Defining and Formulating Operating Reserve Requirements and Deployments

Erik Ela, Eamonn Lannoye, Aidan Tuohy, Bob Entriken, Russ Philbrick

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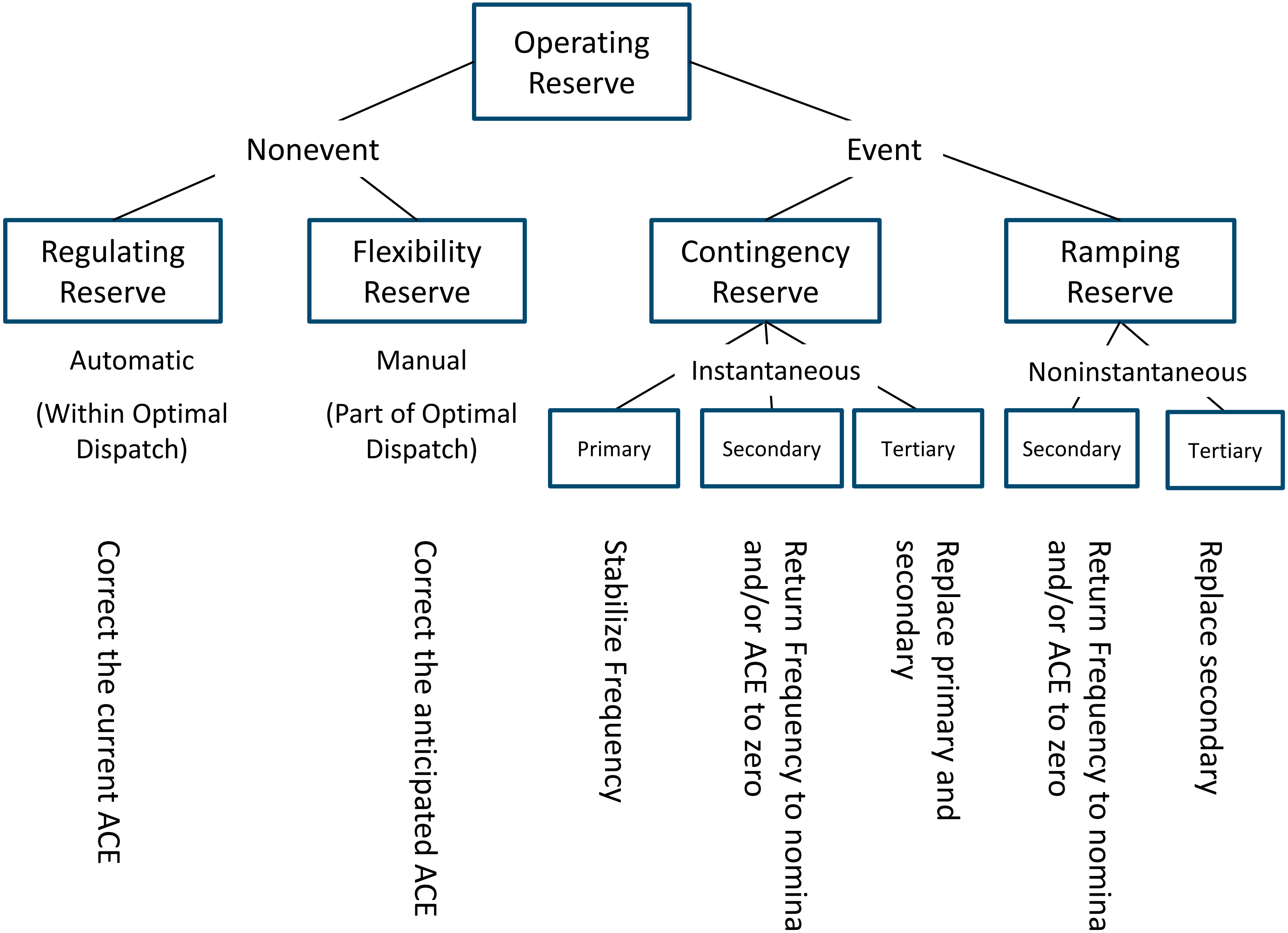
Agenda

- Operating Reserve Needs: A Review
- Defining Operating Reserve from a “Market Software” Perspective
- Operating Reserve Formulations
  - Can the formulation be more important than the quantity?
- Examples (preliminary):
  - Flexible ramping product and regulation interaction
  - Interval timestamp definitions, meeting the average vs. instantaneous demand
- Conclusions and Future Work



E. Ela, M. Milligan, and B. Kirby, *Operating Reserves and Variable Generation,* Technical Report, NREL/TP-5500-51978, Aug. 2011.

