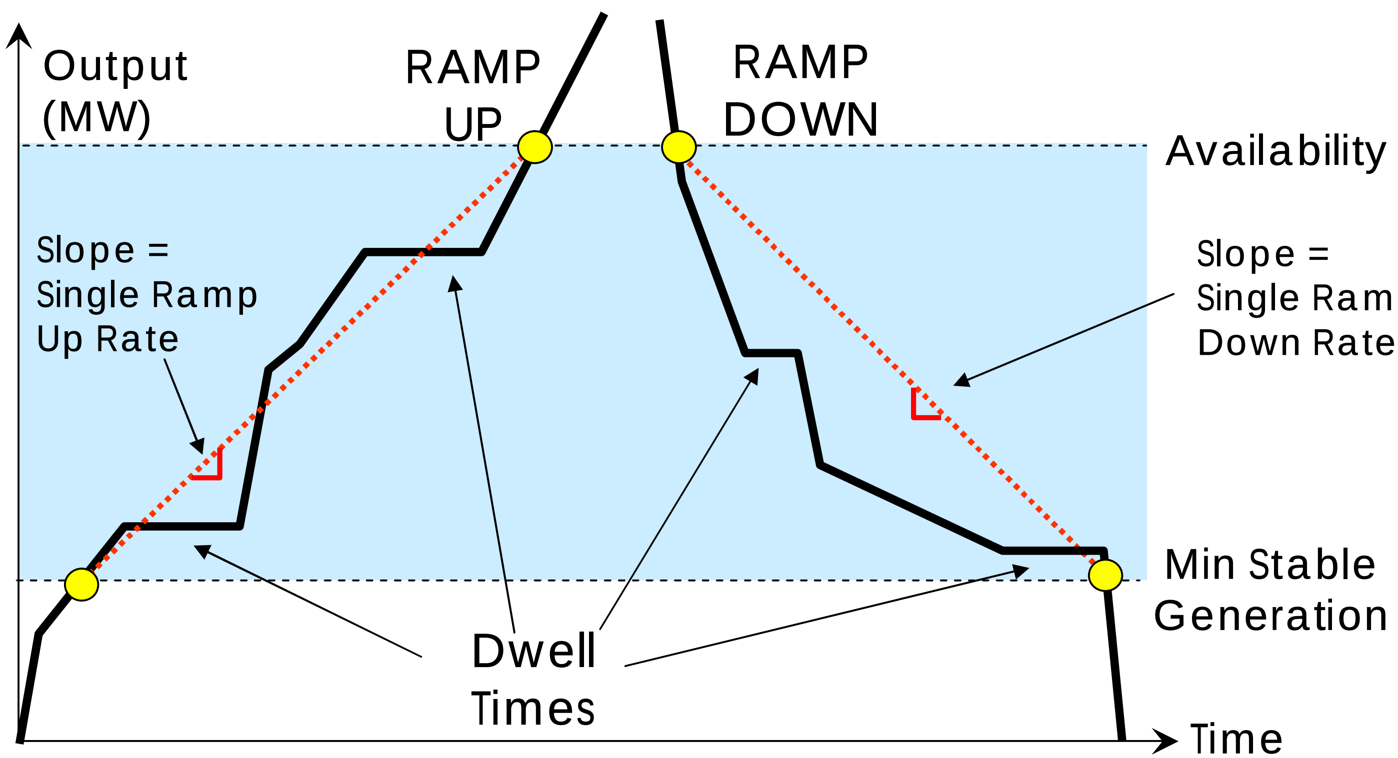
"Normal" Generator Ramp Rates

"Normal" Generator Units can specify:

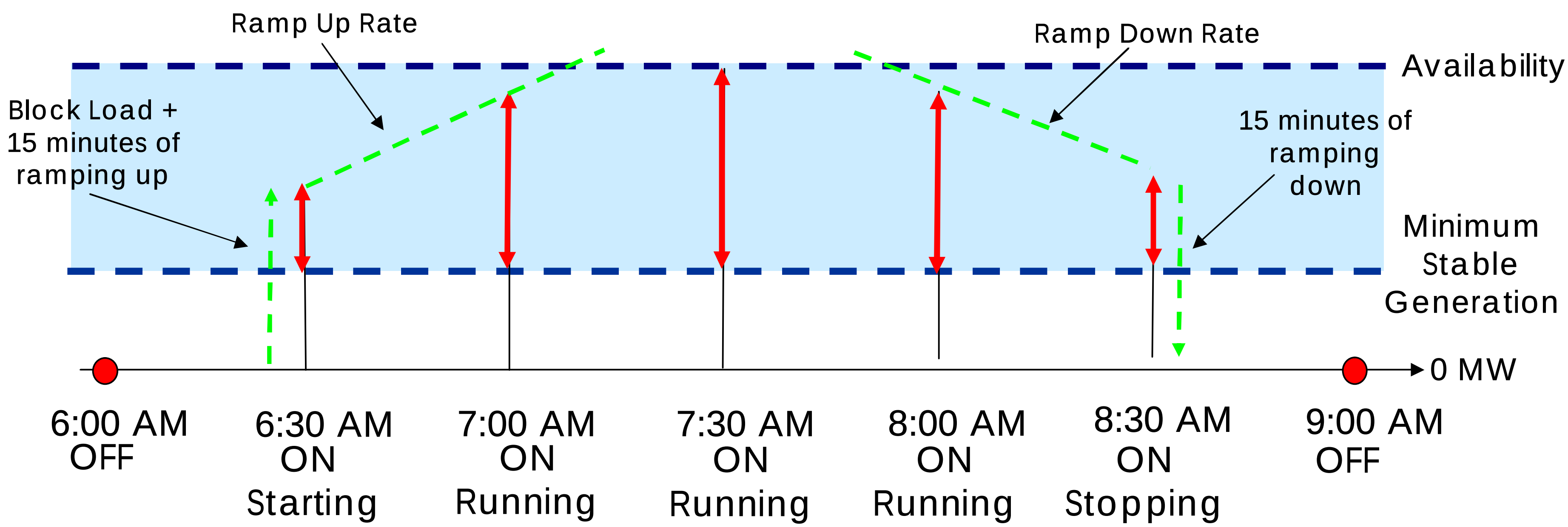
- 5 ramp up rates over 4 ranges and 5 ramp down rates over 4 ranges.
- Dwell times describe output levels at which ramping must pause.

MSP Software uses

- A single ramp rate based on time to ramp between min & max outputs.



“Normal” Generator Ramp Rates



Special Unit Ramp Rates

For some types of units, the single ramp rate is not calculated or applied:

- Single ramp up rate and single ramp down rate for Demand Side Units
- Single Aggregate Interconnector Ramp Rate, which is applied across all Interconnector Units between Trading Periods
- The Ramp Rate for Interconnector Units is set to 99999.9 in MSP Software

Aggregate Interconnector Scheduling

Basic of Interconnector flows

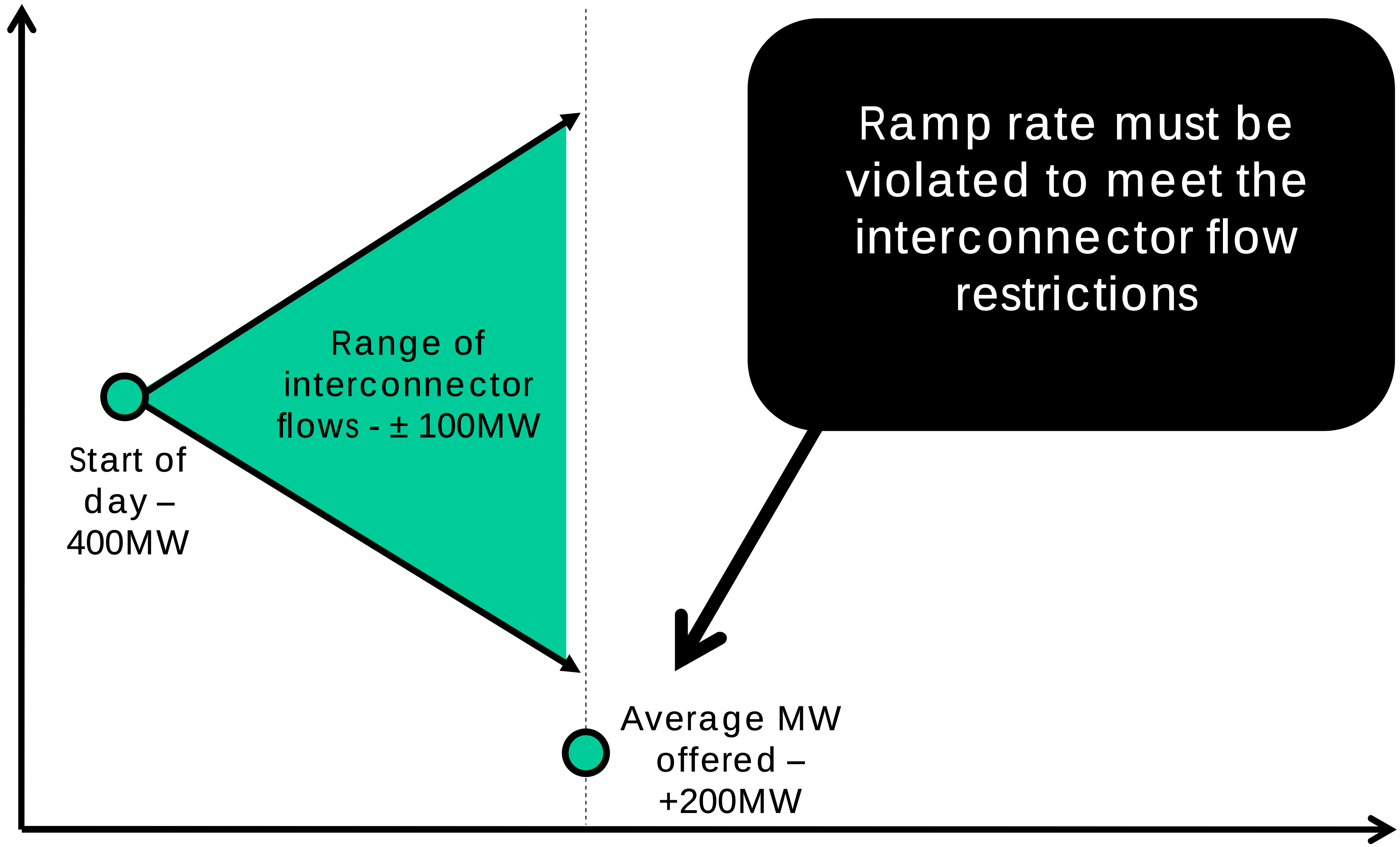
- Imports to SEMO are positive, exports are negative
- The MSP operator sets the initial interconnector flow at the start of each day
- The flow on an interconnector can be positive or negative by Trading Period
- Changes in interconnector flows between periods are constrained by the Aggregate Interconnector Ramp Rate
- There can be positive and negative flows for different Interconnector Units in the same Trading Period

Ramp Rates

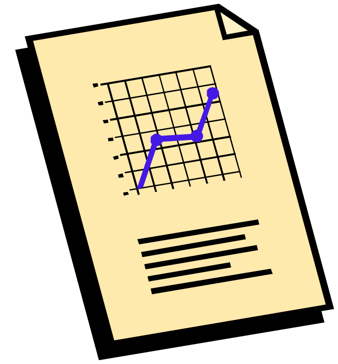
- A single ramp rate, used for ramping up and down (set by Interconnector Administrator) applies to the aggregate rate of change for Interconnector Units

Ramp slack variables exist to resolve any inconsistency between initial flows, ramp limits and the bids.

Aggregate Interconnector Scheduling



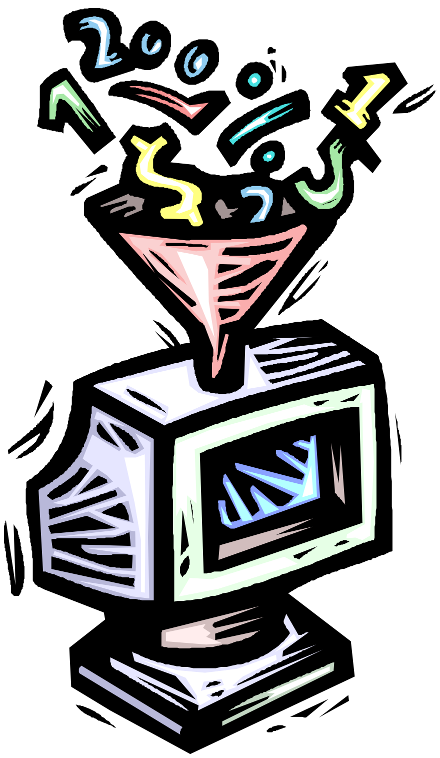
Availability data used in the MSP Software



- Maximum Availability
  - In Ex-Ante, Forecast Availability Profile submitted by the Participant
  - In Ex-Post, calculated using spot availability from TSOs
- Minimum Stable Generation
  - In Ex-Ante, Forecast Minimum Stable Generation Profile submitted by the Participant
  - In Ex-Post, calculated using spot minimum stable generation from TSOs
  - Values may be zero or positive, but cannot be negative
- Minimum Output Profile
  - In Ex-Ante, Forecast Minimum Output Profile submitted by the Participant
  - In Ex-Post, calculated using spot minimum output from TSOs
  - Used for Pumped Storage Units in the MSP Software

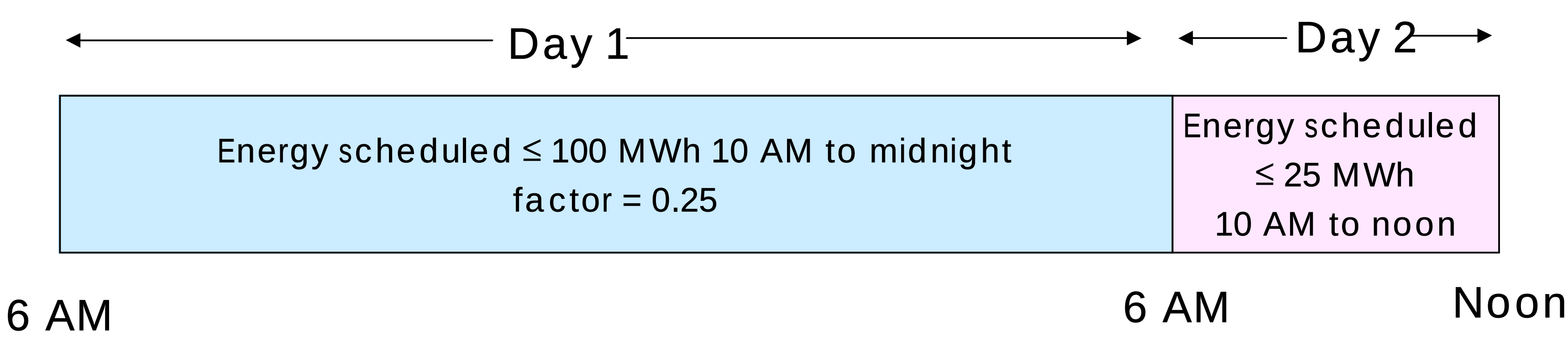
Some other unit data

- Minimum On Time
- Maximum On Time
- Minimum Off Time
- Hot Cooling Down Time Boundary
- Warm Cooling Down Time Boundary
- Synchronous Start-Up Times for Cold, Warm and Hot States
- Block Load Flag
- Block Loads (for Hot, Warm and Cold states)

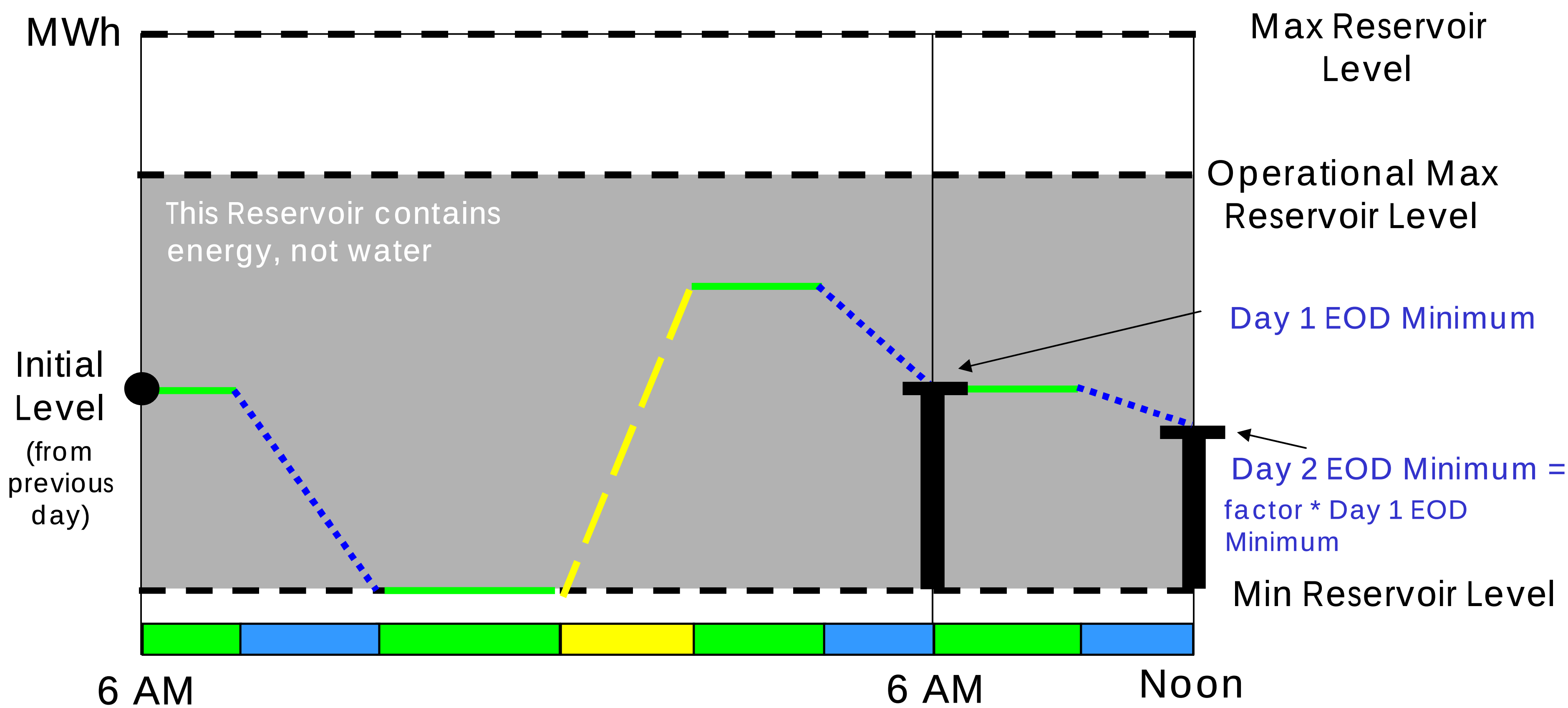


Upper bound constraints applied to relevant hydro units

- Participant (for an Energy Limited Unit) specifies:
- Day 1 energy limit
- Day 2 energy limit

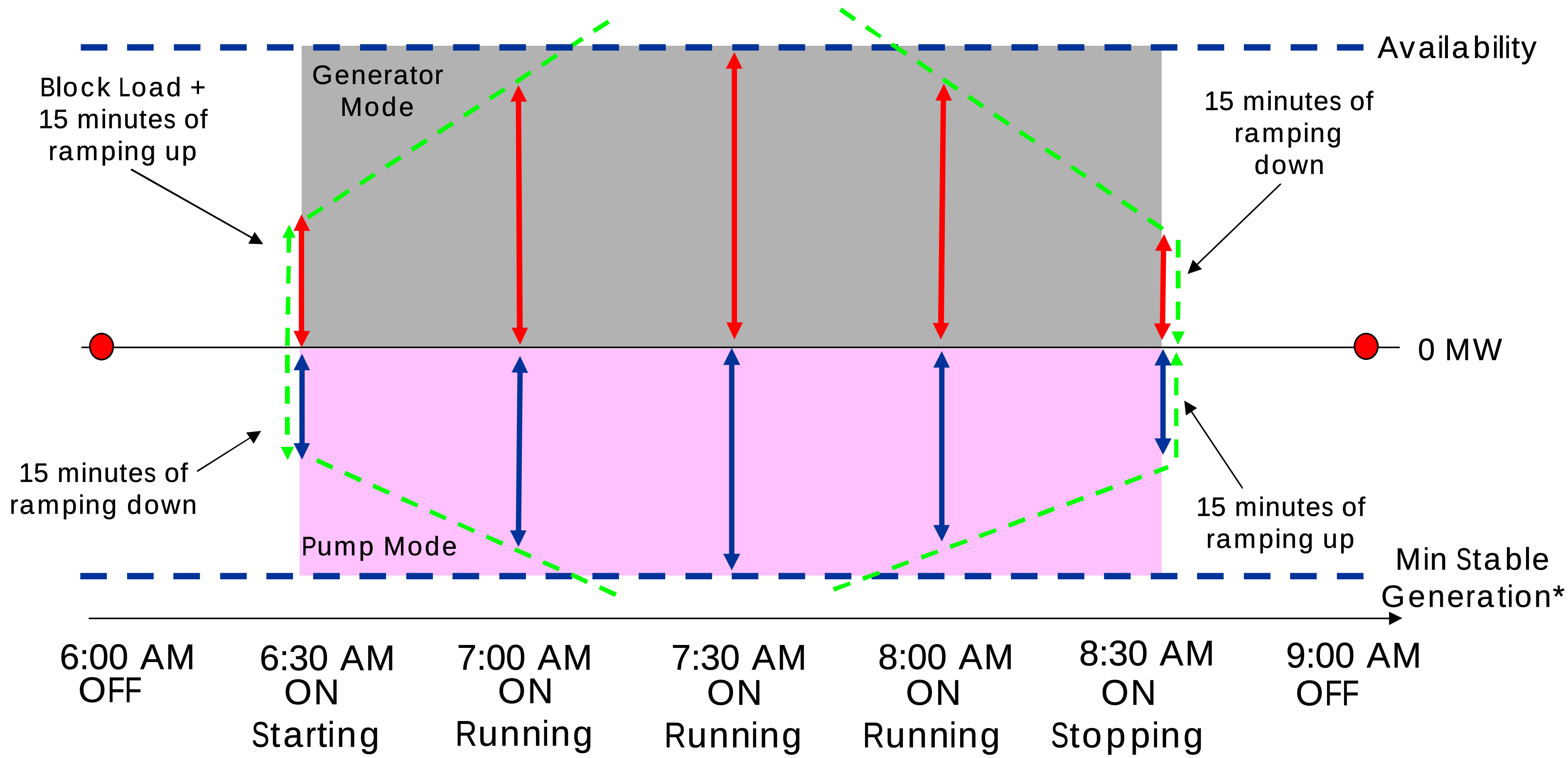


Reservoirs and Pump Storage Generators



- No generation or pumping
- Generation (high relative price). 1 MWh of generation reduces the reservoir by 1 MWh
- Pumping (low relative price). 1 MWh of pumping increases the reservoir by 1 MWh * PSCEuh

Pumped Storage Units and Availability

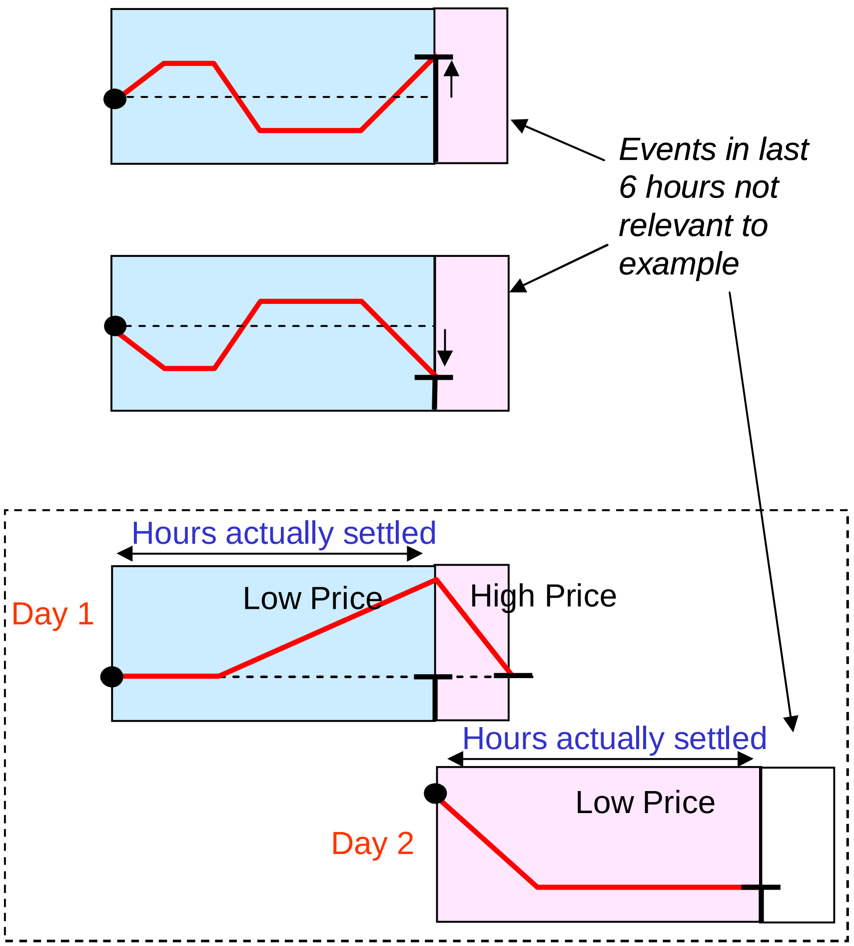


When to Schedule Pumped Storage Units

The MSP Software will tend to schedule pump units so that revenue from energy sales offsets the cost of pumping over the Optimisation Time Horizon.

But:

- If end of day minimum reservoir level > starting level, Unit will be a net consumer
- If end of day minimum reservoir level < starting level, Unit is a net supplier of energy
- If the conditions are bad for generating on day 1 and good early in day 2, the MSP could drive up the reservoir level on day 1 then run it down again on day 2
  - Units will be a net consumer on day 1.
  - On the next trading day prices may not justify such a high reservoir level, hence it theoretically has some risk exposure.

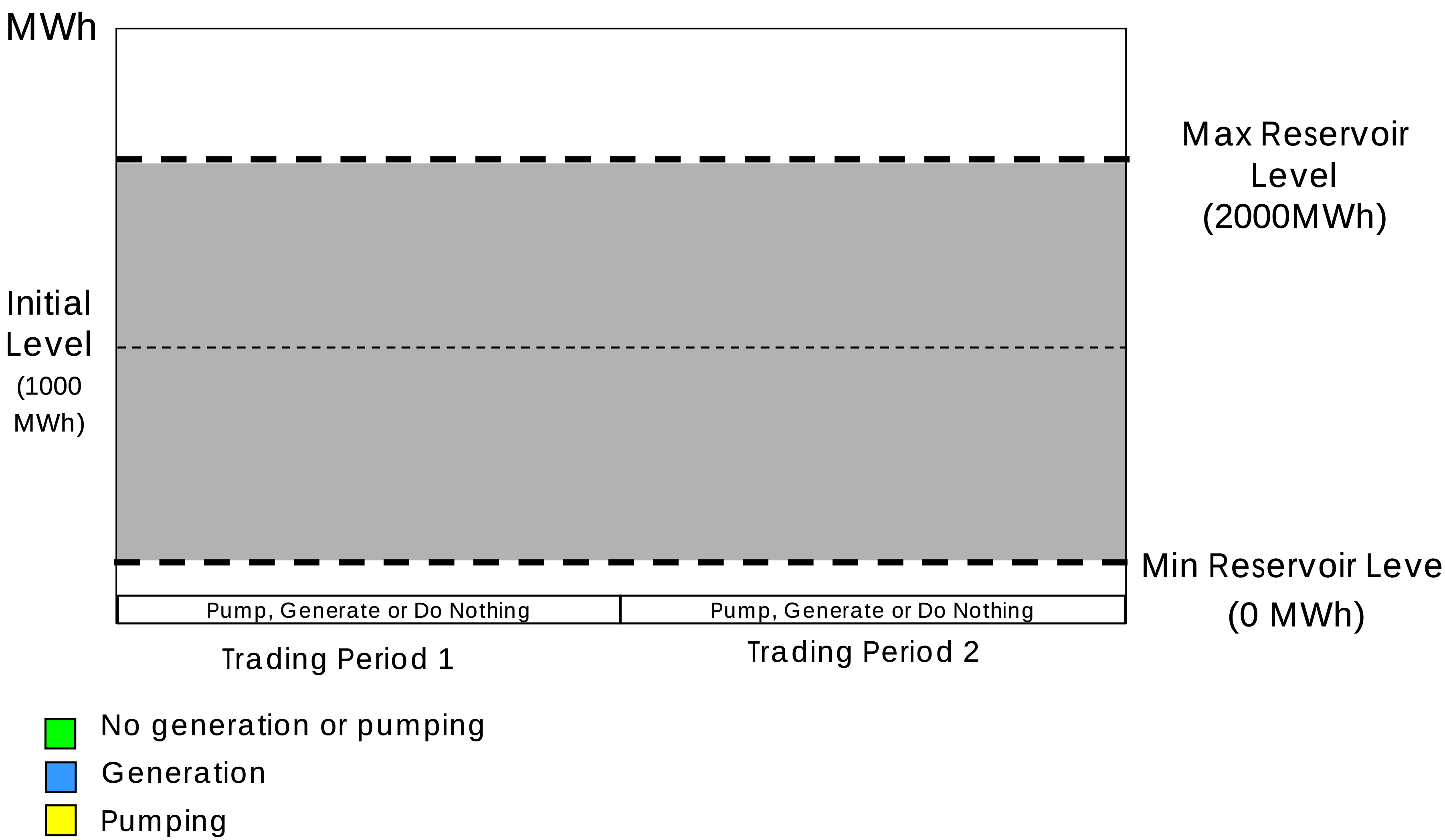


Pumped Storage Example

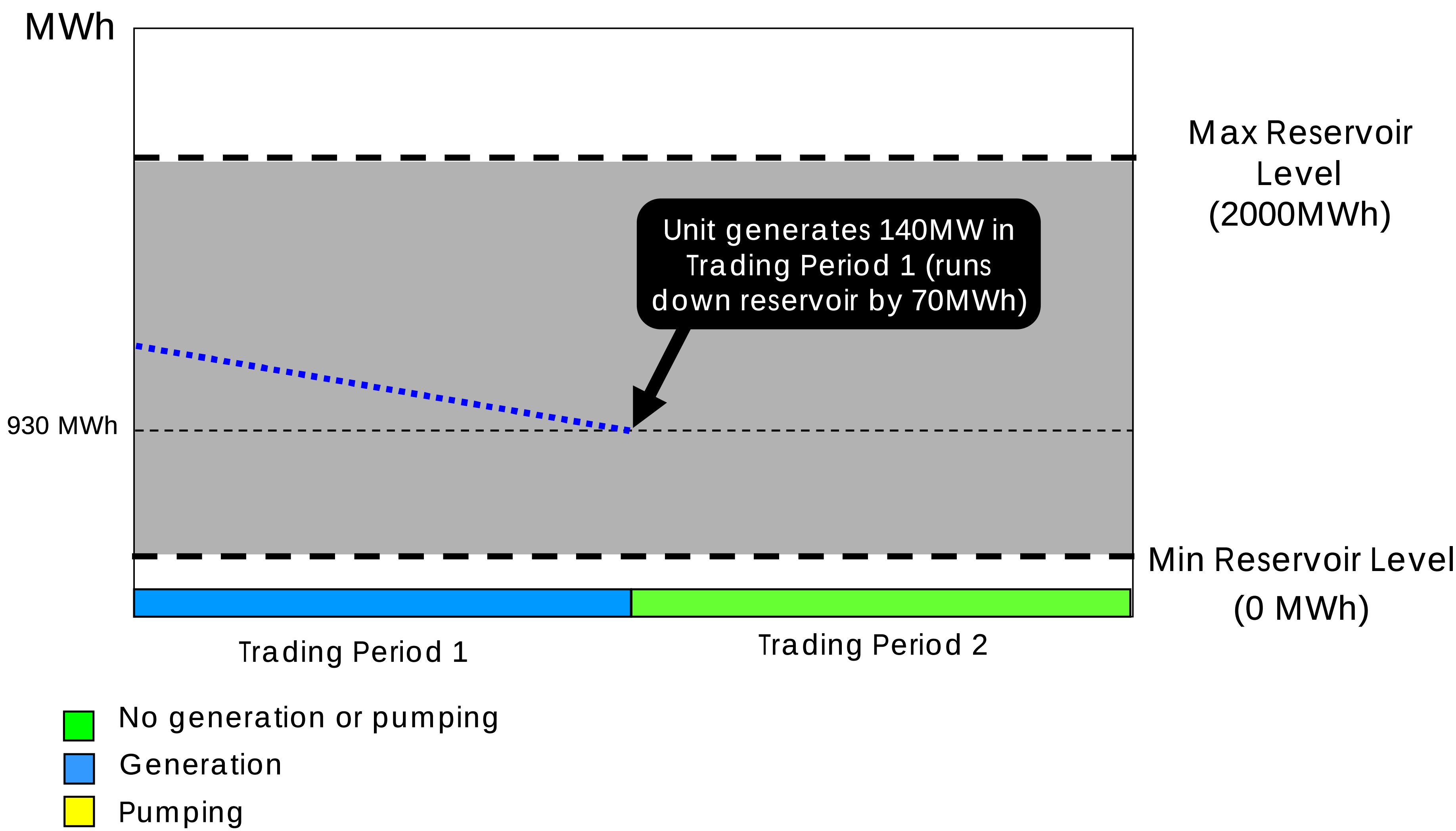
Data

- Initial reservoir level = 1000 MWh
- Generator capacity = 200 MW
- Pump capacity = 200 MW
- Pump efficiency = 0.7
- End target = 1000 MWh
- Min and Max Reservoir limits = 0 and 2000 MWh
- Day has 2 periods (instead of 60)
  - Period 1 price = €80/MWh
  - Period 2 price = €30/MWh

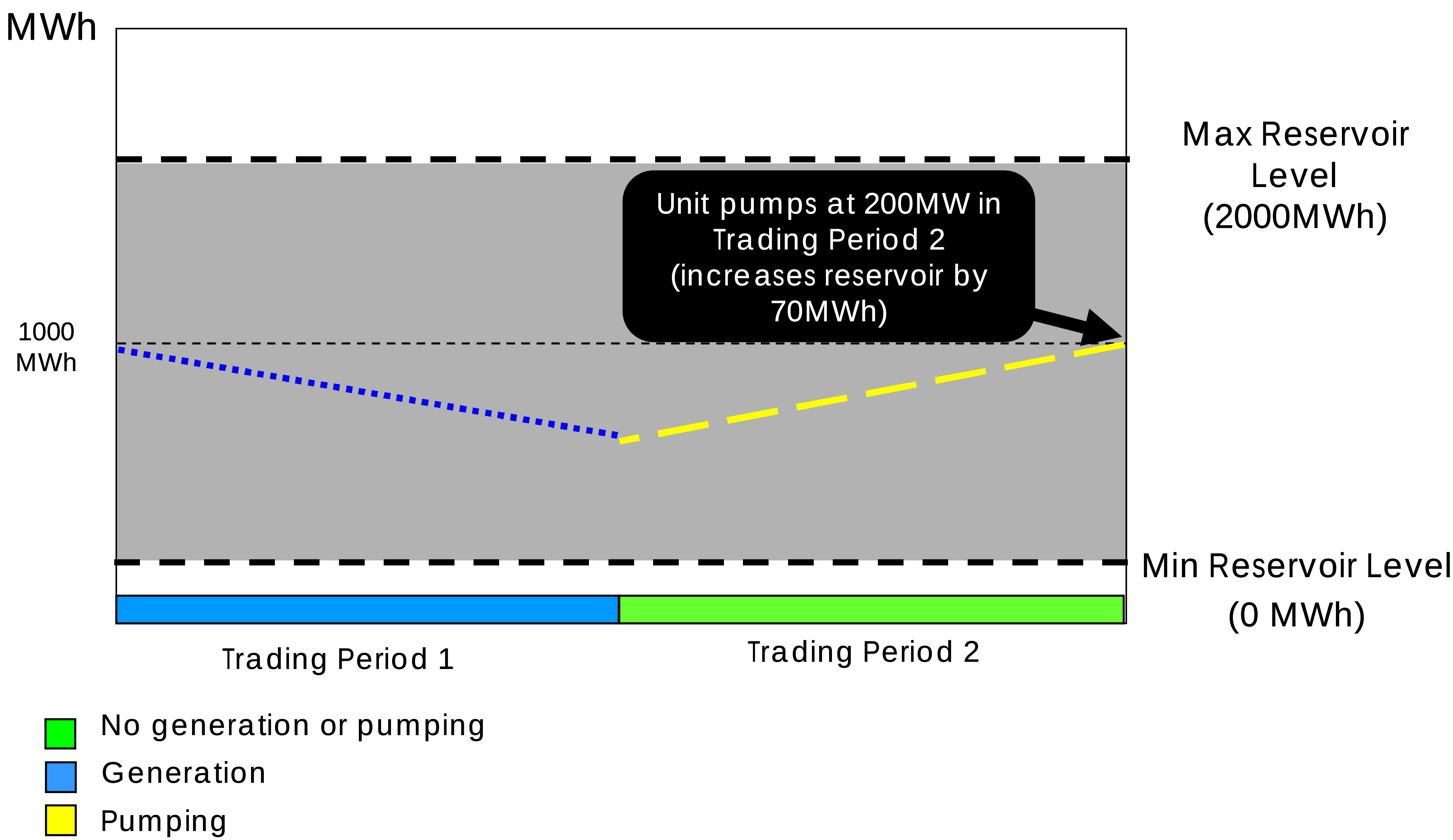
Pumped Storage Example



Pumped Storage Example



Pumped Storage Example



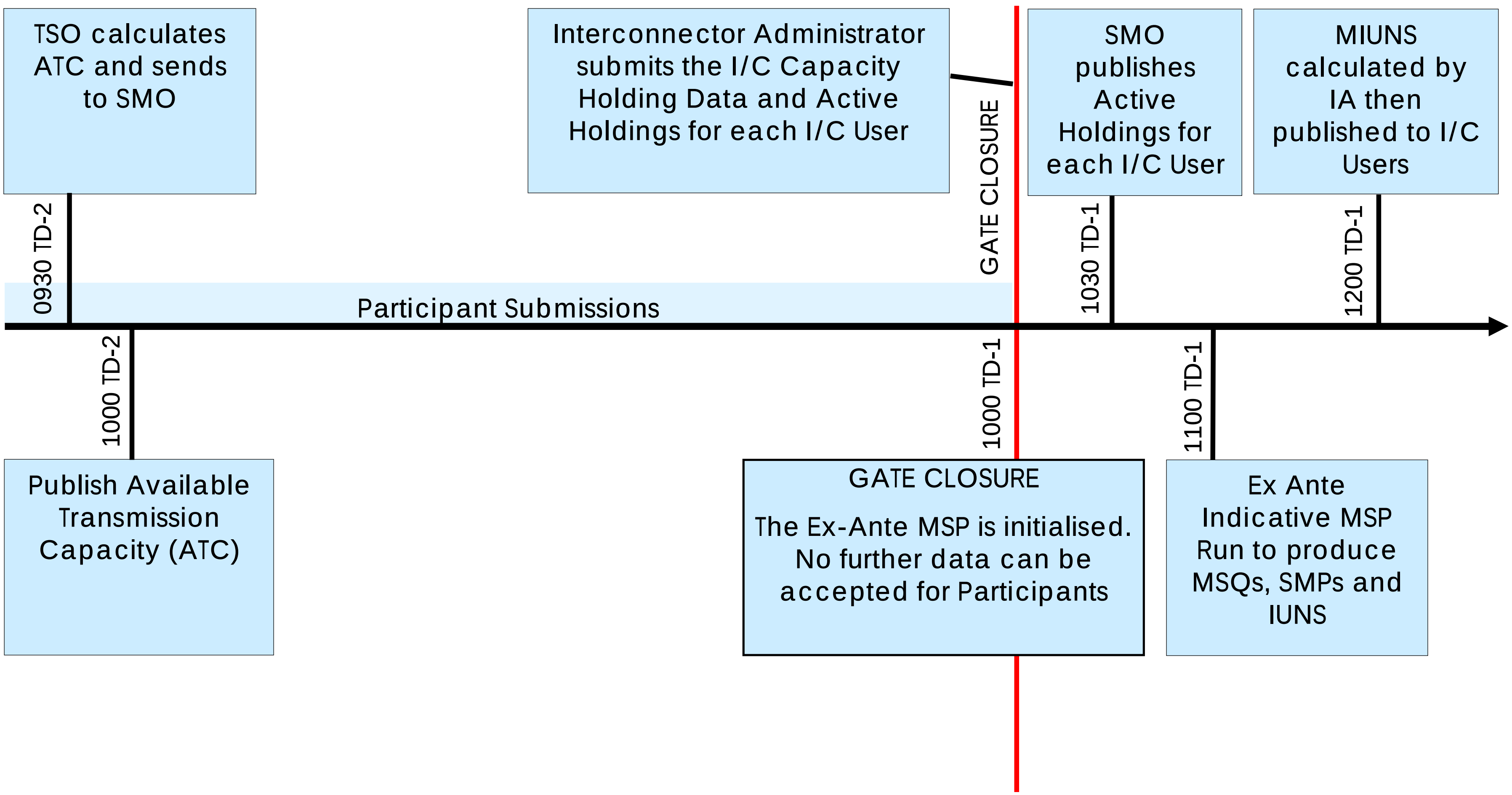
Ex-Ante Indicative

Ex-Ante Indicative MSP Execution

The Ex-Ante Indicative MSP run will be initialised based on the previous Trading Day's Ex-Ante Indicative Market Schedule.

- Decision Data Captured:
  - Market Participant-submitted data,
  - Composite load forecast and
  - Wind generation forecast for each Trading Period.
- These forecasts will be provided by each TSO.
- The Ex-Ante Indicative MSP Run will:
  - Treat Price Takers as "self-scheduled" units
  - Economically commit the Price Maker units using their offer data to meet the load forecast minus Price Taker nominations and Price Taker/Autonomous Wind Forecasts
  - All values submitted net of Unit Load
- The Ex-Ante Indicative MSQs and Ex-Ante Indicative SMPs for each Trading Period for the Trading Day make up the Ex-Ante Indicative Market Schedule.

Ex-Ante Timeline



Ex-Ante Inputs and Outputs

- Generator running and start-up costs
- Forecast max and min output levels over the day
- Information carried over from last Ex-Ante run
- Generator technical characteristics
- Interconnector data
- Data for special plant e.g. energy limited units, pumped storage units
- System load forecast data
- Wind data
- Other data e.g. Exchange rate data

↓

Determine Ex-Ante Market Schedule

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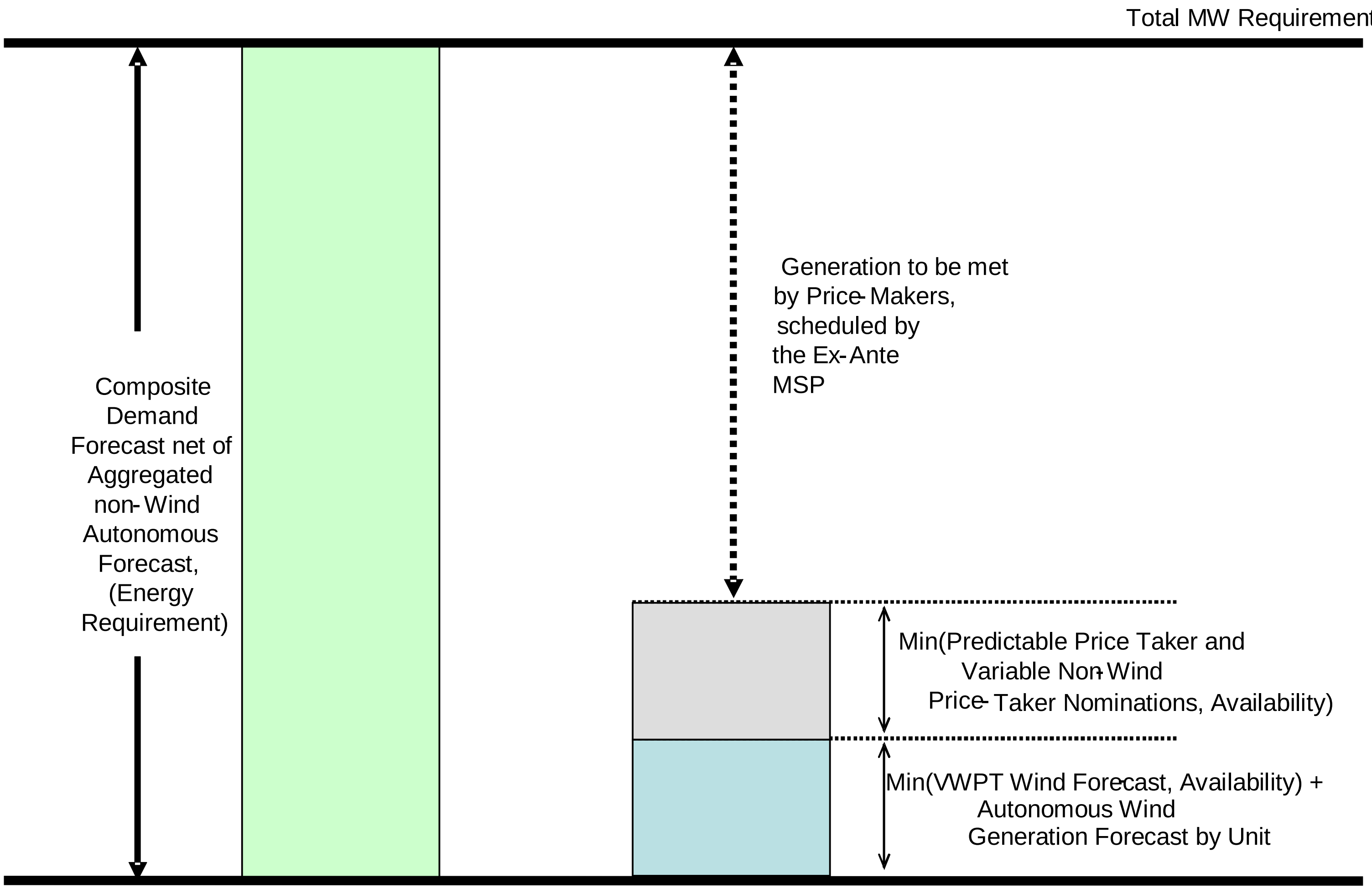
- Generator commitment and dispatch levels over the day
- Market prices over the day