New Reserve Products Emerging

Flexible Ramping

Ramp Capability

Primary Frequency Response

BAAL

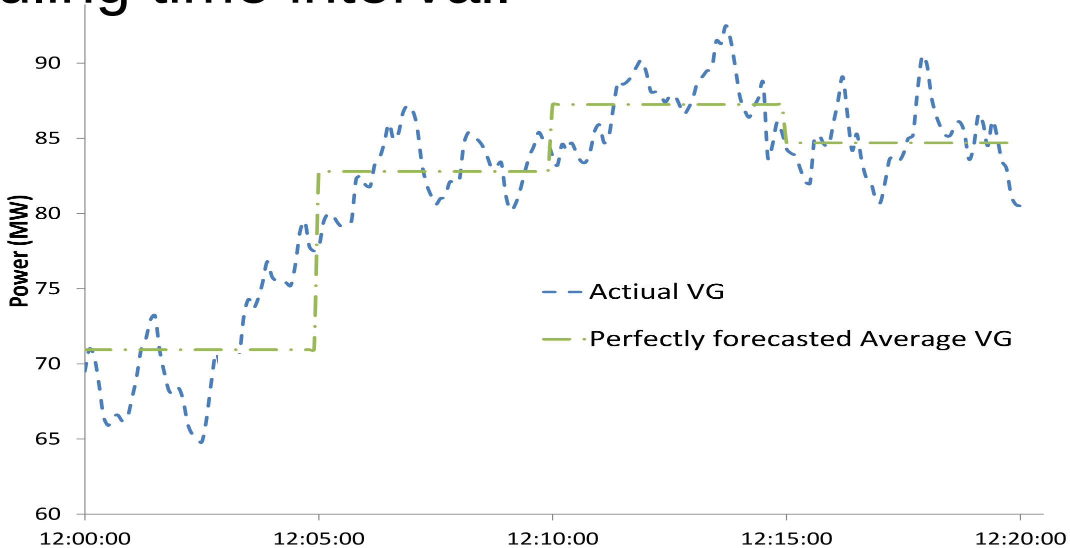
Load Following Reserve

Regulation Mileage

RUC Capacity

Operating Reserve Need

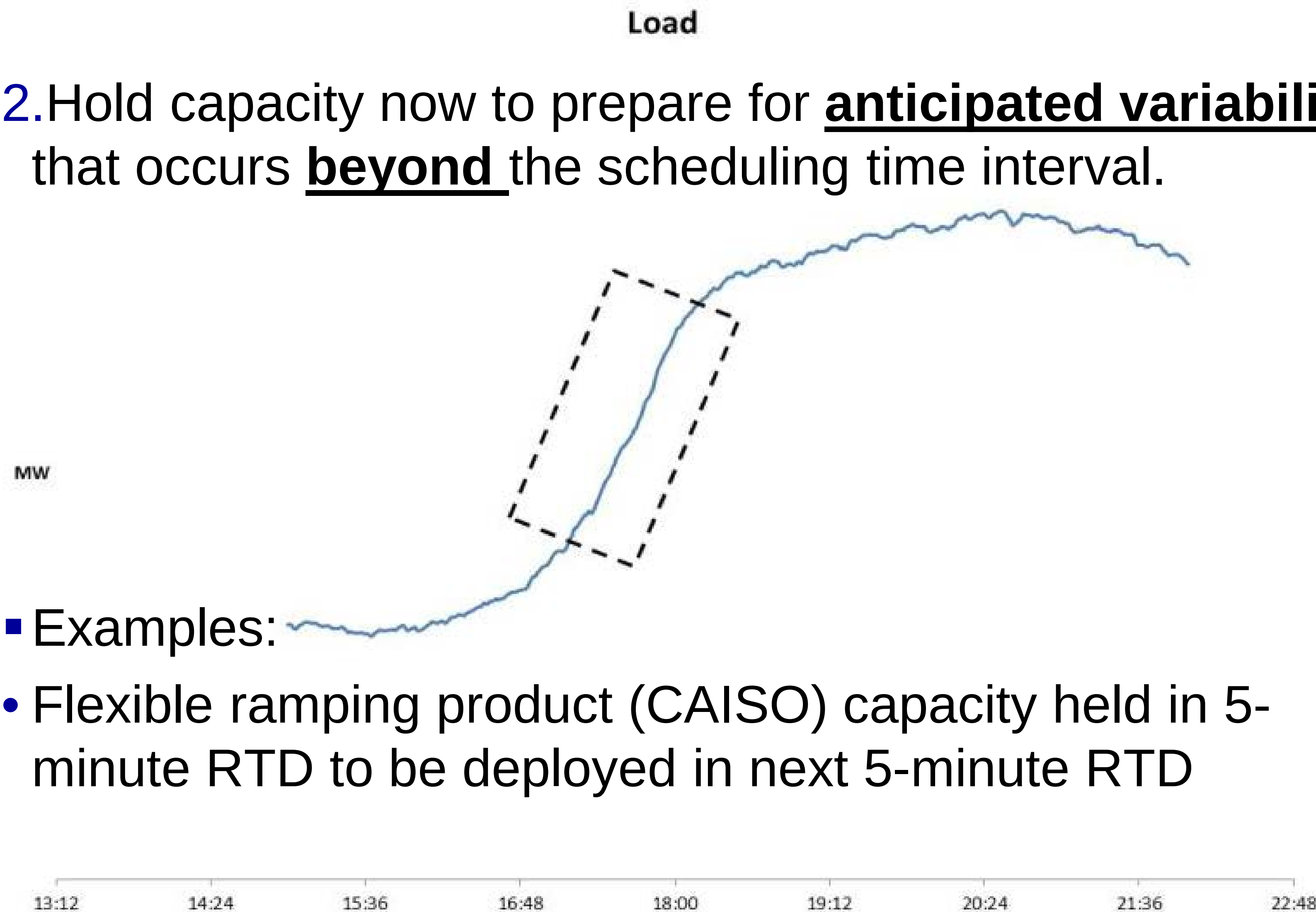
1. Hold capacity now to meet the **variability** that occurs **within** the scheduling time interval.