Ex-Ante Indicative MSP: Generation to be met by Price Makers

EX-ANTE MSP



Ex Ante Indicative MSP – Key Data Outputs

- Composite Price Taker Wind and Autonomous Wind Generation Forecast - MW by Trading Period for Trading Day
- Composite Load Forecast - MW by Trading Period for Trading Day
- Ex-Ante Indicative MSQs - MW amount for Unit for each Trading Period in the Trading Day
- Ex-Ante Indicative SMPs - €/MWh and £/MWh for each Trading Period in the Trading Day
- Interconnector User Nominations (IUNs)
- Modified Interconnector User Nominations (MIUNs)
- Aggregate Modified Interconnector User Nominations (AMIUNs)
- Available Transmission Capacity (ATC)

Physical Markets Example – Ex Ante

In our example, there are 3 Units (2 Price Maker and 1 Price Taker). MSP dispatches Price Makers to meet Schedule Demand

- Small subset of Operational Characteristics

	Unit 1	Unit 2	Unit 3
Settlement Class	PPMG	PPMG	PPTG
Priority Dispatch	NO	NO	NO
Ramp Up Rate (converted to MW/Trading Period)	130	50	25
Ramp Down Rate (converted to MW/Trading Period)	200	100	50
Start Up Cost - Cold	8000	12000	2750
No Load Cost	4000	1000	200
Minimum On Time	10	10	10
Minimum Off Time	0	0	0

Physical Markets Example
Ex Ante Input Data

Our Units submit their bids/offers which define how they are scheduled (in the case of the Price Taker, this is simply a nomination for our example)

- For the Price Makers:
  - Forecast Availability and Minimum Stable Generation
  - PQ pairs (two bid steps for each Price Maker Unit)
- For the Price Taker, simply a Nomination Profile

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 1 - Max Availability	10	160	160	160	0	0
Unit 1 - Minimum Stable Generation	0	0	0	0	0	0
Unit 1 - Price 1	15	15	15	15	15	15
Unit 1 - Quantity 1	10	10	10	10	10	10
Unit 1 - Price 2	45	45	45	45	45	45
Unit 1 - Quantity 2	150	150	150	150	150	150
Unit 2 - Max Availability	50	200	200	250	50	0
Unit 2 - Minimum Stable Generation	0	0	0	0	0	0
Unit 2 - Price 1	10	10	10	10	10	10
Unit 2 - Quantity 1	50	50	50	50	50	50
Unit 2 - Price 2	65	65	65	65	65	65
Unit 2 - Quantity 2	250	250	250	250	250	250
Unit 3 - Nominations	20	20	40	50	40	10

Physical Markets Example
Ex Ante Schedule Demand / Merit Order

Ex Ante Schedule Demand is calculated from Composite Load Forecast, Nominations and Wind Forecasts

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Composite Load Forecast	55	235	290	245	88	10
MINUS Unit 3 Nomination	20	20	40	50	40	10
Schedule Demand (i.e. Generation Requirement)	35	215	250	195	48	0

With no inter-temporal constraints, the schedule would be as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2)	0	5	40	0	0	0
Unit 1 (i=2)	0	150	150	135	0	0
Unit 1 (i=1)	0	10	10	10	0	0
Unit 2 (i=1)	35	50	50	50	48	0
Unit 3 (fixed schedule)	20	20	40	50	40	10

Taking ramp rates into account, the final schedule is as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2)	0	35	40	0	0	0
Unit 1 (i=2)	0	120	150	135	0	0
Unit 1 (i=1)	0	10	10	10	0	0
Unit 2 (i=1)	35	50	50	50	48	0
Unit 3 (fixed schedule)	20	20	40	50	40	10

Physical Markets Example
Shadow Price and SMP discussion

The Shadow Price calculated by the MSP Software will be:

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Ante Shadow Price	10.00	65.00	65.00	45.00	10.00	-

- Shadow Prices form the basis of the SMP calculation
- However, paying for generation at shadow prices will mean that Generator Units will not recover the full costs of production

- As a result, there is a further process undertaken to determine System Marginal Prices (SMPs):
  - SMP takes into account No Load and Start Up Costs
  - SMP ensures that all Units running will at least meet their costs of running (PQ, Start Up and No Load) across the Trading Day

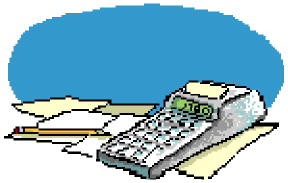
The next section outlines the SMP calculation process

Calculation of SMP

SMP Calculations

Initial SMP Problem

- For each Trading Period a Unit is on, the cost to be recovered for that period needs to be determined
  - The trading interval no load and bid costs incurred, plus
  - The start up cost pro-rated across the periods the unit is on based on its output in each of those periods



Determine minimum settlement price for each period of Trading Day (SMPMin)

- Objective Function
  - Set the SMPMin values to minimise the total payment over the Trading Day to generators
- Constraints
  - SMPMin for each period must be no less than the shadow price for that period.
  - The payment to each unit in each period must ensure no net loss over each contiguous period it is on.

Physical Markets Example
SMP Step 1

SMP Step 1 ensures that Units recover their running costs:

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Ante Shadow Price	10.00	65.00	65.00	45.00	10.00	-
Running Cost - Unit 1	-	7,165.80	8,392.53	7,779.17	-	-
Running Cost - Unit 2	2,038.64	5,199.19	5,556.49	2,698.05	2,610.13	-
Ex Ante Initial SMP	**52.76**	**65.00**	**65.00**	**45.00**	**54.81**	**-**
Revenue - Unit 1	-	8,450.00	10,400.00	6,525.00	-	-
Revenue - Unit 2	1,846.70	5,525.00	5,850.00	2,250.00	2,630.80	-

Production Cost	**43,477.50**
Unit 1 Profit	**2,037.50**
Unit 2 Profit	**-**

- Simple linear program which ensures that:
  - Total production cost is minimised
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
- Prices in Trading Periods 1,4 and 5 are raised, otherwise Unit 2 would not break even

SMP Calculations

Final SMP Problem

- Given there are multiple possible solutions to the initial problem, the final SMP problem tries to drive specific pricing solutions.

Determine final settlement price for each period of Trading Day (SMP)

- Set factors α, β , and δ (all positive)

- Objective Function
  - Set the SMP to minimise

    α * total payment over the Trading Day to the price makers at SMP, plus

    β * Sum over all periods of (SMP – shadow price)^2

- Constraints
  - SMP for each period must be no less than the shadow price for that period.
  - The payment to each unit in each period must ensure no net loss over each contiguous period it is on.
  - Total payment must be less than REVMIN * (1 + δ)
    - REVMIN was the objective function value in the first phase.

Physical Markets Example
SMP Final Step

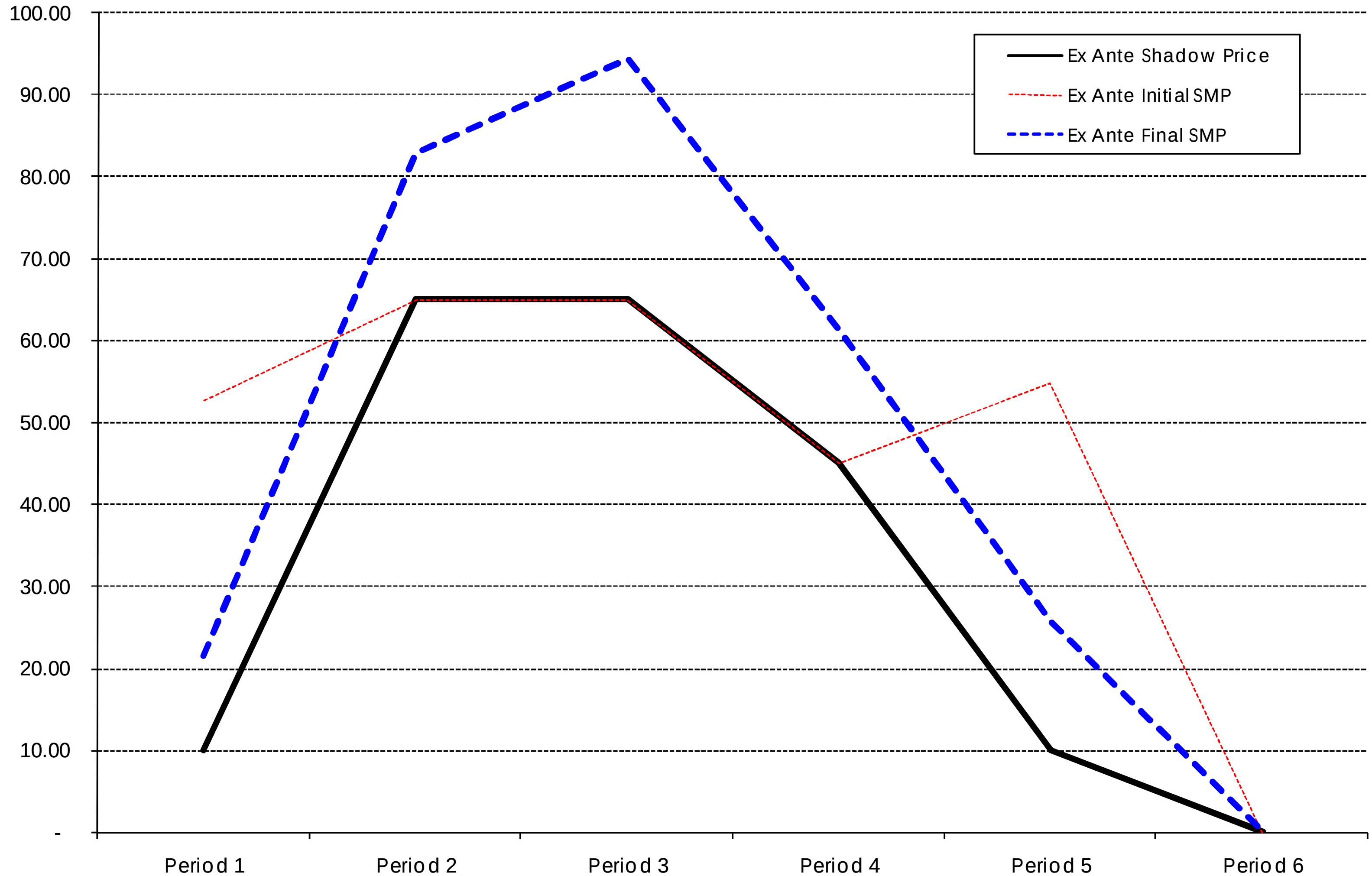
With **α**=0, **β**=1 and **δ**=5 – this ensures that the SMP algorithm will minimise the overall gap between the Shadow Price and the resulting SMP.

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Ante Shadow Price	10.00	65.00	65.00	45.00	10.00	-
Ex Ante Initial SMP	52.76	65.00	65.00	45.00	54.81	-
Running Cost - Unit 1	-	7,165.80	8,392.53	7,779.17	-	-
Running Cost - Unit 2	2,038.64	5,199.19	5,556.49	2,698.05	2,610.13	-
Ex Ante Final SMP	**21.42**	**82.95**	**94.37**	**61.32**	**25.66**	**-**
Revenue - Unit 1	-	13,271.5	15,098.8	8,890.7	-	-
Revenue - Unit 2	749.7	4,562.1	8,493.1	3,065.8	1,231.8	-

Production Cost	**55,363.60**
Unit 1 Profit	**13,923.60**
Unit 2 Profit	**-**

- Simple linear program which ensures that:
  - SMP is set to minimise
    - α * total payment over the Trading Day to the price makers at SMP, plus β * Sum over all periods of (SMP – shadow price)^2
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
  - Total payment must be less than REVMIN * (1 + δ)

Physical Markets Example
SMP and Shadow Prices



Smearing Costs

Start Up Costs are smeared across any period of contiguous running

- Unit comes on and goes off during the same Trading Day
  - Start Up Cost is smeared across this period, pro rata to the MSQs during the period of running
- Unit is on at the start of Trading Day and goes off during the Trading Day
  - Start Up Cost for today is smeared across this period, pro rata to the MSQs during the period of running, plus the carried over amount is added
- Unit starts during day and comes off between the end of the Trading Day and the end of the Optimisation Time Horizon
  - Portion of the Start Up Cost is recovered in the Trading Day, the rest is carried over to tomorrow
- Unit starts during the Trading Day and is still on at the end of the Optimisation Time Horizon
  - Portion of the Start Up Cost is recovered in the Trading Day, plus the Unit is assumed to be come off after the Optimisation Time Horizon

TSO Real Time Operations

Creating an Operations Schedule

An Operation Schedule is determined by System Operator (s) to inform within day actual dispatch

- Tool used by operators to commit and dispatch the power system
- Calculates a least cost commitment and dispatch taking many factors (e.g. Reserve) into consideration
- Is based significantly on real-time data

- Assists in making scheduling decisions on an All Island Basis
- System can be operated by either TSO
- Assist in quantifying and managing constraint costs
- 2 TSO's, 2 Control Centres and 2 Control Areas
- Day Ahead Operations Schedule published by 16.00 TD-1 to Participants
- Significant change in System Conditions will require a new agreed schedule to be produced
- Control Centres dispatch generators within their own jurisdiction

Dispatching Units

Units will be dispatched by the relevant TSO in terms of:

- MW level
- Required changes to operation
- Acknowledgement of problems that have occurred
- Ramp rate required
- Modes of Operation
- Effective Times

Capture dispatch instructions

- Instructions are issued by the TSOs
- The PM systems capture the instructions as they are needed to determine the least cost commitment and schedule

Produce instruction profiles

- Issued by the control centre as and when needed
- The MSP Software works at a half hour resolution so dispatch instructions must be processed before being fed to the scheduling processes

Within-day Data Collection

Data is required and collected for use in MSP runs and settlement:

- Price Effecting Metered Generation (MDP)
- Price Effecting Metered Demand (MDP)
- Dispatch Instructions (TSOs)
- Real-Time Availability (TSOs)
- System Frequency (TSOs)
- Re-declared Energy Limits (TSOs)
- Estimate of Load Shedding (TSOs)
- Latest Modified Interconnector User Nominations (I/C Administrator)

Instruction Profiling

Dispatch Process

The key dispatch instructions from an instruction profiling point of view are:

Dispatch Instruction	Description
SYNC, DESY	Instruction to synchronise to or de-synchronise from the relevant power system.
TRIP	This is a retrospective instruction which indicates that a Unit has tripped (i.e. is unintentionally de-synchronised).
MXON, MXOF	MXON is an instruction to maximise output. MXOF indicates that the period of maximisation is over.
WIND [LOCL, LCLO]	Wind curtailment (i.e. output to stay below X) because of localised transmission constraints.
WIND [CURL, CRLO]	Wind curtailment (i.e. output to stay below X) for reasons other than localised transmission constraints.
FAIL	This is a retrospective instruction which indicates that a Unit has failed to synchronise as instructed.
GOOP [PGEN, PUMP, SCT, SCP]	Instructions to pumped storage units – PGEN=generate; PUMP=pump water; SCT=change to generation mode; SCP=change to pumping mode.

Instruction Profiling – Important Notes

Instruction Profiling (See Appendix P of the Trading and Settlement Code)

- The SEM Instruction Profiling system actually uses calculated Dispatch Quantities on a Trading Day (06:00-05:59) basis, whereas instructions are submitted on a Settlement Day (00:00-23:59) basis. Therefore, the examples presented here are for illustration only.

- Instruction Profiling also incorporates a number of other operational characteristics (e.g. dwell times, soak times). However, these are not presented in the examples, to aid ease of presentation.

Instruction Profiling:
Example 1 – UNIT_1

Instruction Profiling – Example 1 (UNIT_1) (operational characteristics)

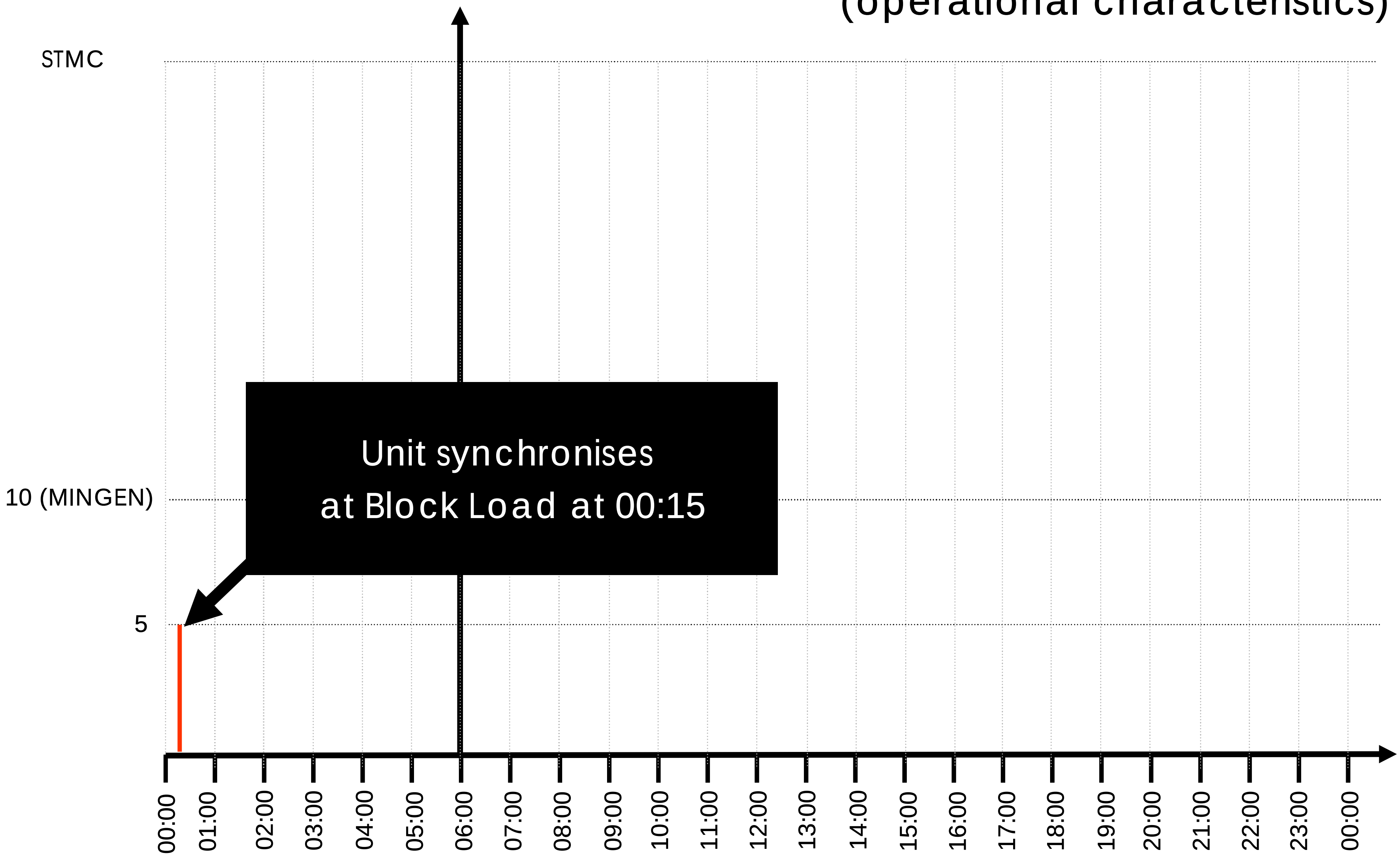
- The key operational characteristics for UNIT_1 are:
- MINGEN = 10MW
- Block Load = 5MW
- Loading rate =0.1MW/min
- Ramp Rate 1 = 0.05MW/min
- Short Term Maximisation Capacity (STMC) = 30MW
- Max Availability = 20MW

Instruction Profiling – Example 1 (UNIT_1) (instructions)

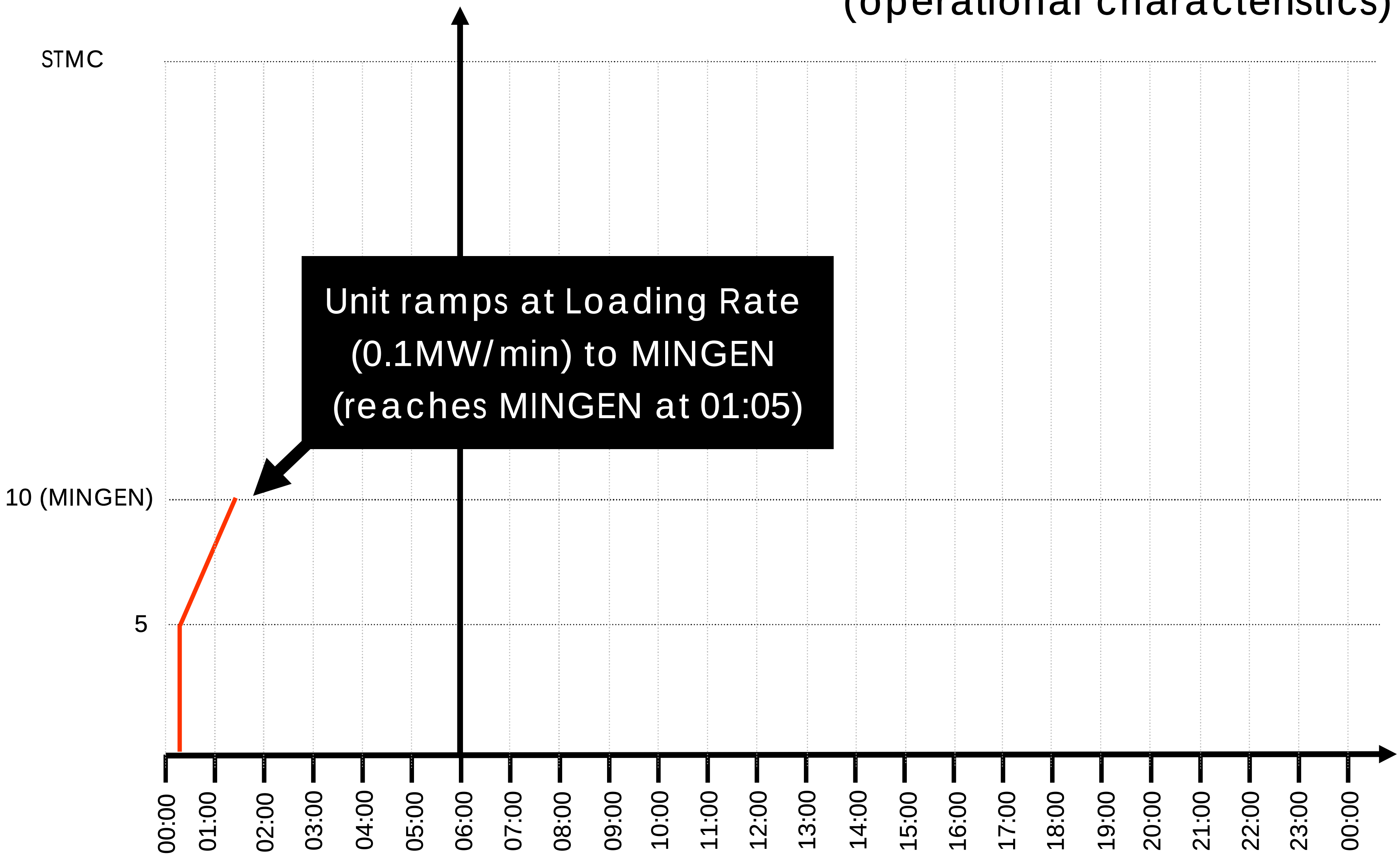
- Instructions given to UNIT_1 as follows (note that the formats of the information sent by TSOs will not be as per the following table):

Unit Name	Effective Time	Instruction	Issue Time	Description
UNIT_1	1 April 2006, 00:00	MWOF0		Unit off at the beginning of the day.
UNIT_1	1 April 2006, 00:15	SYNC	1 April 2006, 00:13	Unit instructed to synchronise.
UNIT_1	1 April 2006, 01:40	MWOF20		Unit instructed to ramp to 20MW generation.
UNIT_1	1 April 2006, 10:10	DESY		Unit instructed to de-synchronise.
UNIT_1	1 April 2006, 15:45	SYNC	1 April 2006, 15:43	Unit instructed to synchronise.
UNIT_1	1 April 2006, 15:45	MWOF18		Unit instructed to ramp to 18MW generation.
UNIT_1	1 April 2006, 15:58	FAIL		Unit has failed to synchronise.
UNIT_1	1 April 2006, 15:58	MWOF0		Confirms that the Unit is off.
UNIT_1	1 April 2006, 16:38	SYNC	1 April 2006, 16:36	Unit instructed to synchronise.
UNIT_1	1 April 2006, 16:38	MXON		Unit instructed to maximise its output.

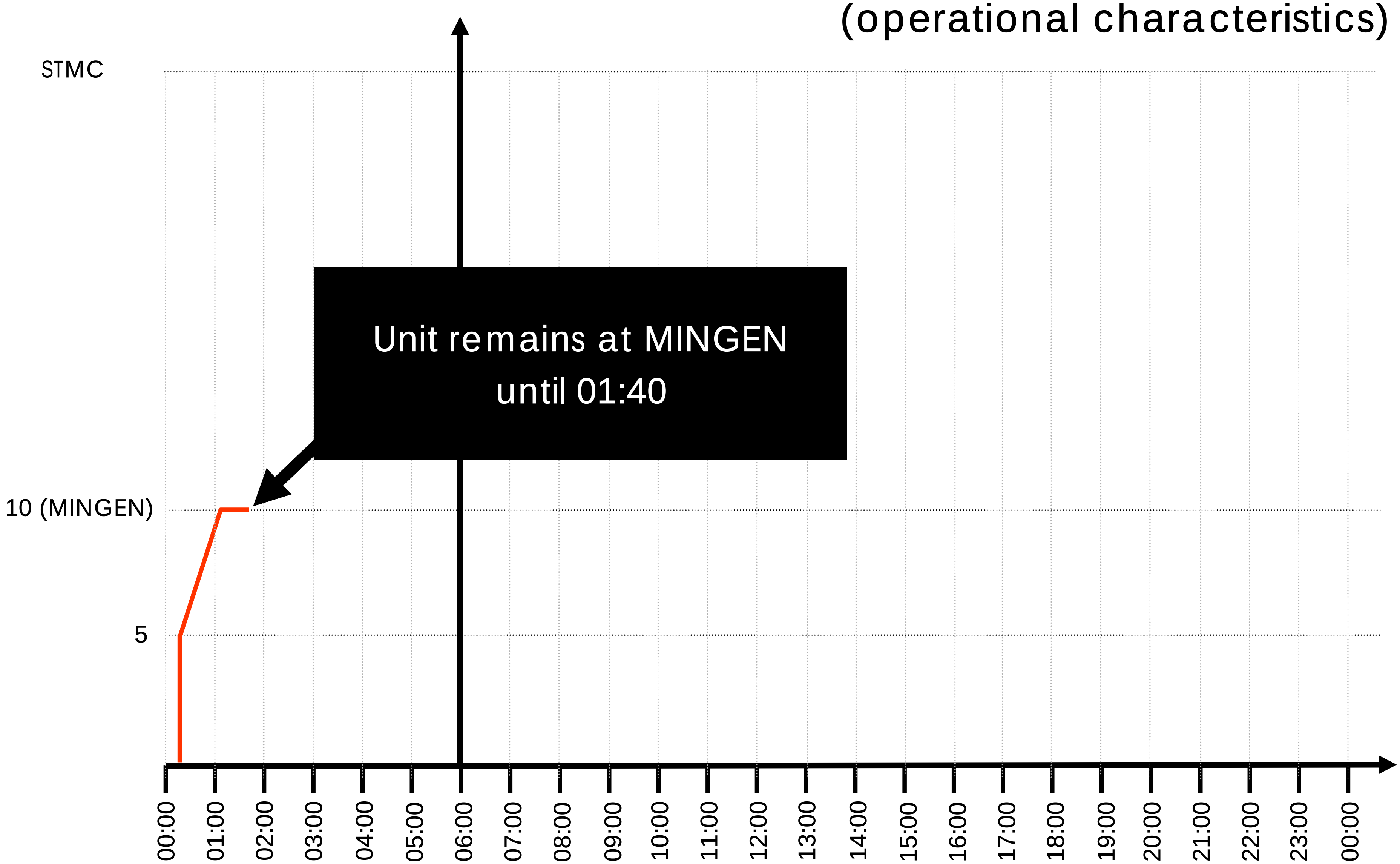
Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



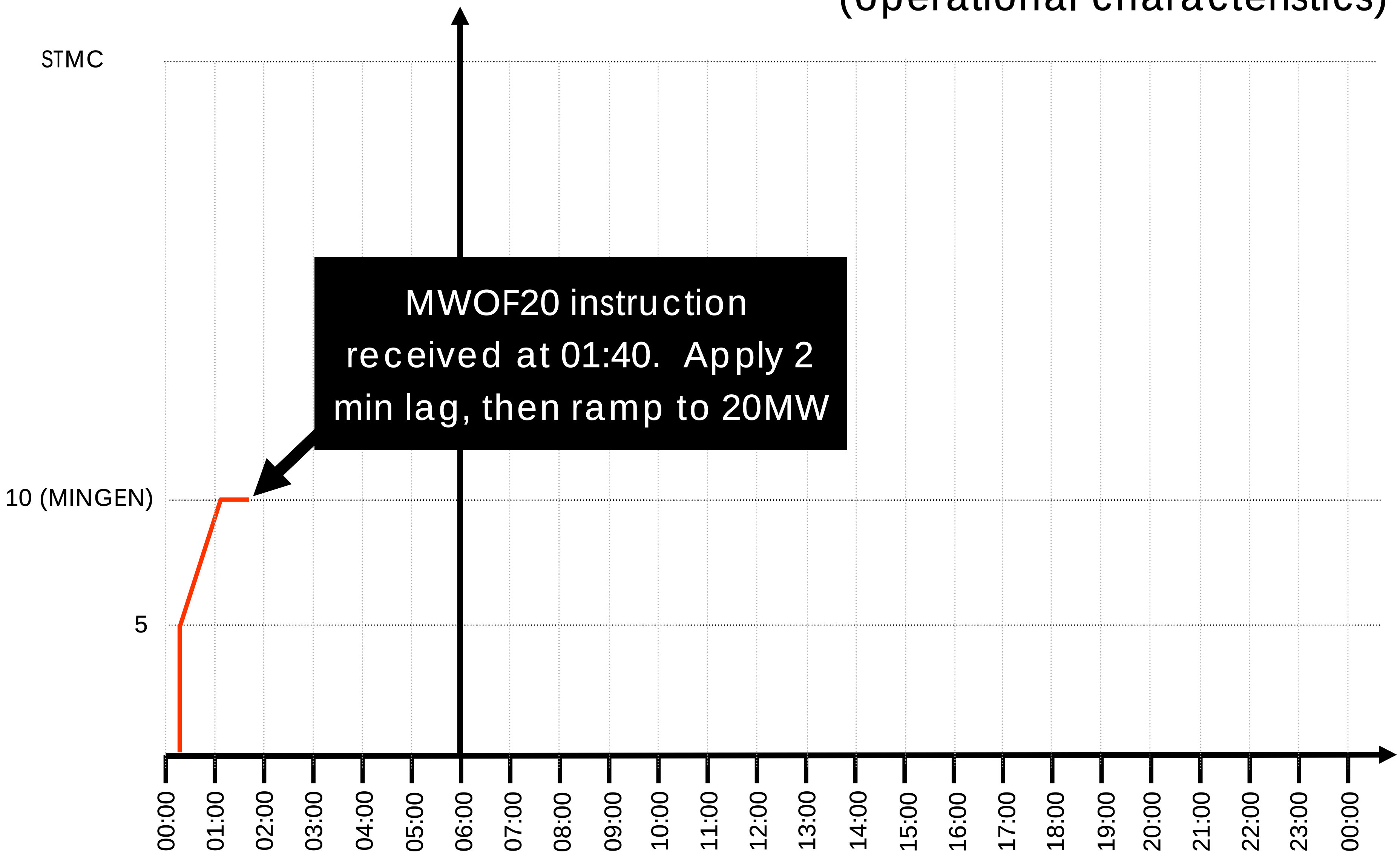
Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



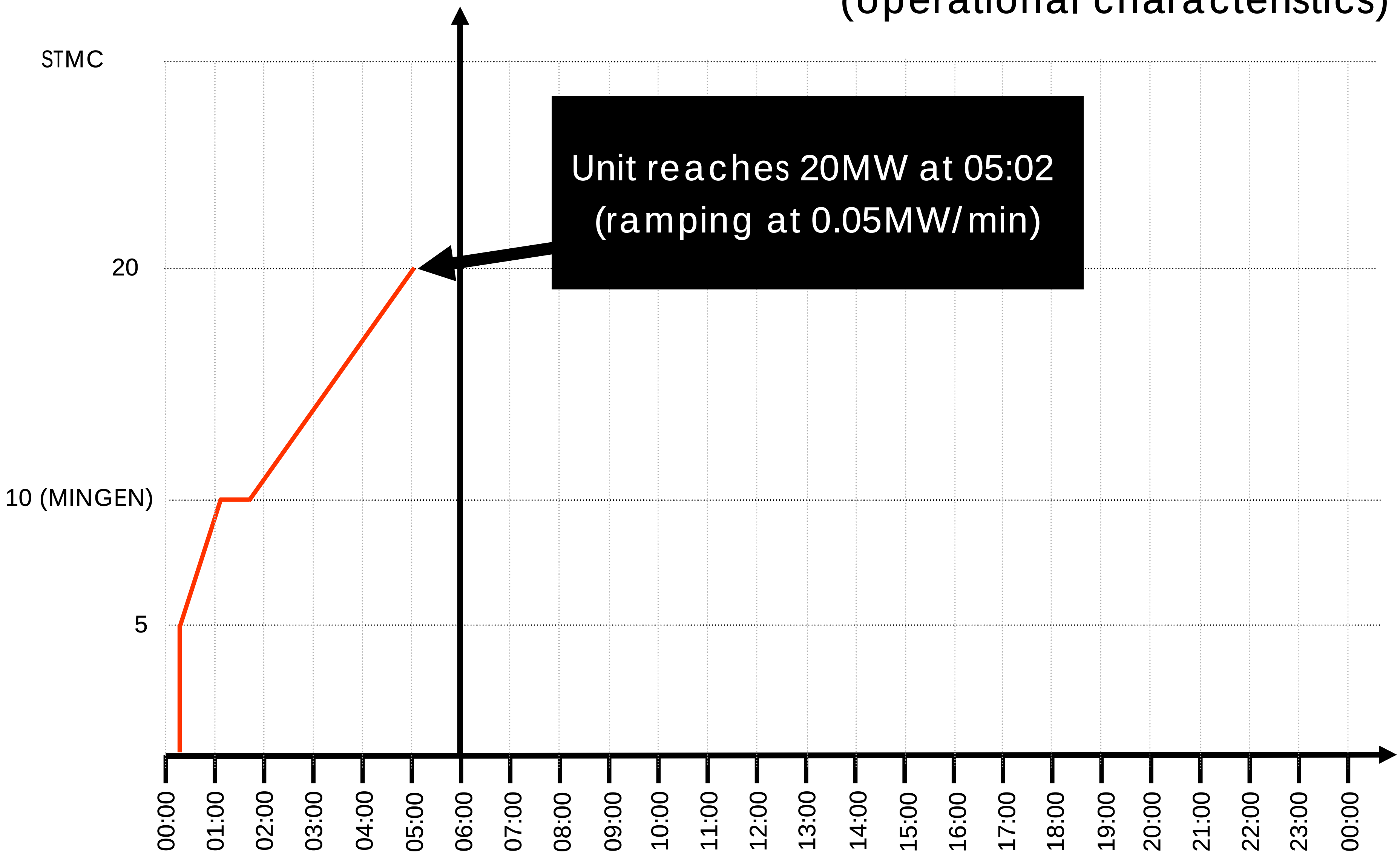
Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



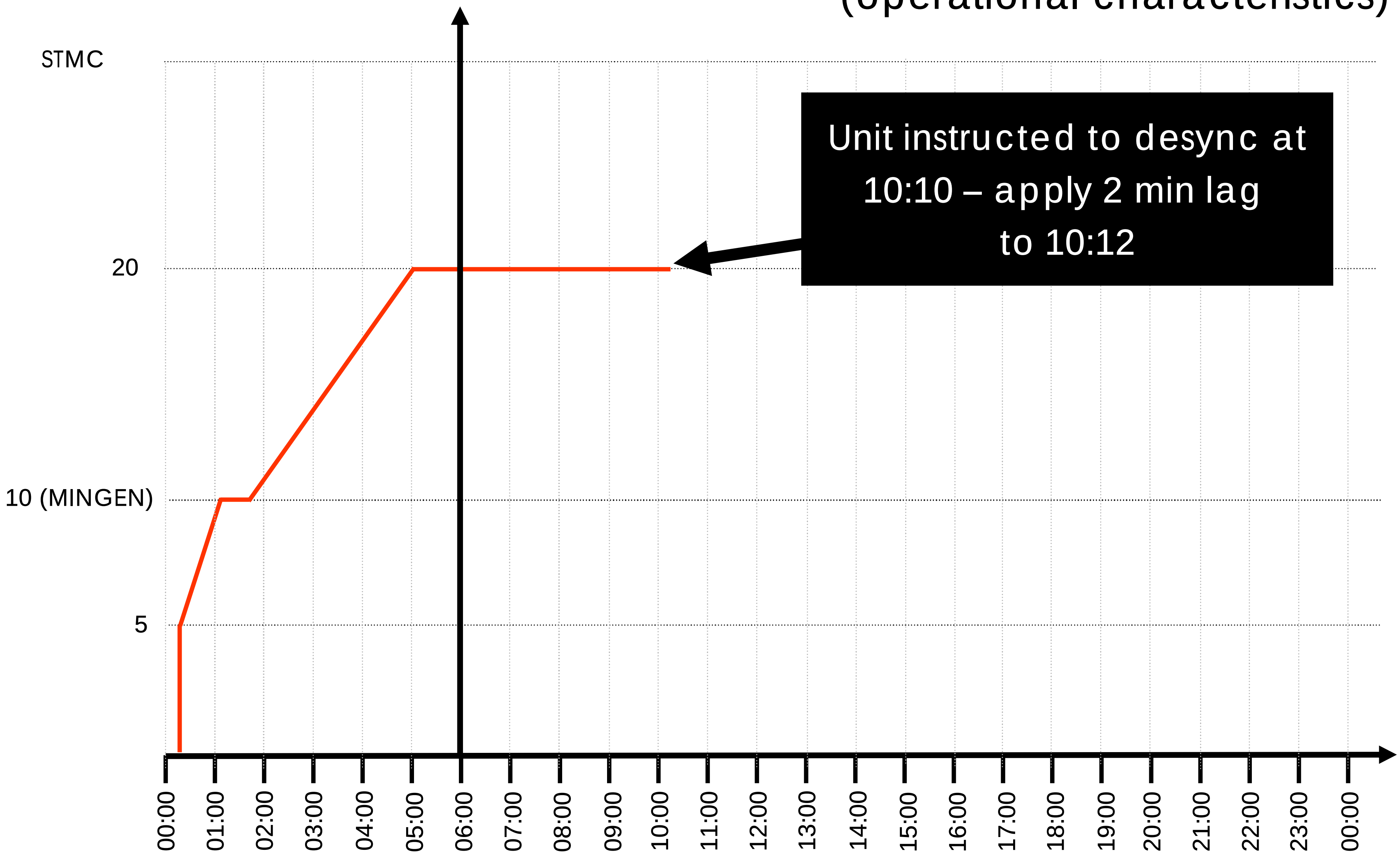
Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



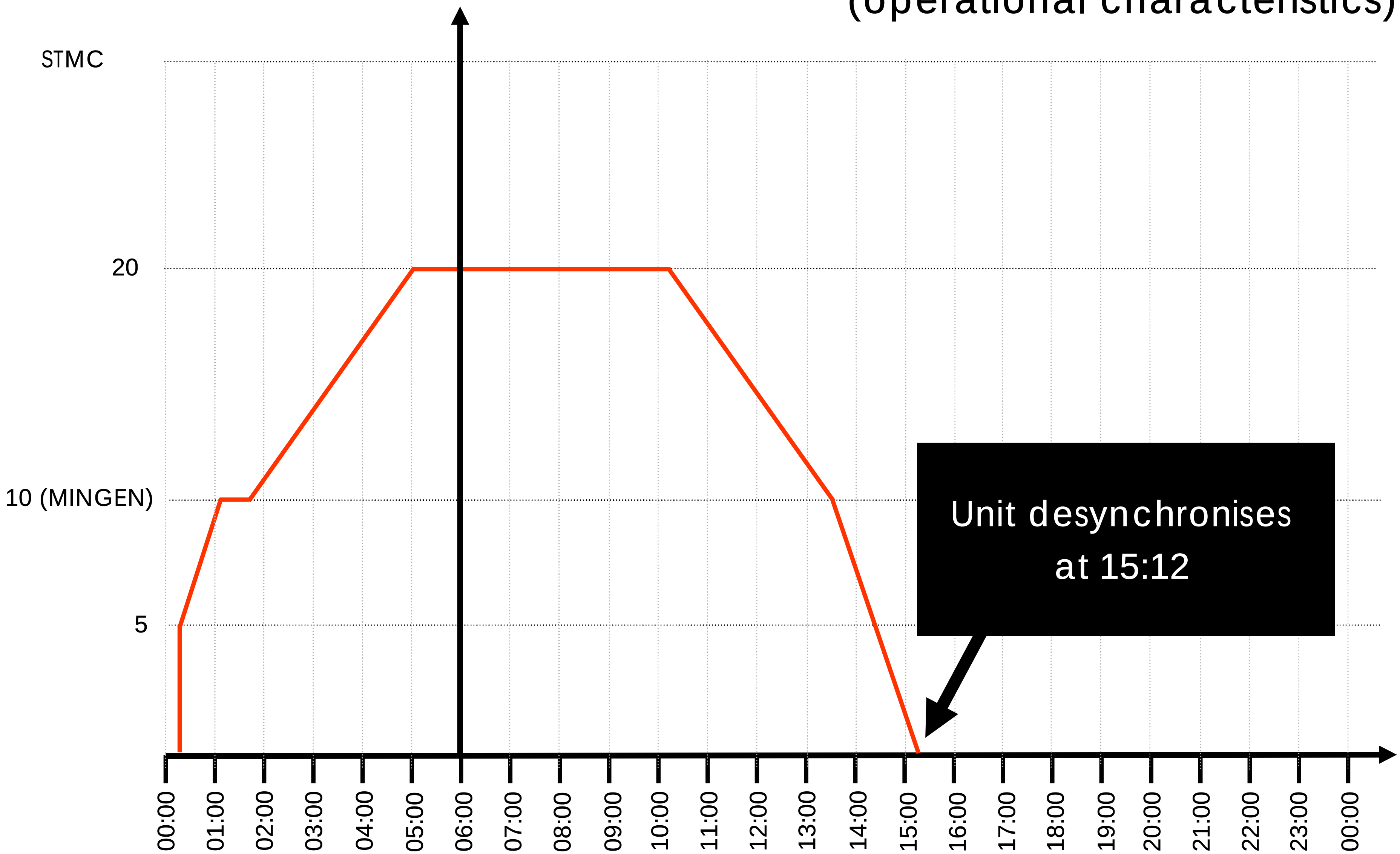
Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



Instruction Profiling – Example 1- UNIT_1 (operational characteristics)



Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



Instruction Profiling – Example 1 – UNIT_1 (FAIL)