- Examples:
- Regulation (NERC/FERC) capacity held in hourly DASCUC, and 5-min RTSCED to be deployed in 4-second AGC
- Flexible ramp constraint (CAISO) capacity held in 15-minute RTPD to be deployed in 5-minute RTD

Operating Reserve Need

2. Hold capacity now to prepare for **<u>anticipated variability</u>** that occurs **<u>beyond</u>** the scheduling time interval.



- Examples:
- Flexible ramping product (CAISO) capacity held in 5-minute RTD to be deployed in next 5-minute RTD

Operating Reserve Need

3. Hold capacity now to prepare for **uncertain outcomes** that occur in **within or beyond** the scheduling time interval.

- Examples:
  - Contingency reserve held in all normal scheduling models and deployed due to uncertain contingencies
  - (everything else)

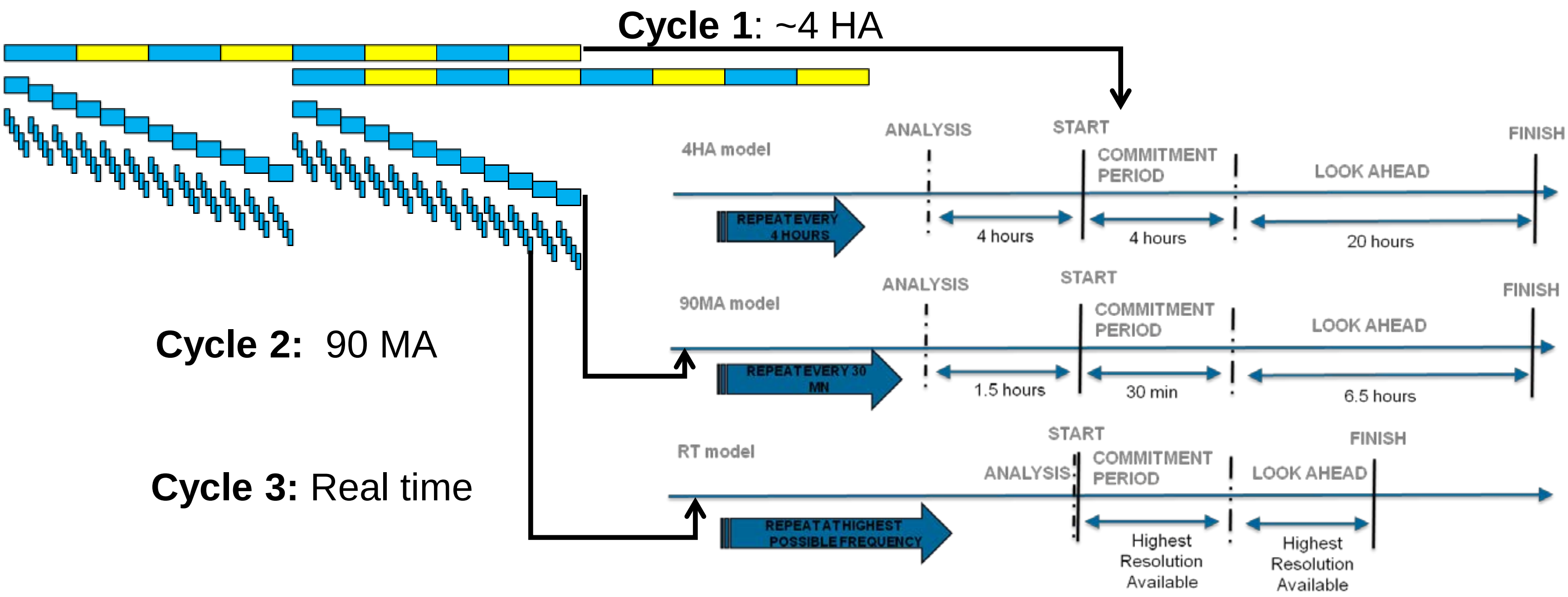
Operating Reserve Need

1. Hold capacity now to meet the **variability** that occurs **within** the scheduling time interval.
   - Reserve constraint vs. faster scheduling time resolution