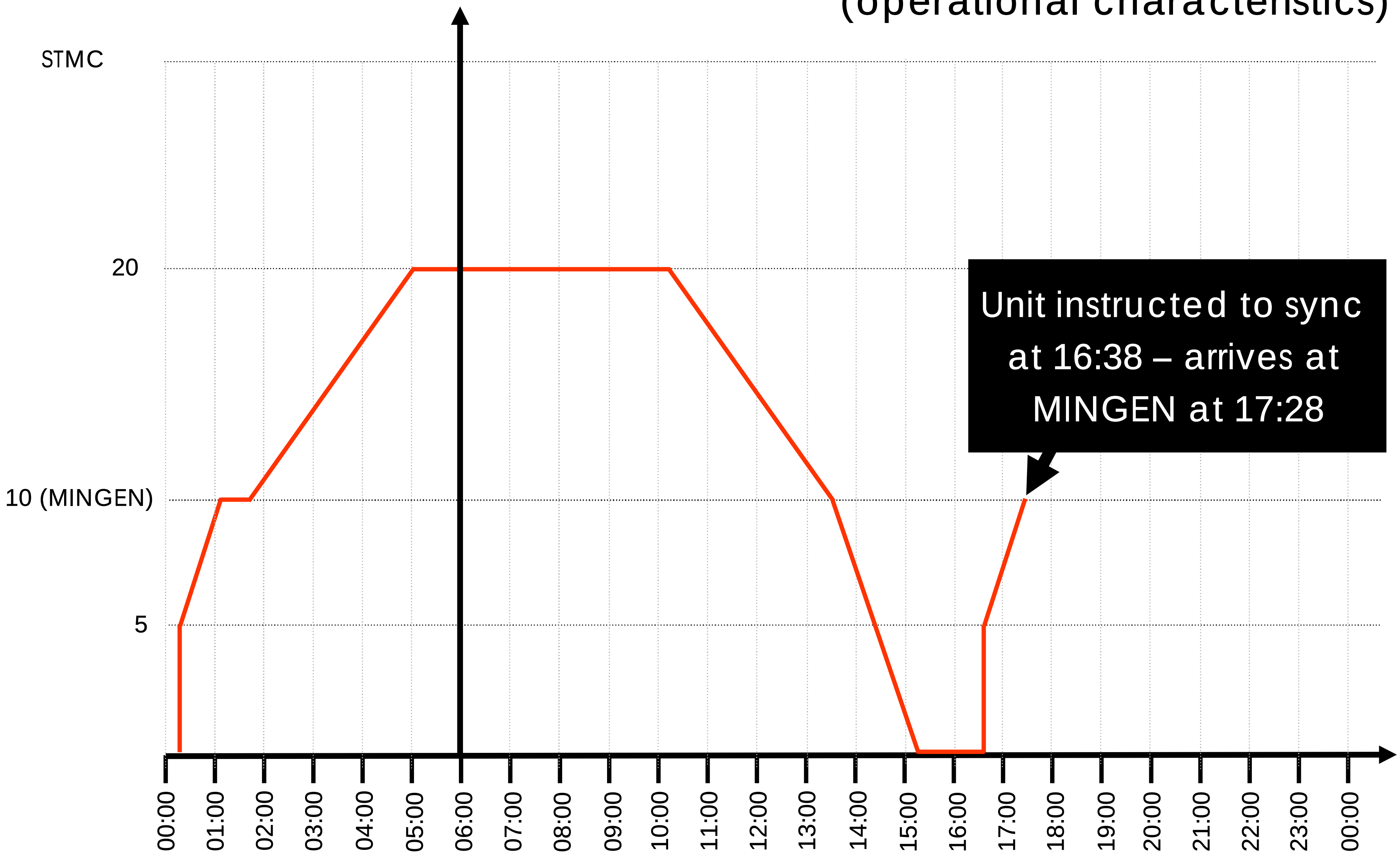
- Instructions given to UNIT_1 as follows (note that the formats of the information sent by TSOs will not be as per the following table):

Unit Name	Effective Time	Instruction	Issue
UNIT_1	1 April 2006, 00:00	MWOF0	
UNIT_1	1 April 2006, 00:15	SYNC	1 April 20
UNIT_1	1 April 2006, 01:40	MWOF20	
UNIT_1	1 April 2006, 10:10	DESY	
UNIT_1	1 April 2006, 15:45	SYNC	1 April 20
UNIT_1	1 April 2006, 15:45	MWOF18	
UNIT_1	1 April 2006, 15:58	FAIL	
UNIT_1	1 April 2006, 15:58	MWOF0	
UNIT_1	1 April 2006, 16:38	SYNC	1 April 20
UNIT_1	1 April 2006, 16:38	MXON	

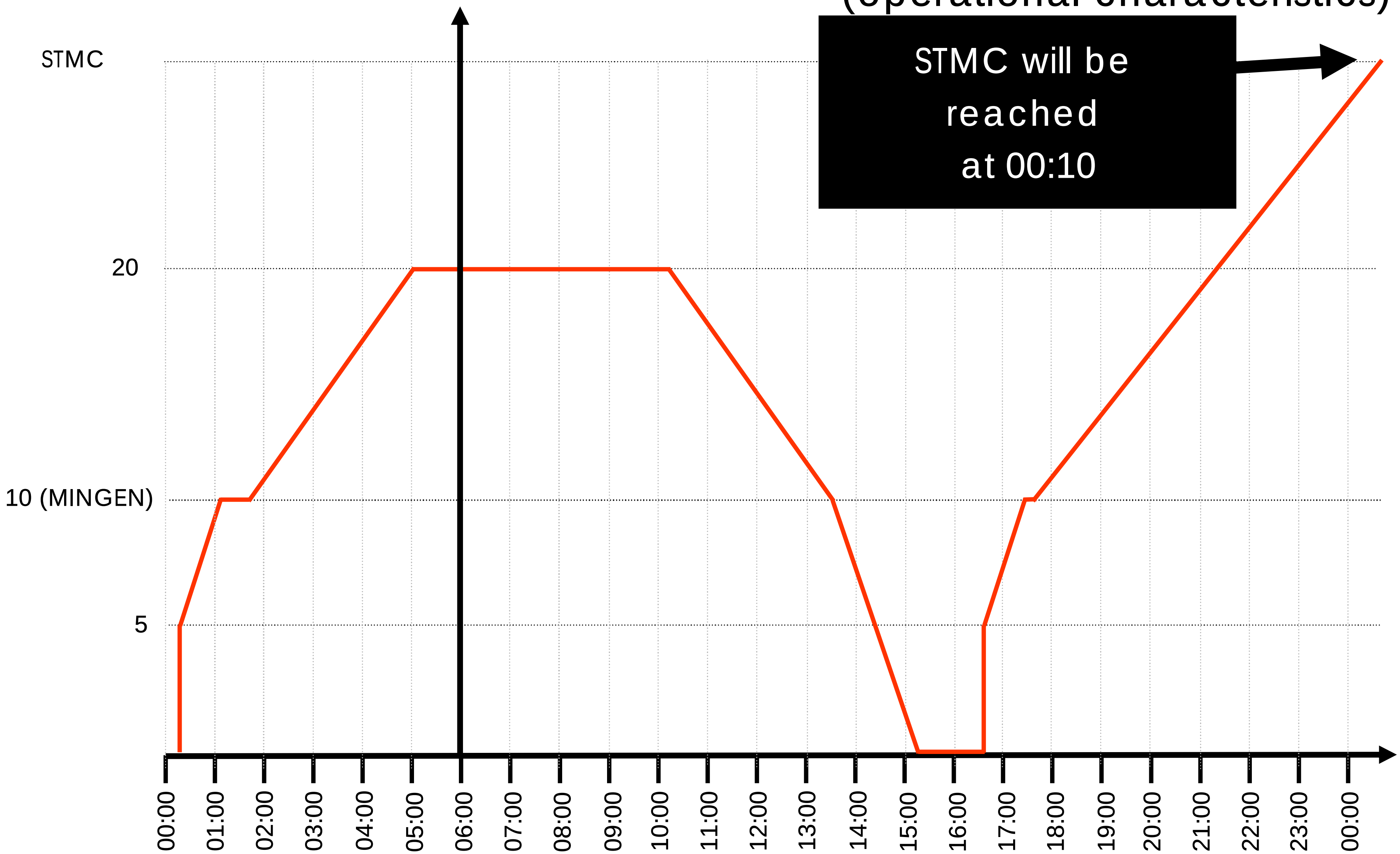
Unit is instructed to sync, but fails to do so. IP checks if FAIL received within one hour. If so, all instructions in between are discarded. If not, FAIL instruction is ignored.

In this case, FAIL is received within one hour, so all instructions between (and including) SYNC and FAIL are ignored.

Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



Instruction Profiling – Example 1 – UNIT_1 (operational characteristics)



Calculating Dispatch Quantities (DQuh)

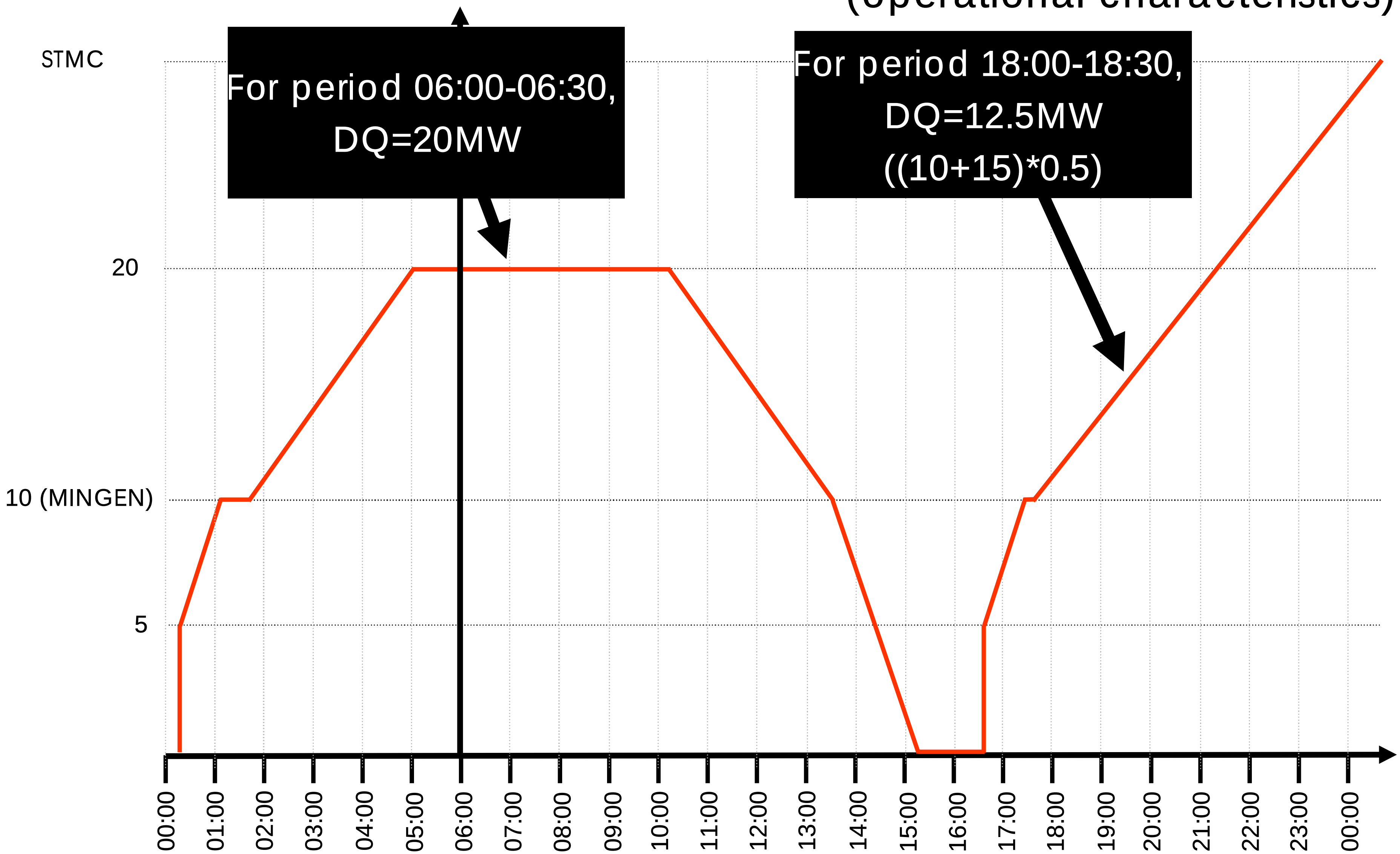
Once the instruction profiles have been generated, Dispatch Quantities can be calculated

- MW levels at Trading Period boundaries are inserted
- Area under the curve for each Trading Period is calculated

Special cases

- For some types of Unit, dispatch instructions are not issued by TSOs. As a result, there are special rules for the calculation of Dispatch Quantities for:
  - Interconnector Residual Capacity Unit (SIIQuh + SIEQuh)
  - Autonomous Units (Actual Output – AOuh)
  - Interconnector Units (Modified Interconnector User Nomination)
  - Interconnector Error Unit (zero)
  - Variable Price Maker/Taker Generator Units (AOuh if not curtailed in a Trading Period or time weighted average of real time availability and curtailed value if curtailed in a Trading Period)

Instruction Profiling – Example 1- UNIT_1 (operational characteristics)



Instruction Profiling: Example 2

(TRIP instructions)

Instruction Profiling – Example 2 – UNIT_2 (operational characteristics)

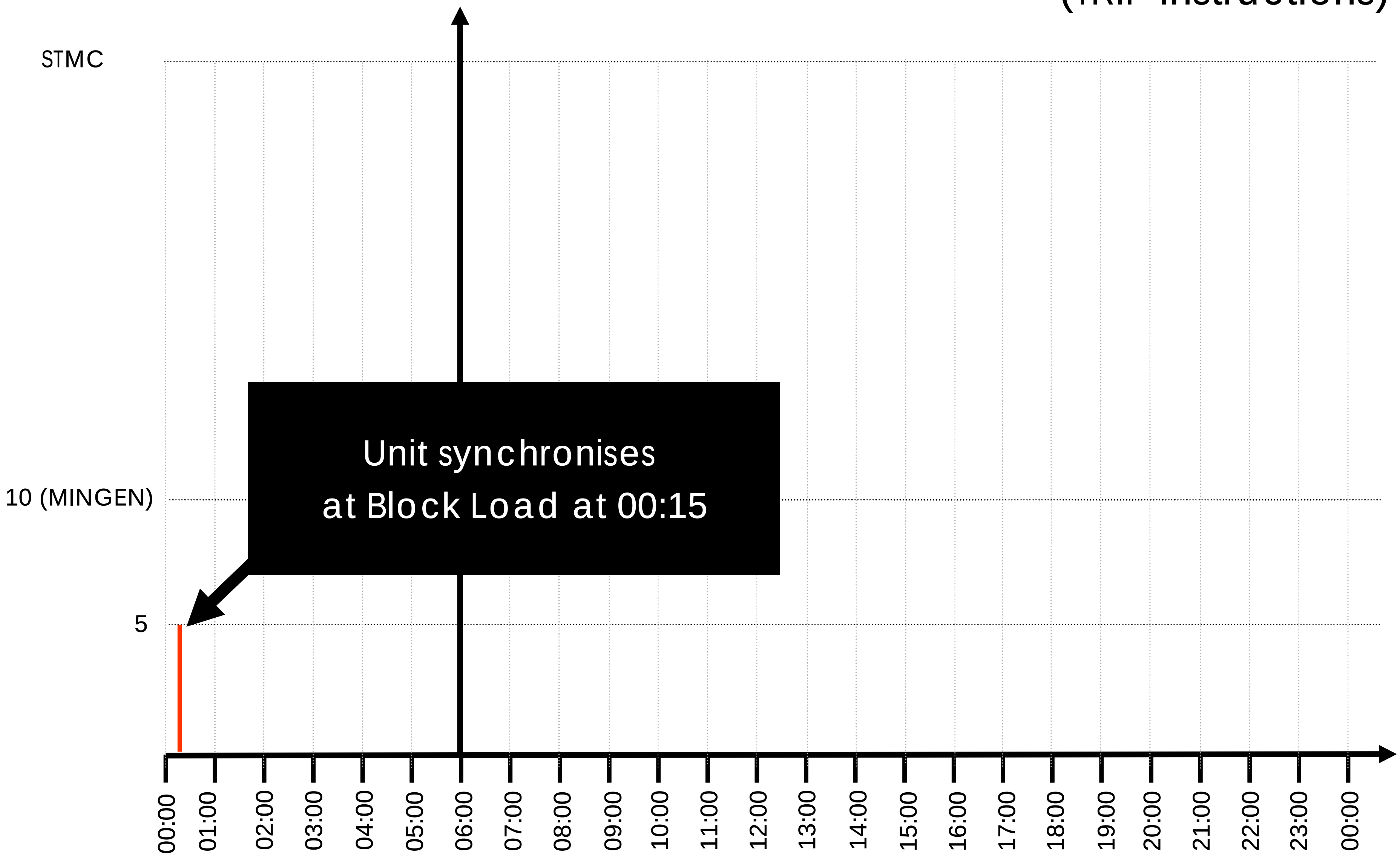
- The key operational characteristics for UNIT_2 are:
- MINGEN = 10MW
- Block Load = 5MW
- Loading rate =0.1MW/min
- Ramp Rate 1 = 0.05MW/min
- Short Term Maximisation Capacity (STMC) = 30MW
- Max Availability = 20MW

Instruction Profiling – Example 2 – UNIT_2 (TRIP)

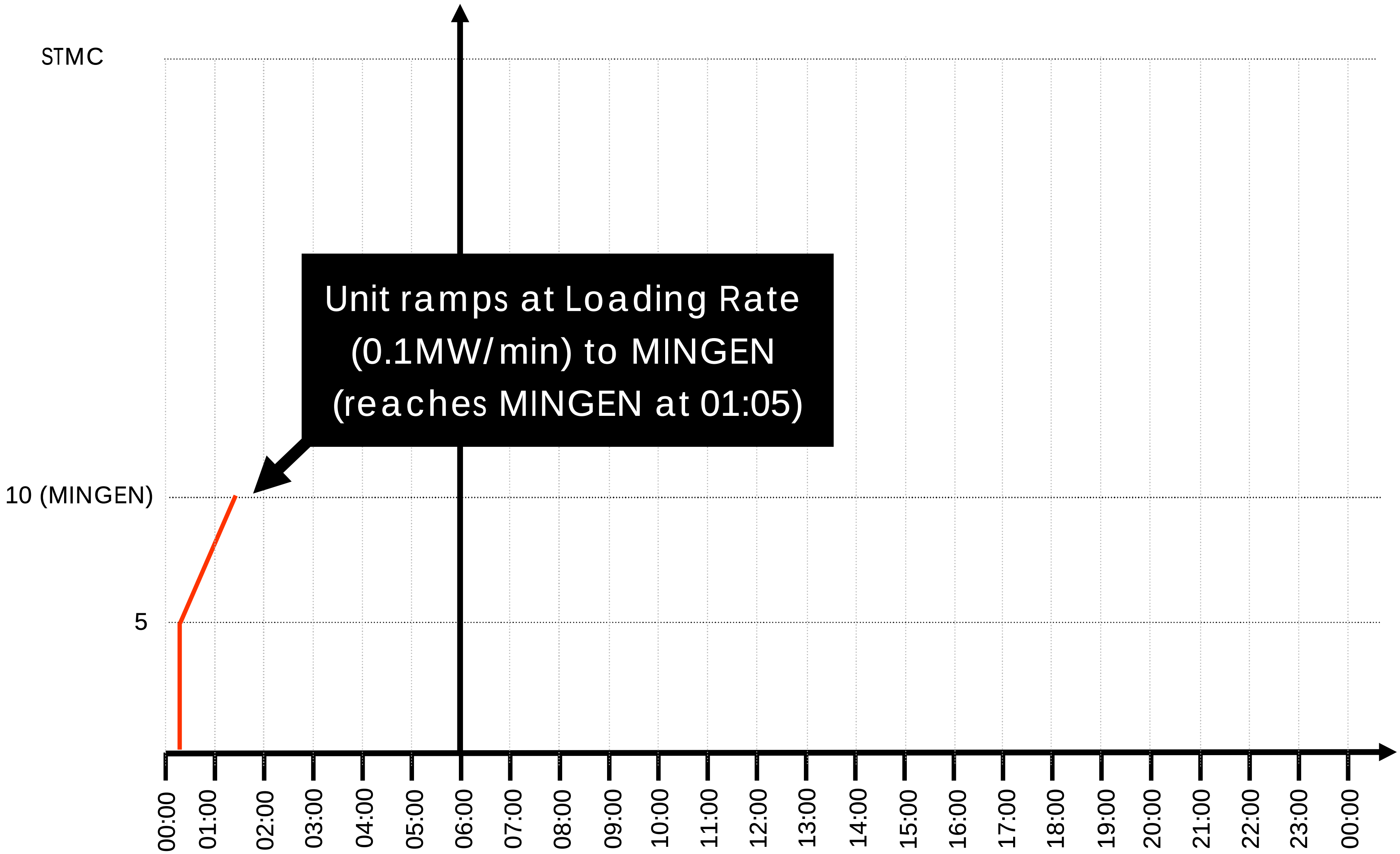
- Instructions given to UNIT_2 as follows (note that the formats of the information sent by TSOs will not be as per the following table):

Unit Name	Effective Time	Instruction	Issue Time	Description
UNIT_2	1 April 2006, 00:00	MWOF0		Unit off at the beginning of the day.
UNIT_2	1 April 2006, 00:15	SYNC	1 April 2006, 00:58	Unit instructed to synchronise.
UNIT_2	1 April 2006, 01:40	MWOF20		Unit instructed to ramp to 20MW generation.
UNIT_2	1 April 2006, 05:34	TRIP		Unit trips from the system.

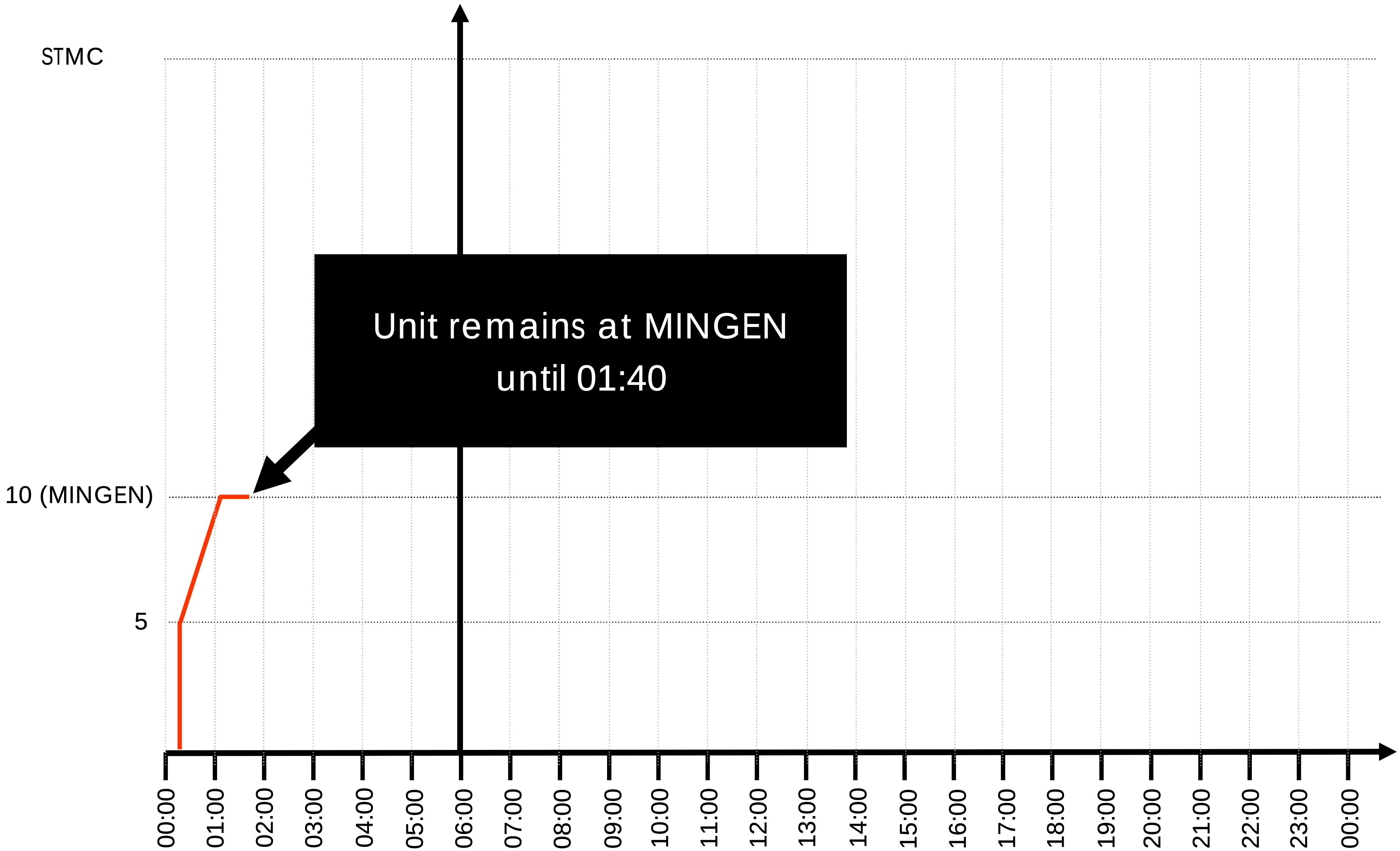
Instruction Profiling – Example 2 – UNIT_2 (TRIP instructions)



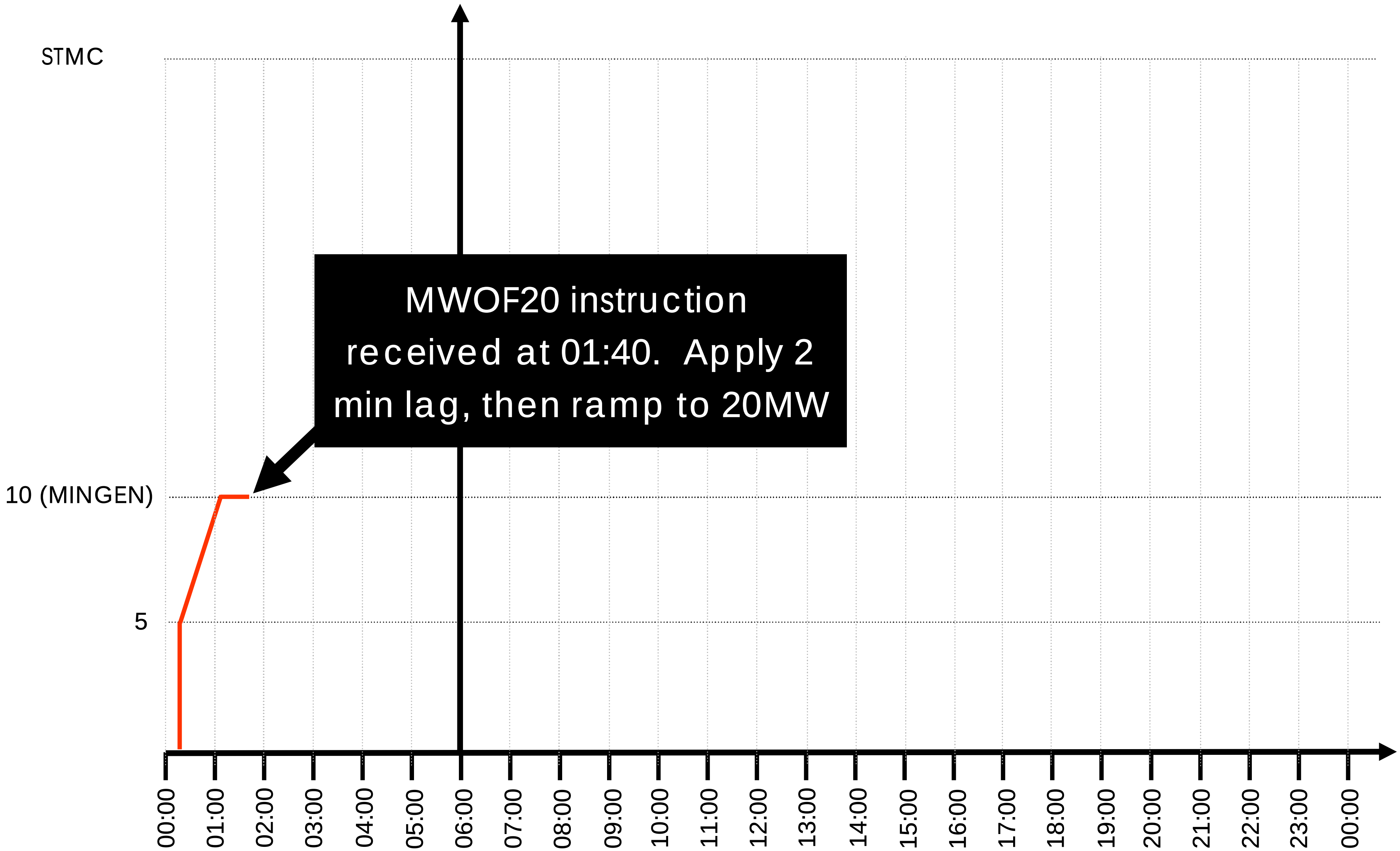
Instruction Profiling – Example 2 – UNIT_2



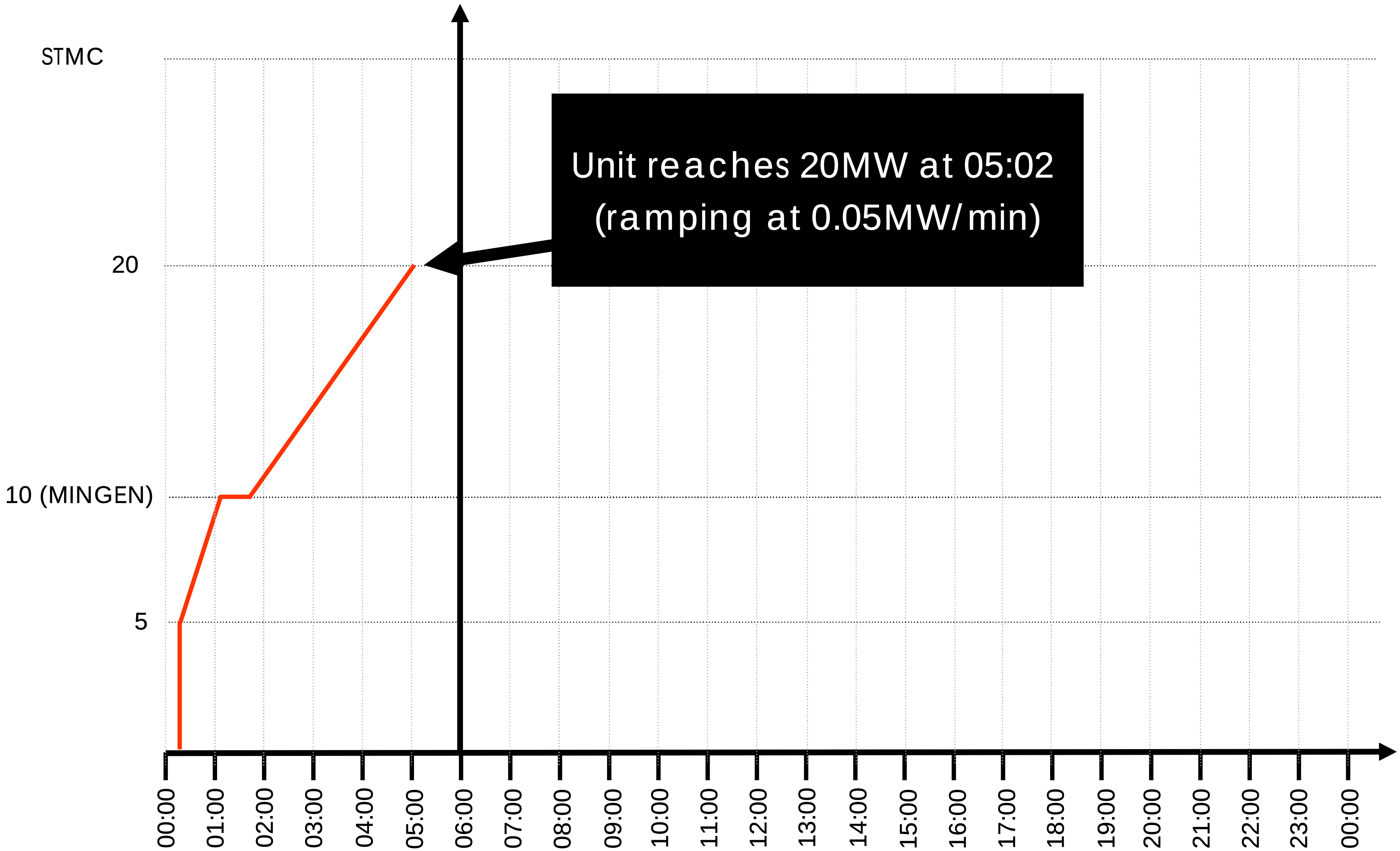
Instruction Profiling – Example 2 – UNIT_2



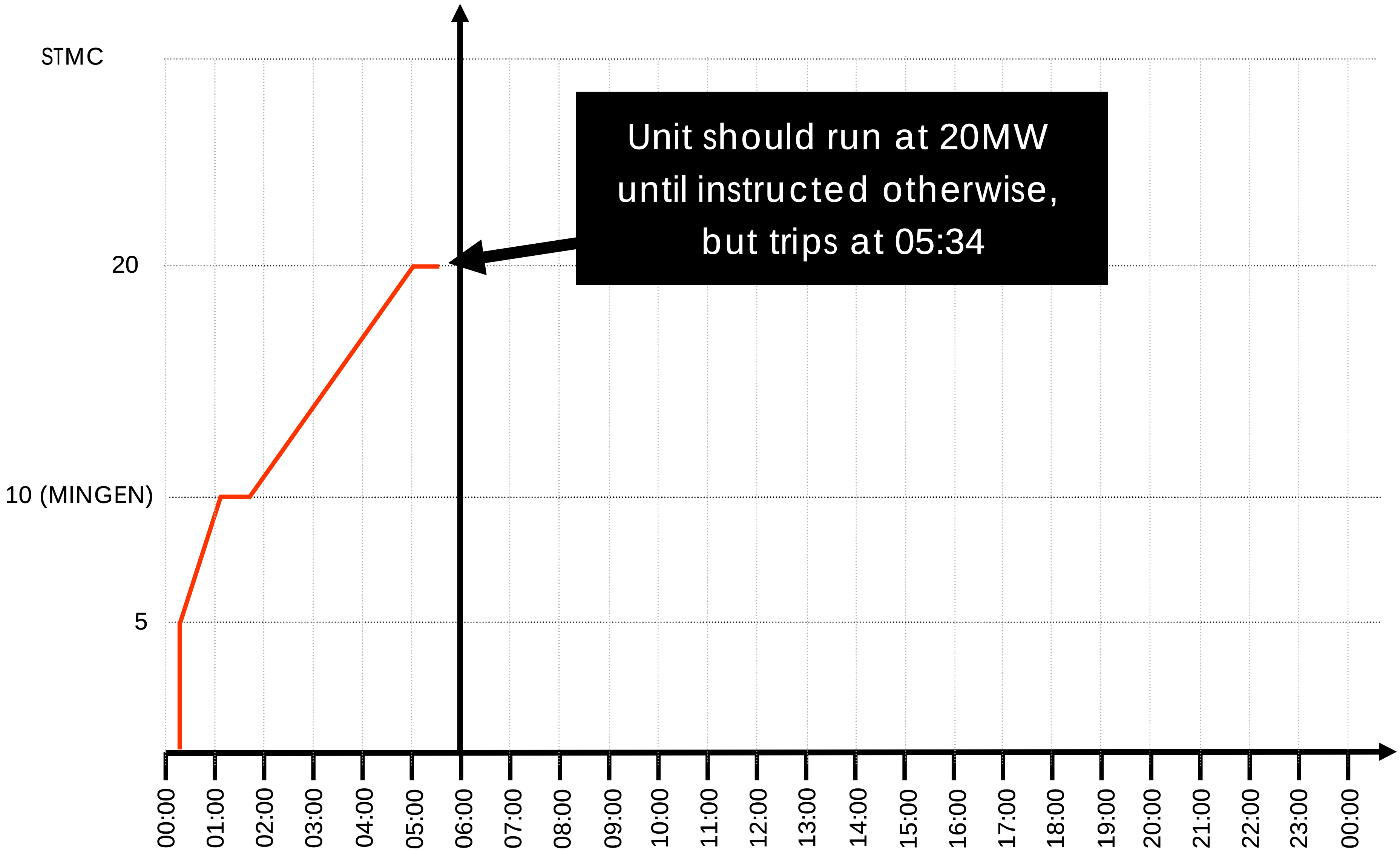
Instruction Profiling – Example 2 – UNIT_2



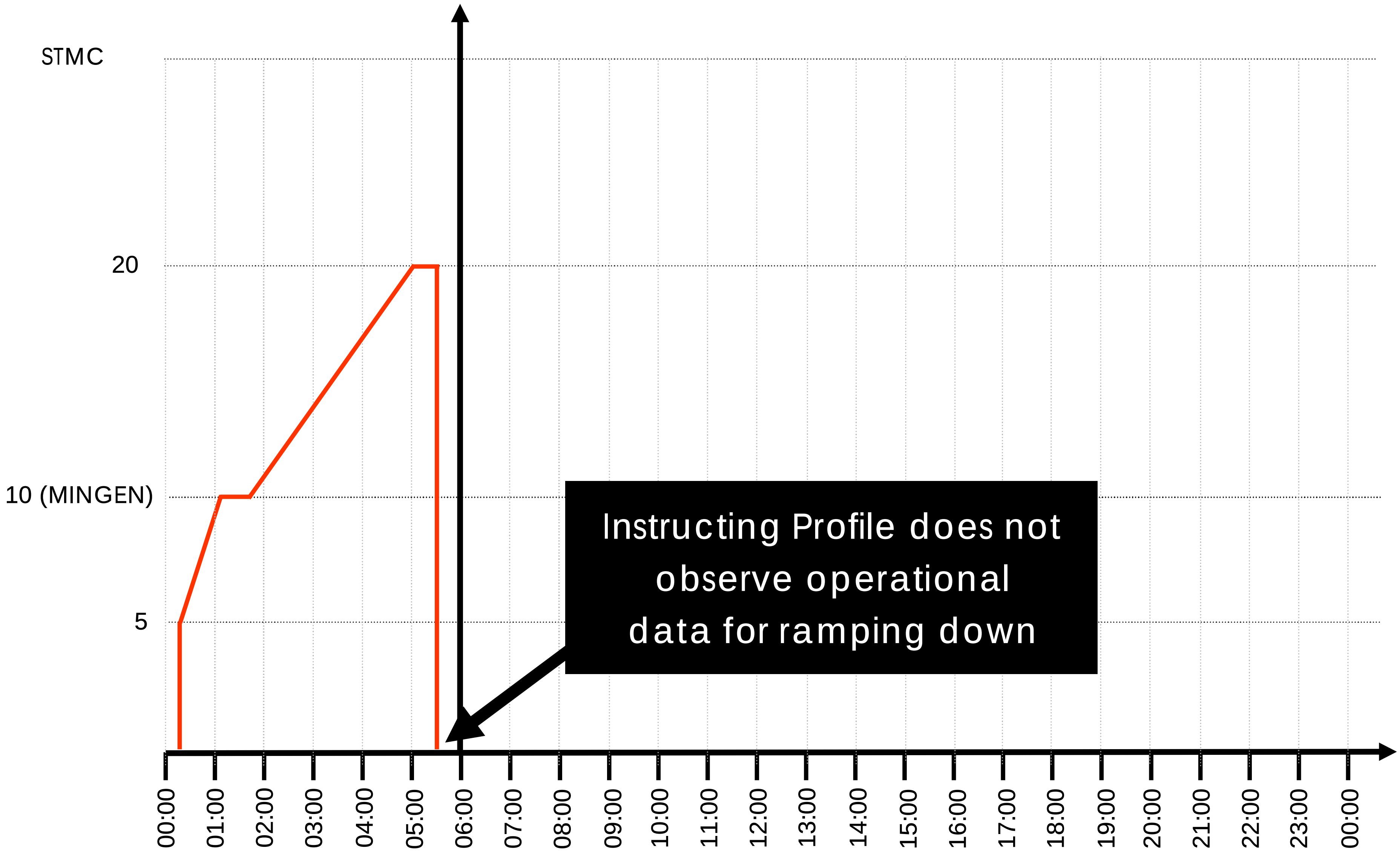
Instruction Profiling – Example 2 – UNIT_2



Instruction Profiling – Example 2 – UNIT_2



Instruction Profiling – Example 2 – UNIT_2



Instruction Profiling:
Example 3
(WIND instructions)

Instruction Profiling – Example 3 – UNIT_3 (WIND)

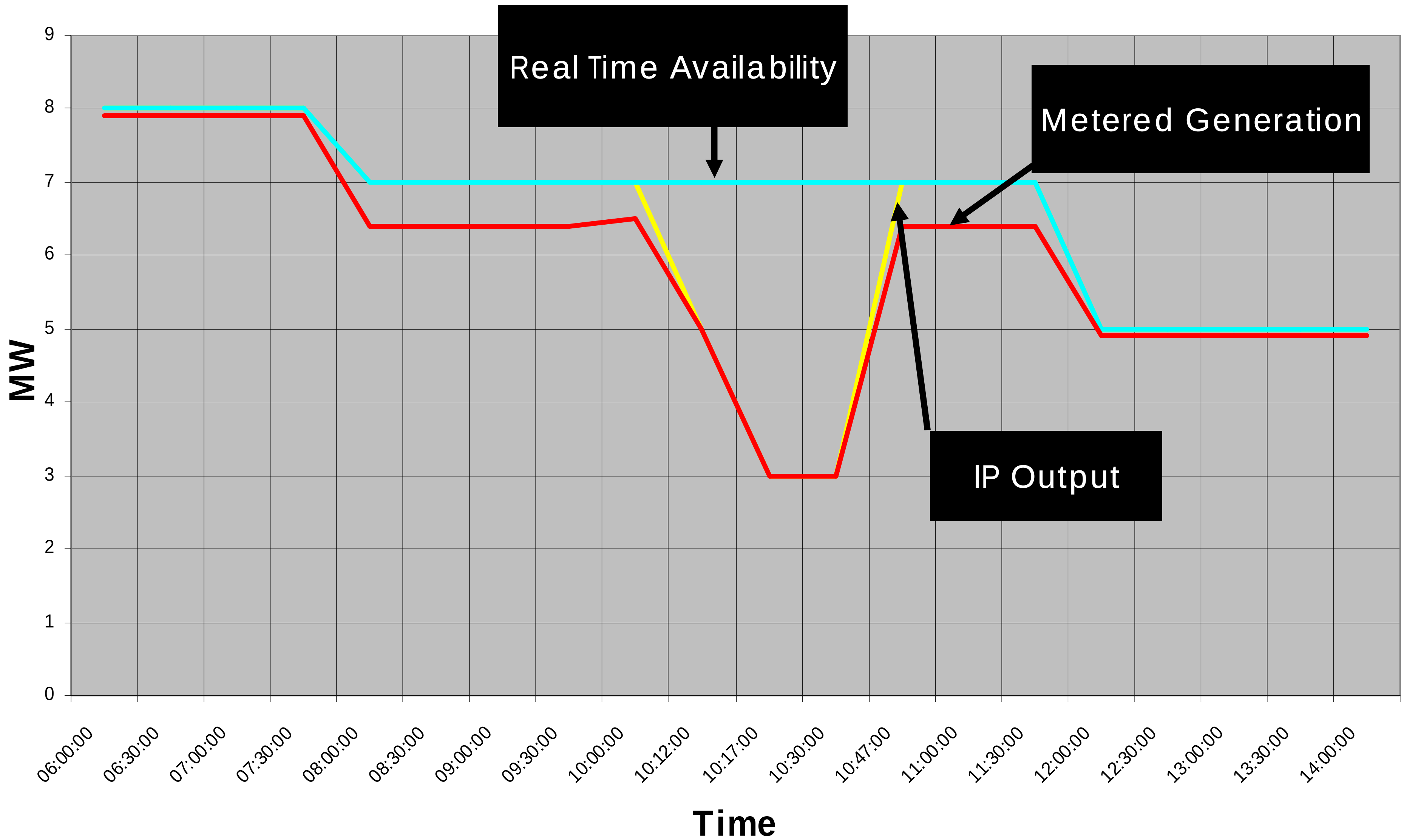
- Wind units are not treated like any other unit in terms of dispatch instructions
- Wind units are only given dispatch instructions when the Transmission System Operator makes a decision to curtail the output of a particular unit
- Under normal circumstances (i.e. not during a period of curtailment), the dispatch quantity for a wind unit will be set equal to its metered generation

Instruction Profiling – Example 3 – UNIT_3 (Dispatch Instructions)

- Instructions given to UNIT_3 as follows:

Unit Name	Effective Time	Instruction	Issue Time	Description
UNIT_3	14/02/2007 10:10:00 GMT	WIND CURL	14/02/2007 02:00:00 GMT	Unit 3 is instructed to curtail its output
UNIT_3	14/02/2007 10:10:00 GMT	MWOF 5	14/02/2007 06:18:00 GMT	Unit 3 is instructed to keep its generation output below 5MW
UNIT_3	14/02/2007 10:15:00 GMT	MWOF 3	14/02/2007 10:00:00 GMT	Unit 3 is instructed to keep its generation output below 3MW
UNIT_3	14/02/2007 10:45:00 GMT	WIND CRLO	14/02/2007 10:06:00 GMT	Unit 3 is instructed to return to the level of generation prior to curtailment

Instruction Profiling – Example 3 – UNIT_3



Instruction Profiling – Example 3 – UNIT_3 (Calculation of Dispatch Quantities)

- DQ = Metered Generation *(when not constrained down within a trading period)*

- DQ = Time weighted average of (Real Time Availability when not constrained down , Min (X, Real Time Availability) when constrained down

  (when constrained down for all or part of a trading period)

  where X = constrained down output

For Unit 3:

- Unit is not constrained down from 10:00 until 10:12 (12 mins)
- Unit is constrained down to 5 MW from 10:12 to 10:17 (5 mins)
- Unit is further constrained down to 3 MW from 10:17 to 10:30 (13 mins)
- So, for TP 10:00 to 10:30
  - DQ = ((12* 7)+5*min(5 ,7) +13*min(3,7))/30 = 4.93 MW

- Similarly Unit is constrained down to 3 MW from 10:30 to 10:47 (17 mins)
- Unit is no longer constrained down from 10:47 to 11:00 (13mins)
- So for TP 10:30 to 11:00:
  - DQ = (17*min(3 ,7) +13*7)/30 = 4.73 MW

Physical Markets Example
Unit 1 Dispatch Instructions / Quantities

Each dispatchable Unit will receive dispatch instructions as follows:

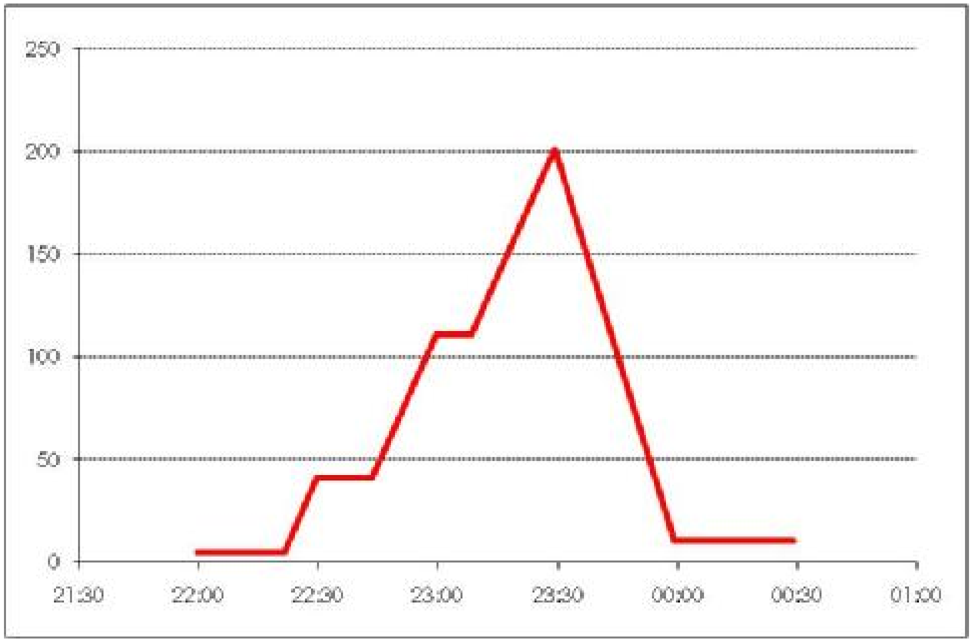
Unit Name	Effective Time	Instruction	Issue Time
UNIT_1	1 April 2006, 22:00	MWOF5	
UNIT_1	1 April 2006, 22:20	MWOF41	1 April 2006, 22:18
UNIT_1	1 April 2006, 22:42	MWOF111	1 April 2006, 22:40
UNIT_1	1 April 2006, 23:07	MWOF201	1 April 2006, 23:05
UNIT_1	1 April 2006, 23:29	MWOF10	1 April 2006, 23:27

- Unit 1 is already on at 5MW at the start of the example Trading Day
- It is dispatched to 41MW, then 111MW, then 201MW and finally 10MW

Physical Markets Example
Unit 1 Dispatch Instructions / Quantities

The Instruction Profiling Tool draws a piecewise curve using the Operational Characteristics

- DQuh for period 1 = 10MW
- DQuh for period 2 = 60MW
- DQuh for period 3 = 142MW
- DQuh for period 4 = 110MW
- DQuh for period 5 = 10MW
- DQuh for period 6 = 0MW



This data is then used in further processes (e.g. Settlements)

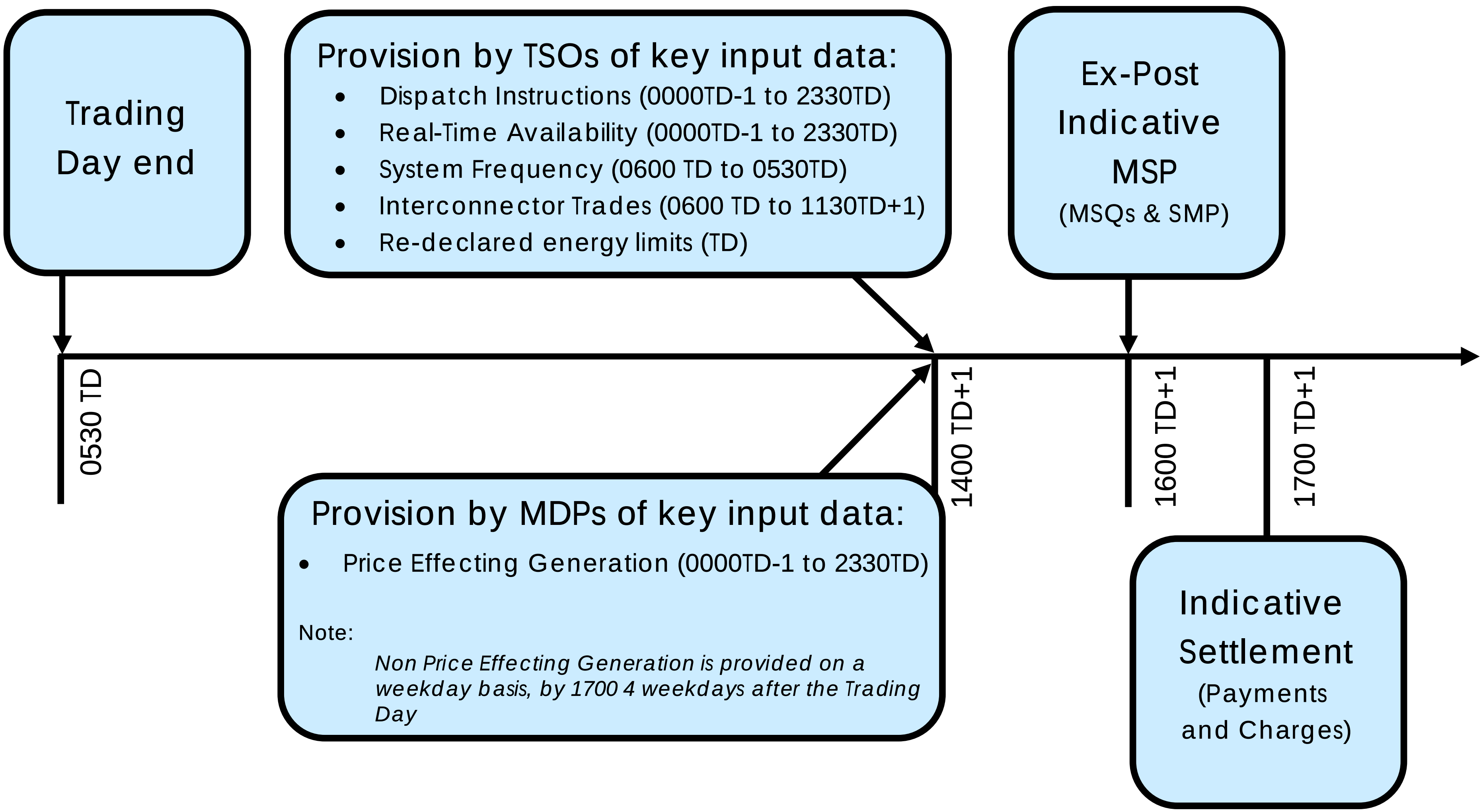
Ex-Post Indicative MSP Runs

Execution of Ex-Post Indicative MSP on TD+1

Based on the previous Trading Day's Ex-Post Indicative Market Schedule
Where possible, actual data is used

- Market Participant Data
- Prior to the execution of MSP, Dispatch Quantities will be calculated
- The Ex-Post Indicative MSP will:
  - Economically commit the Price Maker units using their offer data to meet the calculated Schedule Demand
  - Set MSQs for Price Taker Units based on Table 1 of the Trading and Settlement Code
- Ex-Post Indicative MSQs and Ex-Post Indicative SMPs for each Trading Period in the Trading Day make up the Ex-Post Indicative Market Schedule.

Ex-Post Indicative Timeline



Ex-Post Indicative MSP Inputs and Outputs

- Generator running and start-up costs
- Actual max and min availability levels until 00:00 on TD
- Information carried over from last Ex-Post MSP run
- Generator technical characteristics
- Interconnector data
- Data for special units e.g. energy limited units, pumped storage units
- Metered Generation and Metered Demand until 00:00 on TD
- Dispatch Instructions until 00:00 on TD
- Modified Interconnector User Nominations

Determine Ex-Post Indicative Market Schedule

- Market Schedule Quantities (MSQuh) over the Trading Day
- Dispatch Quantities (DQuh) until 00:00 on TD
- Availability Profile (APuh) and Actual Availability (AAuh) until 00:00 on TD
- Market prices over the day (SMPh used in Settlement)

Why all of these calculations?

For sites with on-site demand:

- Say that a Generator site has 2 Generator Units of 70MW and 50MW each (non-firm) and has on-site demand of 15MW. The site has a MEC (FAQSst) of 80MW.
- FAQuh allows the registered Firm Access Quantity to take into account the on-site demand.
- Without this credit, only 80MW would be able to be offered to the market.

Actual Availability Example: FAQ

Trading Site Name	Firm Access Quantity (FAQSsh)	Supplier Unit (v)	Metered Demand (MDvh - MW)	Resource Name	Resource Type	Trading Period	Dispatch Quantity (DQuh)	Availability Profile (APuh)
Example Trading Site	80.00	ETSSU1	30.00	UU1	PPMG	07/02/2007 07:30:00 GMT	65.00	70.00
				UU2	PPMG	07/02/2007 07:30:00 GMT	45.00	50.00

Step1 :

FAQSsh+MDvh	110.00
SumAPuh	120.00

Resource Name	FAQuh
UU1	64.17
UU2	45.83

Step 2 :

Sum(AQuh)-SAQsh	0.83

Resource Name	AQuh	AQuh-DQuh
UU1	65.00	-
UU2	45.83	0.83

Step 3 :

SumDQuh	110.00

Trading Site Name	SAQuh
Example Trading Site	110.00

Step 4 :

Resource Name	AAuh
UU1	65.00
UU2	45.00

Ex-Post Indicative MSP:
Generation to be met by Price Makers

For the Ex Post Indicative MSP, input data combines actual and forecast values

Optimisation Time Horizon	
Schedule Demand = 1. Metered Price-Maker generation (non-DSU/IU) Plus 2. Metered Interconnector Unit generation (calculated) Plus 3. Metered Demand-Side Unit generation (calculated) Plus 4. Load Shedding Estimate Plus 5. Dispatch Quantity for the Int. Residual Capacity Unit Minus 6. Sum of PPTG differences (NomProfile-MG) Minus 7. Sum of VPTG differences (AvailProfile-MG)	Schedule Demand = 1. Composite Demand Forecast Minus 2. Min(Predictable Price Taker and Variable Non-Wind Price-Taker Nominations, Availability) Minus 3. Min(Variable Wind Price-Taker Forecast, Availability) 4. Autonomous Wind Generation Forecast by Unit

0600 0000 0600 1200

System Operator Interconnector Trades

TSO Trades can be made by TSOs, using spare capacity on the relevant interconnector. These trades will be made at TSO discretion.

Data recorded by the relevant TSO (for each Trading Period in the Optimisation Time Horizon):

- SIIP (Import Price in £/MWh or €/MWh)
- SIEP (Export Price in £/MWh or €/MWh)
- SIIQ (Import Quantity in MW)
- SIEQ (Export Quantity in MW)

- DQ = SIIQ + SIEQ

Ex Post Indicative MSP – Key Data Outputs

Data Outputs

- Availability Profile (APuh) per Trading Period for 0600 to 0000 on Trading Day
- Actual Availability (AAuh) per Trading Period for 0600 to 0000 on Trading Day
- Ex Post Indicative SMP (€ or £/MWh by Trading Period for Trading Day)
- Ex Post Indicative MSQs (MW by Trading Period by Unit for Trading Day)
- Dispatch Quantity (DQuh) for 0600 to 0000 on Trading Day for each Unit for use in Settlement
- Alarm Reports by Trading Period (Alarm Time, Alarm Description, Alarm Acceptance, Other...)
- Violated Constraints by Trading Period (Violation Time, Constraint, Other...)

Physical Markets Example
Ex Post Indicative Inputs

Ex Post MSP Runs use actual data where possible (for the following data, rules are applied where data is not available for the full Optimisation Time Horizon)

- From Meter Data Providers - Metered Generation
- From TSOs - Dispatch Instructions (Dispatch Quantities calculated)
- From TSOs – Spot Availability (Actual Availability calculated – in our example it is assumed that AAuh = APuh)

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 1 - Availability Profile - APuh	10	150	170	150	20	0
Unit 1 - Minimum Stable Generation Profile MINGENuh	0	0	0	0	0	0
Unit 1 - Dispatch Quantity - DQuh	10	60	142	110	10	0
Unit 1 - Metered Generation - MGuh	10	60	142	90	10	0
Unit 2 - Availability Profile - APuh	55	180	300	300	100	0
Unit 2 - Minimum Stable Generation Profile MINGENuh	0	0	0	0	0	0
Unit 2 - Dispatch Quantity - DQuh	50	175	170	180	0	0
Unit 2 - Metered Generation - MGuh	50	175	170	180	10	0
Unit 3 - Dispatch Quantity - DQuh	22	22	38	52	42	10
Unit 3 - Metered Generation - MGuh	22	22	38	52	42	10

Physical Markets Example
Ex Post Indicative Schedule Demand

Ex Post Indicative Schedule Demand is calculated from a combination of actual and estimated data

- In our example, we do not have sufficient data from period 5
- Instead, we use the Schedule Demand calculated for the Ex Ante MSP run

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Metered Generation for Price Makers	60	235	312	270		
Metered Generation for Interconnector Units	0	0	0	0		
Metered Generation for Demand Side Units	0	0	0	0		
Load Shedding Estimate	0	0	0	0		
DQ for the Interconnector Residual Capacity Unit	0	0	0	0		
Sum of PPTG differences	-2	-2	2	-2		
Ex Ante Schedule Demand					48	0
Schedule Demand (i.e. Generation Requirement)	58	233	314	268	48	0

Physical Markets Example
Ex Post Indicative Schedule

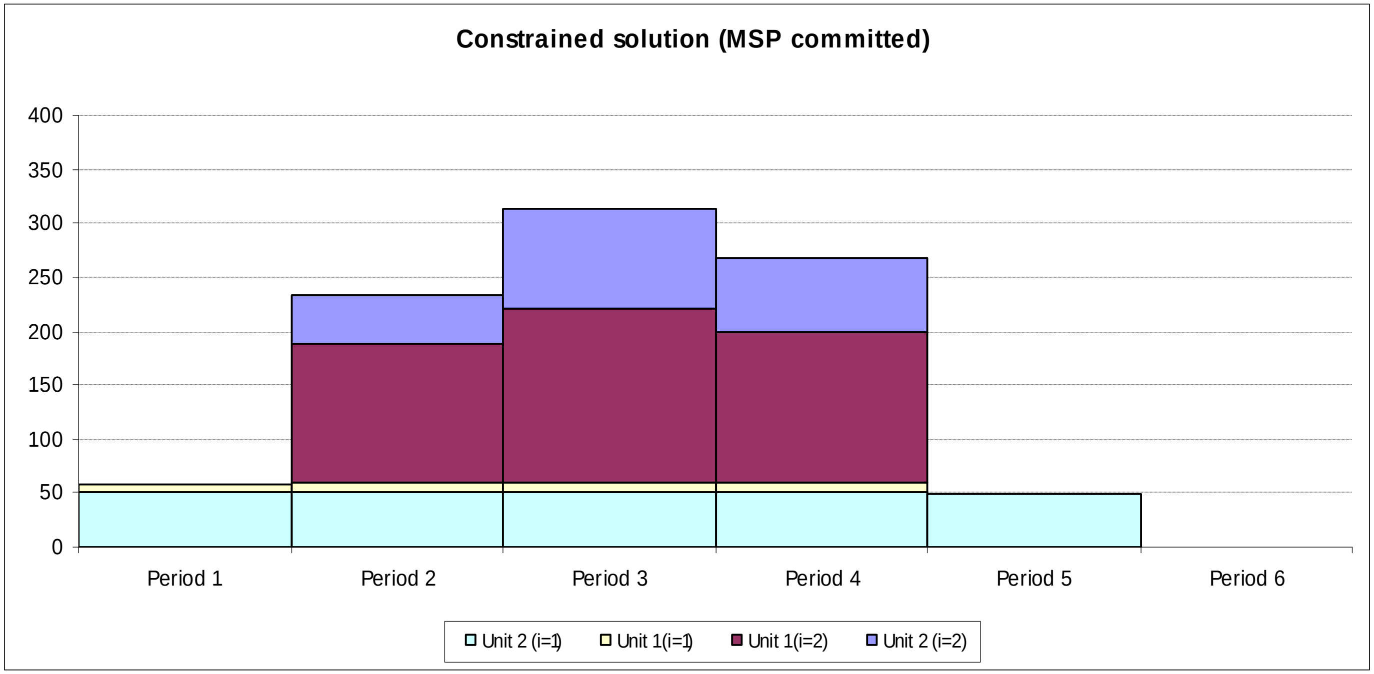
With no inter-temporal constraints, the schedule would be as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2)	0	33	94	68	0	0
Unit 1 (i=2)	0	140	160	140	0	0
Unit 1 (i=1)	8	10	10	10	0	0
Unit 2 (i=1)	50	50	50	50	48	0

Taking ramp rates into account, the final schedule is as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2) Price = 65	0	45	94	68	0	0
Unit 1 (i=2) Price = 45	0	128	160	140	0	0
Unit 1 (i=1) Price = 15	8	10	10	10	0	0
Unit 2 (i=1) Price = 10	50	50	50	50	48	0

Physical Markets Example
Ex Post Indicative Merit Order



This is the "ramp-constrained" schedule, minimising costs (bids) to meet Schedule Demand

Physical Markets Example
Shadow Price and SMP discussion

The Shadow Price calculated by the MSP Software will be:

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Indicative Shadow Price	15	65	65	65	10	0

- Shadow Prices form the basis of the SMP calculation
- However, paying for generation at shadow prices will mean that Generator Units will not recover the full costs of production

- As a result, there is a further process undertaken to determine System Marginal Prices (SMPs):
  - SMP takes into account No Load and Start Up Costs
  - SMP ensures that all Units running will at least meet their costs of running (PQ, Start Up and No Load) across the Trading Day

Physical Markets Example
Ex Post Indicative SMP Step 1

SMP Step 1 ensures that Units recover their running costs:

INITIAL SMP CALCULATIONS

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Indicative Shadow Price	15.00	65.00	65.00	65.00	10.00	-
Running Cost - Unit 1	-	12,320	14,319	13,070	-	-
Running Cost - Unit 2	2,819	4,005	5,298	4,612	2,746	
Ex Post Indicative - SMP Step 1	**15.00**	**125.27**	**65.00**	**65.00**	**10.00**	**-**
Revenue - Unit 1	120	18,790	11,050	9,750	-	-
Revenue - Unit 2	750	10,397	9,360	7,670	480	-

Production Cost	**68,367**
Unit 1 Profit	**-**
Unit 2 Profit	**9,177**

- Simple linear program which ensures that:
  - Total production cost is minimised
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
- Price in Trading Period raised from €65 to €125.27, otherwise Unit 1 would not break even

Physical Markets Example
Ex Post Indicative SMP Final Step

With **α**=0, **β**=1 and **δ**=5 – this ensures that the SMP algorithm will minimise the overall gap between the Shadow Price and the resulting SMP.

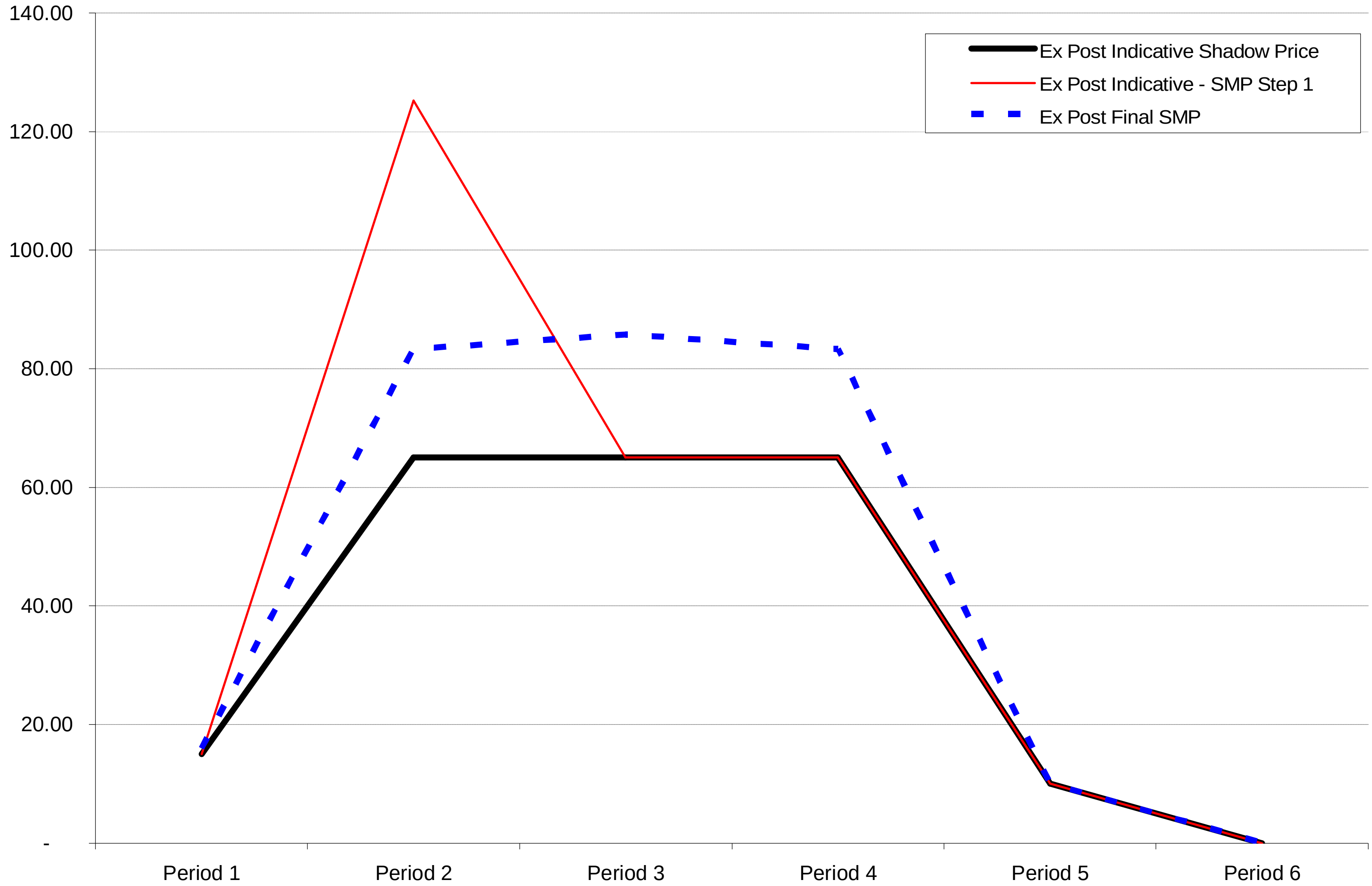
FINAL SMP CALCULATIONS

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Shadow Price	15.00	65.00	65.00	65.00	10.00	-
SMP from Step 1	15.00	125.27	65.00	65.00	10.00	-
Running Cost - Unit 1	-	12,320	14,319	13,070	-	-
Running Cost - Unit 2	2,819	4,005	5,298	4,612	2,746	-
Ex Post Indicative Final SMP	**15.98**	**83.33**	**85.78**	**83.33**	**10.00**	**-**
Revenue - Unit 1	128	12,500	14,582	12,500	-	-
Revenue - Unit 2	799	6,917	12,352	9,833	480	-

Production Cost	**70,091**
Unit 1 Profit	**-**
Unit 2 Profit	**10,901**

- Simple linear program which ensures that:
  - SMP is set to minimise
    - α * total payment over the Trading Day to the price makers at SMP, plus β * Sum over all periods of (SMP – shadow price)^2
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
  - Total payment must be less than REVMIN * (1 + δ)

Physical Markets Example
SMP and Shadow Prices



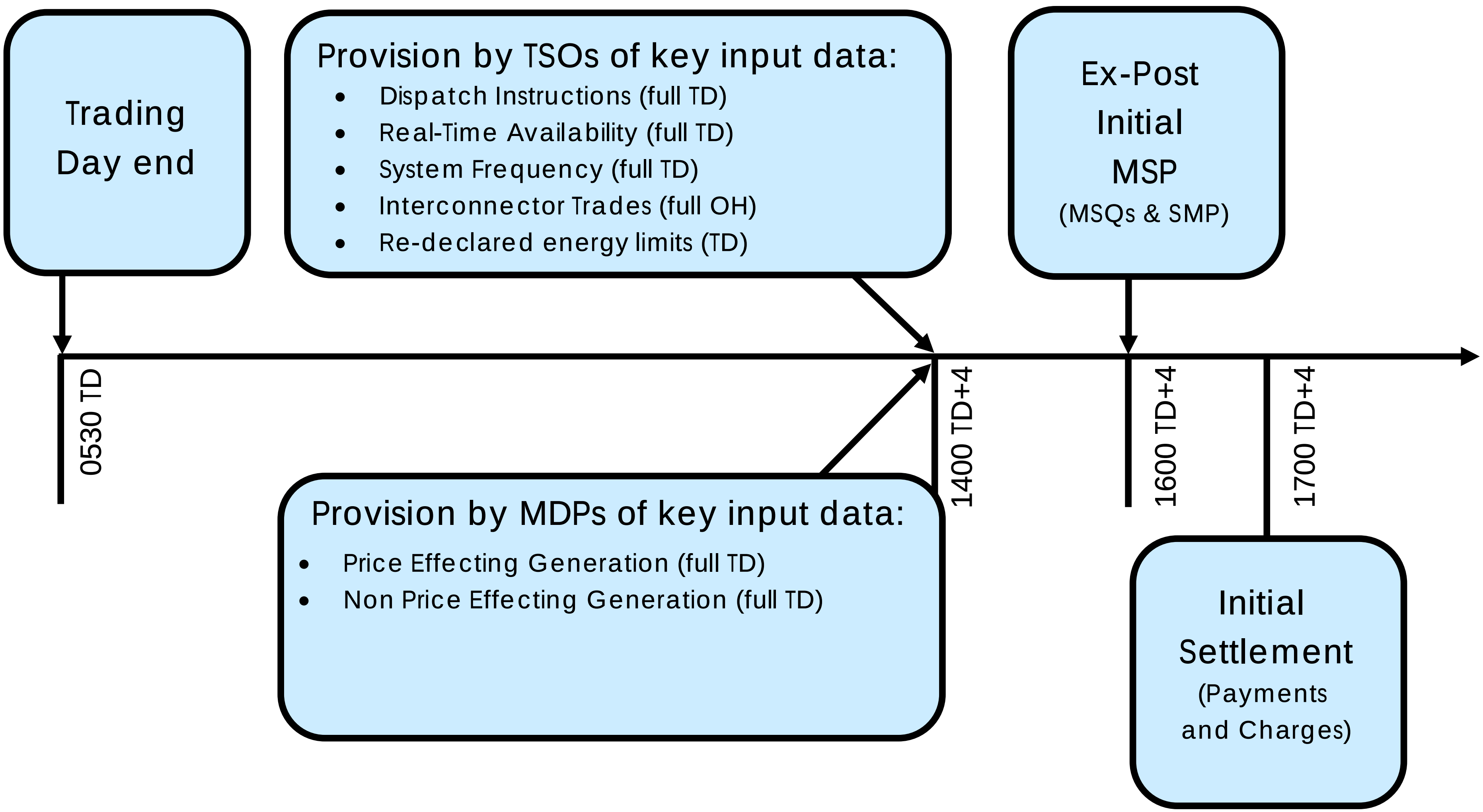
Ex-Post Initial MSP Runs

Execution of Ex-Post MSP on TD+4 and as required

Based on the previous Trading Day's Ex-Post Market Schedule
All actual data required for the run will be available

- Market Participant Data
- Prior to the execution of MSP, Dispatch Quantities will be re-calculated (in case Dispatch Instructions have been re-submitted between TD+1 and TD+4)
- The Ex-Post Initial MSP run will:
  - Economically commit the Price Maker units using their offer data to meet the calculated Schedule Demand
  - Set MSQs for Price Taker Units based on Table 1 of the Trading and Settlement Code
- Ex-Post Initial MSQs and Ex-Post Initial SMPs for each Trading Period in the Trading Day make up the Ex-Post Initial Market Schedule.

Ex-Post Initial Timeline



Ex-Post Initial MSP Inputs and Outputs

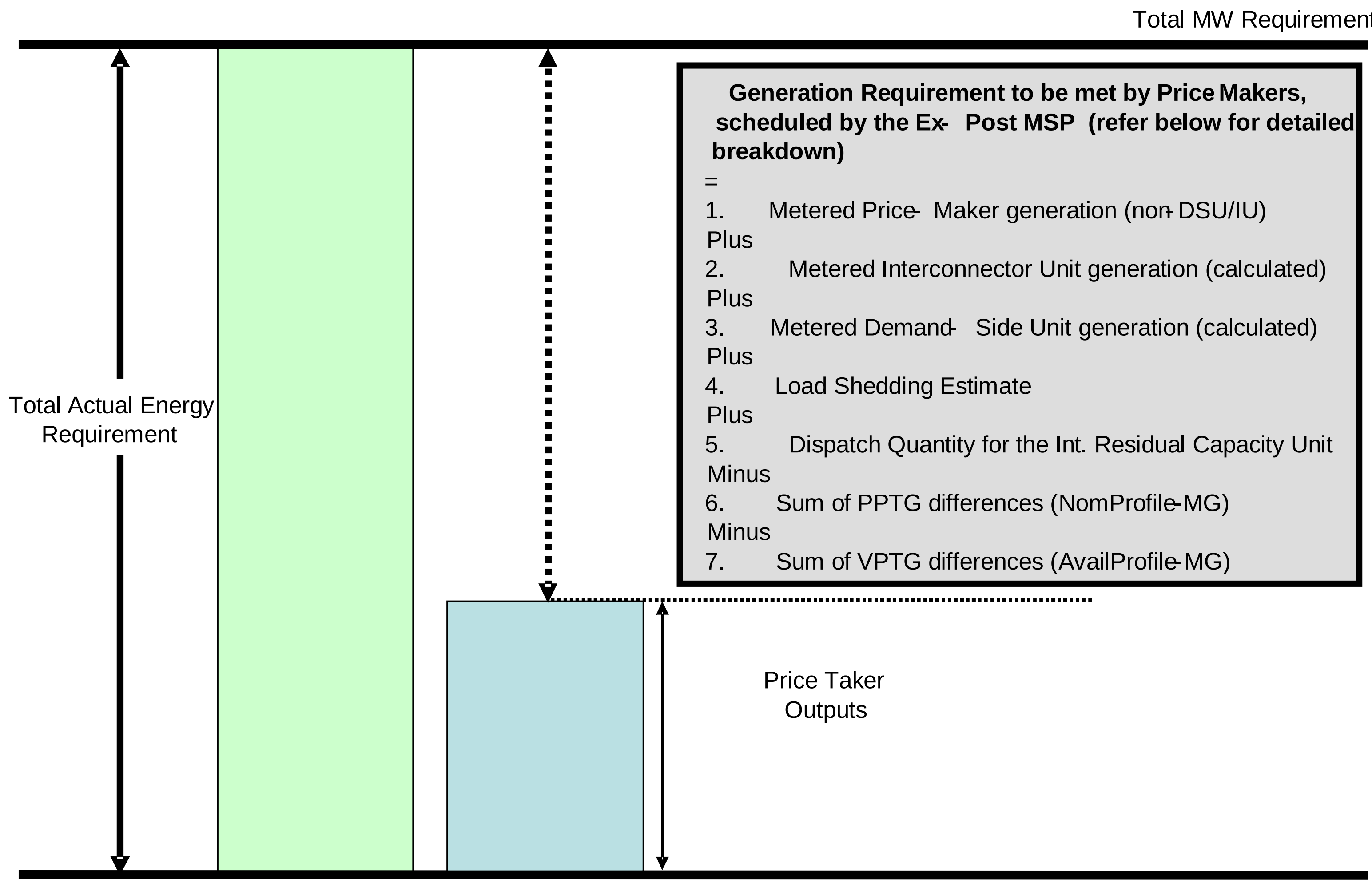
- Generator running and start-up costs
- Actual max and min availability levels over the day
- Information carried over from last Ex-Post MSP run
- Generator technical characteristics
- Interconnector data
- Data for special units e.g. energy limited units, pumped storage units
- Metered Generation and Metered Demand
- Dispatch Instructions
- Modified Interconnector User Nominations

Determine Ex-Post Market Schedule

- Market Schedule Quantities (MSQuh) over the Trading Day
- Dispatch Quantities (DQuh) over the Trading Day
- Availability Profile (APuh) and Actual Availability (AAuh) for each Trading Period
- Market prices over the day (SMPh used in Settlement)

Ex-Post Initial MSP:
Generation to be met by Price Makers

EX-POST MSP



Ex Post Initial MSP – Key Data Outputs

Data Outputs

- Availability Profile (APuh) per Trading Period for Trading Day
- Actual Availability (AAuh) per Trading Period for Trading Day
- Ex Post Indicative SMP (€ or £/MWh by Trading Period for Trading Day)
- Ex Post Indicative MSQs (MW by Trading Period by Unit for Trading Day)
- Dispatch Quantity (DQuh) for each Unit for use in Settlement
- Alarm Reports by Trading Period (Alarm Time, Alarm Description, Alarm Acceptance, Other...)
- Violated Constraints by Trading Period (Violation Time, Constraint, Other...)

Physical Markets Example
Ex Post Initial Inputs

For Ex Post Initial MSP Runs, all actual data required will be available

- From Meter Data Providers - Metered Generation
- From TSOs - Dispatch Instructions (Dispatch Quantities calculated)
- From TSOs – Spot Availability (Actual Availability calculated – in our example it is assumed that AAuh = APuh)

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 1 - Availability Profile - APuh	9	150	170	150	20	0
Unit 1 - Minimum Stable Generation Profile MINGENuh	0	0	0	0	0	0
Unit 1 - Dispatch Quantity - DQuh	10	60	148	110	10	0
Unit 1 - Metered Generation - MGuh	10	60	148	90	20	0
Unit 2 - Availability Profile - APuh	55	180	300	300	100	0
Unit 2 - Minimum Stable Generation Profile MINGENuh	0	0	0	0	0	0
Unit 2 - Dispatch Quantity - DQuh	50	175	170	180	0	0
Unit 2 - Metered Generation - MGuh	50	175	170	180	40	0
Unit 3 - Dispatch Quantity - DQuh	22	22	38	52	42	10
Unit 3 - Metered Generation - MGuh	22	22	38	52	42	10

Physical Markets Example
Ex Post Indicative Schedule Demand

Ex Post Initial Schedule Demand is calculated in the same way for the entire Optimisation Time Horizon

- Same as Ex Post Indicative for periods 1 to 4
- Periods 5 and 6 use same calculation as 1 to 4, as data is available
- Ex Post Initial MSP uses this data to schedule Price Makers

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Metered Generation for Price Makers	60	235	312	270	60	0
Metered Generation for Interconnector Units	0	0	0	0	0	0
Metered Generation for Demand Side Units	0	0	0	0	0	0
Load Shedding Estimate	0	0	0	0	0	0
DQ for the Interconnector Residual Capacity Unit	0	0	0	0	0	0
Sum of PPTG differences	-2	-2	2	-2	-2	0
Schedule Demand (i.e. Generation Requirement)	58	233	314	268	58	0

Calculated for Unit 3 as:

1) Nomination Quantity = 40MW

2) Metered Generation = 38MW

Unit 3 is constrained up by 2MW.

Physical Markets Example
Ex Post Initial Schedule

With no inter-temporal constraints, the schedule would be as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2)	0	33	100	68	0	0
Unit 1 (i=2)	0	140	160	140	0	0
Unit 1 (i=1)	8	10	10	10	8	0
Unit 2 (i=1)	50	50	50	50	50	0

Taking ramp rates into account, the final schedule is as follows

Merit Order (in descending order of cost):	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Unit 2 (i=2)	0	50	100	68	0	0
Unit 1 (i=2)	0	123	160	140	0	0
Unit 1 (i=1)	8	10	10	10	8	0
Unit 2 (i=1)	50	50	50	50	50	0

Physical Markets Example
Shadow Price and SMP discussion

The Shadow Price calculated by the MSP Software will be:

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Initial Shadow Price	15	45	45	65	10	0

- Shadow Prices form the basis of the SMP calculation
- SMP takes into account No Load and Start Up Costs
- SMP ensures that all Units running will at least meet their costs of running (PQ, Start Up and No Load) across the Trading Day

Physical Markets Example
Ex Post Initial SMP Step 1

SMP Step 1 ensures that Units recover their running costs:

INITIAL SMP CALCULATIONS

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Initial Shadow Price	15.00	45.00	45.00	65.00	10.00	-
Running Cost - Unit 1	-	12,033.79	14,352.21	13,099.01	-	-
Running Cost - Unit 2	2,782.05	4,064.10	5,346.15	4,525.64	2,782.05	
Ex Post Initial - SMP Step 1	**15.00**	**145.90**	**45.00**	**65.00**	**10.00**	**-**
Revenue - Unit 1	120.00	21,885.00	7,650.00	9,750.00	80.00	-
Revenue - Unit 2	750.00	12,109.70	6,750.00	7,670.00	500.00	-

Production Cost	**67,264.70**
Unit 1 Profit	**-**
Unit 2 Profit	**8,279.70**

- Simple linear program which ensures that:
  - Total production cost is minimised
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
- Price in Trading Period 2 raised from €45 to €145.90, otherwise Unit 1 would not break even

Physical Markets Example
SMP Final Step

With **α**=0, **β**=1 and **δ**=5 – this ensures that the SMP algorithm will minimise the overall gap between the Shadow Price and the resulting SMP.

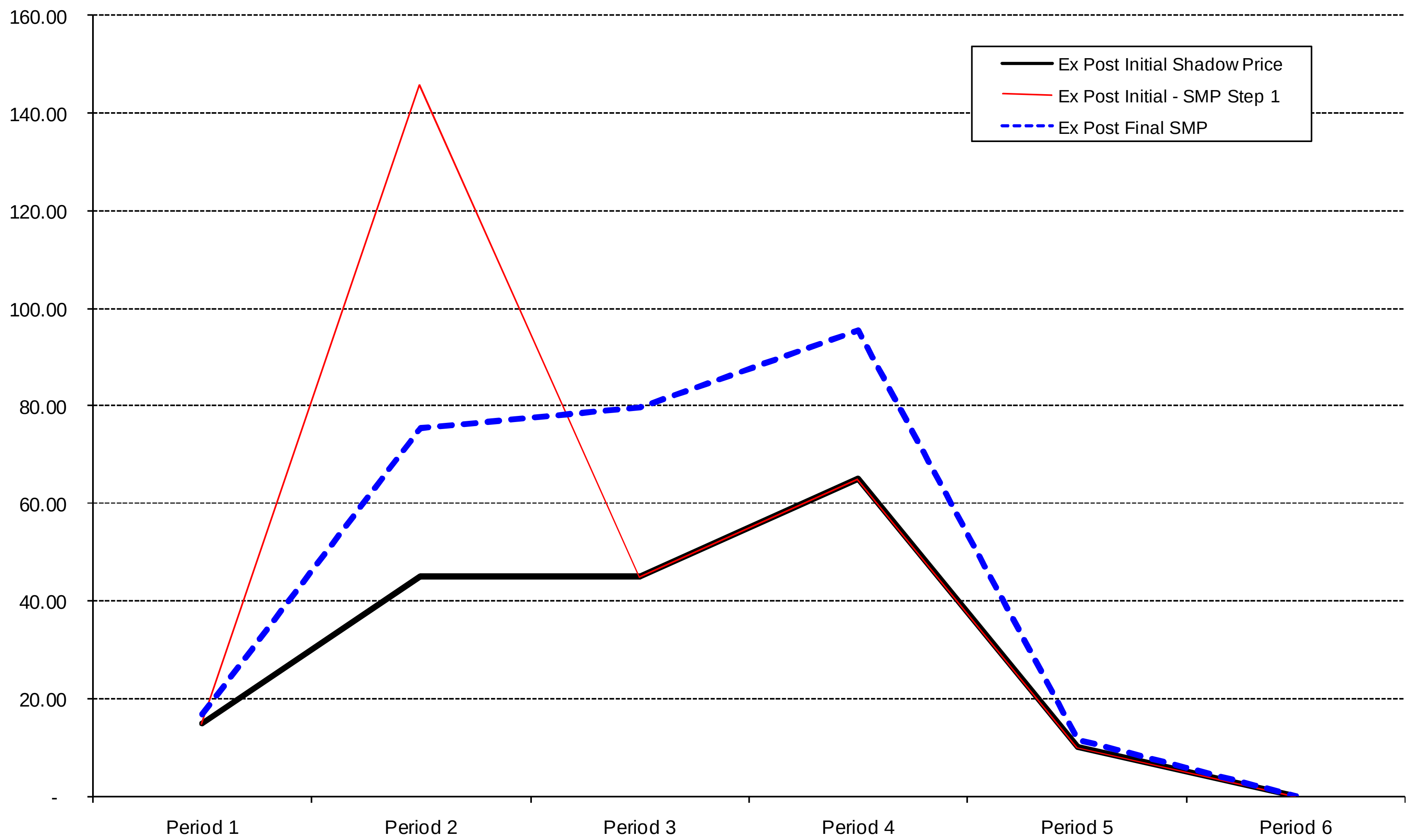
FINAL SMP CALCULATIONS

	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
Ex Post Shadow Price	15.00	45.00	45.00	65.00	10.00	-
Initial SMP	15.00	145.90	45.00	65.00	10.00	-
Running Cost - Unit 1	-	12,033.79	14,352.21	13,099.01	-	-
Running Cost - Unit 2	2,782.05	4,064.10	5,346.15	4,525.64	2,782.05	-
Ex Post Initial - Final SMP	**16.64**	**75.67**	**79.76**	**95.67**	**11.64**	**-**
Revenue - Unit 1	133.08	11,350.12	13,558.60	14,350.12	93.08	-
Revenue - Unit 2	831.78	6,280.40	11,963.47	11,288.76	581.78	-

Production Cost	**70,431.18**
Unit 1 Profit	**0.00**
Unit 2 Profit	**11,446.18**

- Simple linear program which ensures that:
  - SMP is set to minimise
    - α * total payment over the Trading Day to the price makers at SMP, plus β * Sum over all periods of (SMP – shadow price)^2
  - Unit 1 and Unit 2 at least break even
  - Resulting SMP values are ≥ Shadow Prices
  - Total payment must be less than REVMIN * (1 + δ)

Physical Markets Example
Ex Post Initial SMP and Shadow Prices



Summary of Physical Market

Physical Market Summary

The Physical Market has the following components:

- MSP Software Runs, including:
  - Ex Ante Indicative MSP Runs
  - Ex Post Indicative MSP Runs
  - Ex Post Initial MSP Runs
  - Re-runs as required
- Operations Scheduling
- Instruction Profiling

Physical Market Summary – MSP Runs

3 stages of MSP software:

1. Unit Commitment
2. Economic Dispatch
3. System Marginal Price

Key constraints:

- Meeting Schedule Demand
- Observing Generating Unit technical constraints
- Minimising total production cost of meeting Schedule Demand
- Observing energy limits and target reservoir levels

Physical Market Summary – SMPs

Interim outputs of the MSP Software include Shadow Prices, which do not reflect the full costs (bids, Start Up Costs and No Load Costs) of running:

1. Minimise production costs, but raise prices to ensure that costs are recovered

2. "Sculpt" SMPs using the tuning parameters (α, β and δ) which are defined by the Regulatory Authorities

Physical Market Summary – Operations Scheduling

Operations Scheduling:

- Carried out by TSOs
- Indicate how MPs are planned to be run the next day
- Used within day to assist scheduling and dispatch decisions
    - Reserve requirements – 4 types modelled
    - Transmission constraints – not currently fully modelled, instead as Generator groups
    - North – South Limitations

Physical Market Summary – Instruction Profiling

- Designed to calculate Dispatch Quantities provided to Generating and Demand Side Units within the Trading Day
- Used to calculate constraint payment, uninstructed imbalances and make whole payments
- Dispatch Instructions are submitted by TSOs
- Validations and logic is applied to the received instructions
- For Units which have received dispatch instructions:
  - Using Participant-submitted technical data (e.g. ramp rates), a dispatch profile is generated
  - Instructed quantities are inserted at the boundary of each Trading Period
  - The area under the curve and bounded by the Trading Period boundary is calculated
  - For most units, this area is the Dispatch Quantity (DQuh)
- Specific rules for Special Units

Physical Market Scope

Did we achieve our scope?

Element	Done?
Key elements of the Physical Market	þ
Key data submitted by different Units	þ
How Units are scheduled by the MSP Software	þ
Data used for the Ex Ante Indicative MSP Run	þ
How SMP is calculated	þ
What the Operations Schedule is	þ
How Instruction Profiling works	þ
Data used for the Ex Post Indicative MSP Run	þ
Data used for the Ex Post Initial MSP Run	þ

Questions?

Appendix

Key Terminology

- ACH (Active Capacity Holdings)
- APTG (Autonomous Price Taker Generator)
- ATC (Available Transmission Capacity)
- BETTA (British Electricity Transmission & Trading Arrangements)
- CH (Capacity Holdings)
- COD (Commercial Offer Data)
- DQs (Dispatch Quantities)
- EA (Ex Ante)
- Ex-Ante IMS (Indicative Market Schedule)
- I/C (Interconnector)
- IA (Interconnector Administrator)
- ID (Identification)
- IU (Interconnector User)
- IUNS (Interconnector User Nominations)

Key Terminology

- MDP (Meter Data Provider)
- MIUNS (Modified Interconnector User Nominations)
- MP (Market Participant)
- MRSO (Meter Registration System Operator)
- MSP (Market Scheduling and Pricing)
- MW (Mega watt)
- MWh (Mega watt hours)
- NIE (Northern Ireland Energy)
- PM (Physical Market)
- PPMG (Predictable Price Maker Generator)
- PPTG (Predictable Price Taker Generator)
- PQ (Price Quantity)
- PSCE (Pumped Storage Cycle Efficiency)
- RAs (Regulators)
- SEM (Single Electricity Market)
- SEMO (Single Electricity Market Operator)
- SMO (Single Market Operator)

Key Terminology

- SMP (System Marginal Price)
- SONI (System Operator Northern Ireland)
- STMC (Short Term Maximisation Capacity)
- T&SC (Trading and Settlement Code)
- TD (Trading Day)
- TOD (Technical Offer Data)
- TSO (Transmission System Operator)
- Tx (Transmission)
- UC (Unit Commitment)
- VPMG (Variable Price Maker Generator)
- VPTG (Variable Price Taker Generator)