2. Hold capacity now to prepare for **anticipated variability** that occurs **beyond** the current scheduling time interval.
   - Reserve constraint vs. multi-period optimization and longer horizons

3. Hold capacity now to prepare for **uncertain outcomes** that occur in **within or beyond** the scheduling time interval.
   - Reserve constraint vs. scheduling toward multiple scenarios

Defining Reserve in "Market Software" Context



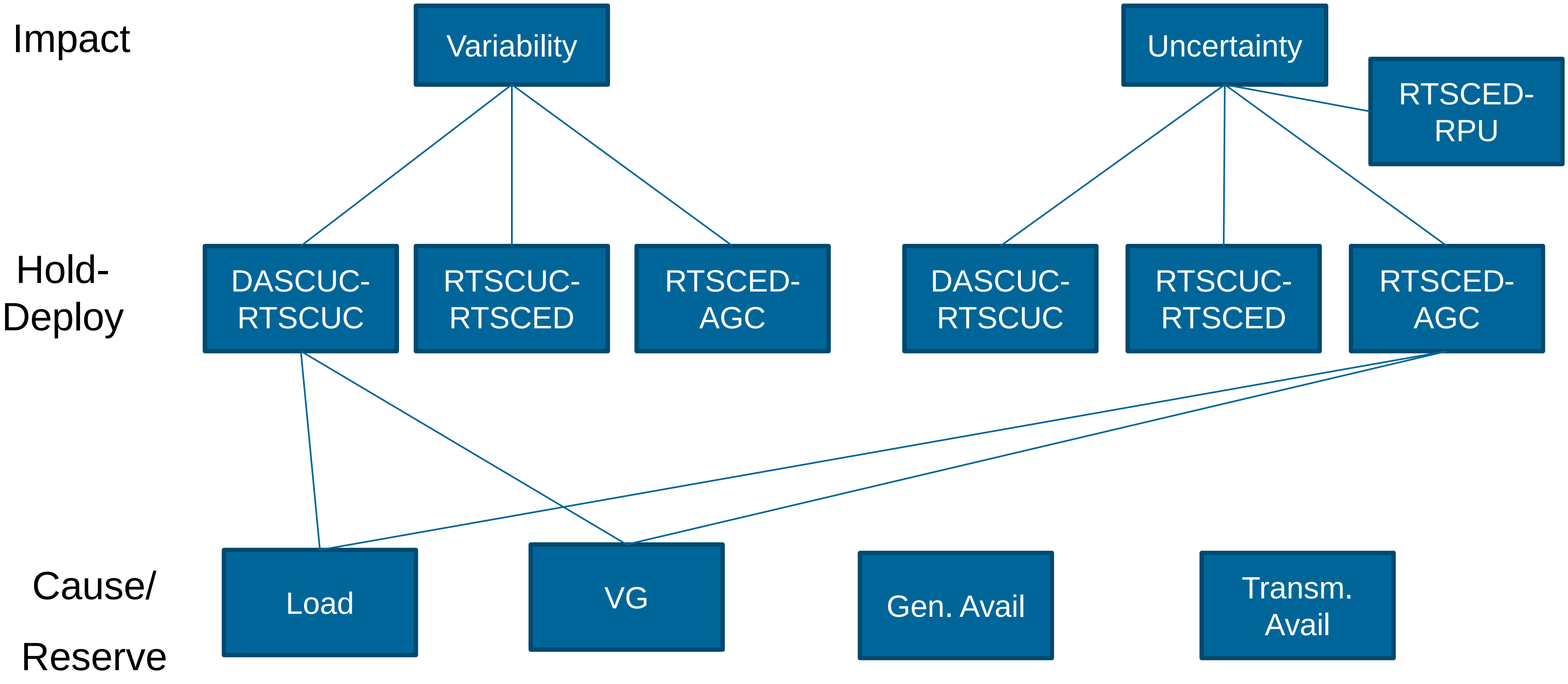
- Capacity held above or below the scheduled energy in one scheduling procedure, deployed in some future scheduling procedure
  - What event will trigger its deployment?
  - Is the scheduled energy toward instantaneous or average load?
  - What does the scheduling interval represent?
  - What scheduling procedures eliminate the need for exogenous reserve?
  - What level of anticipated imbalance is deemed acceptable?

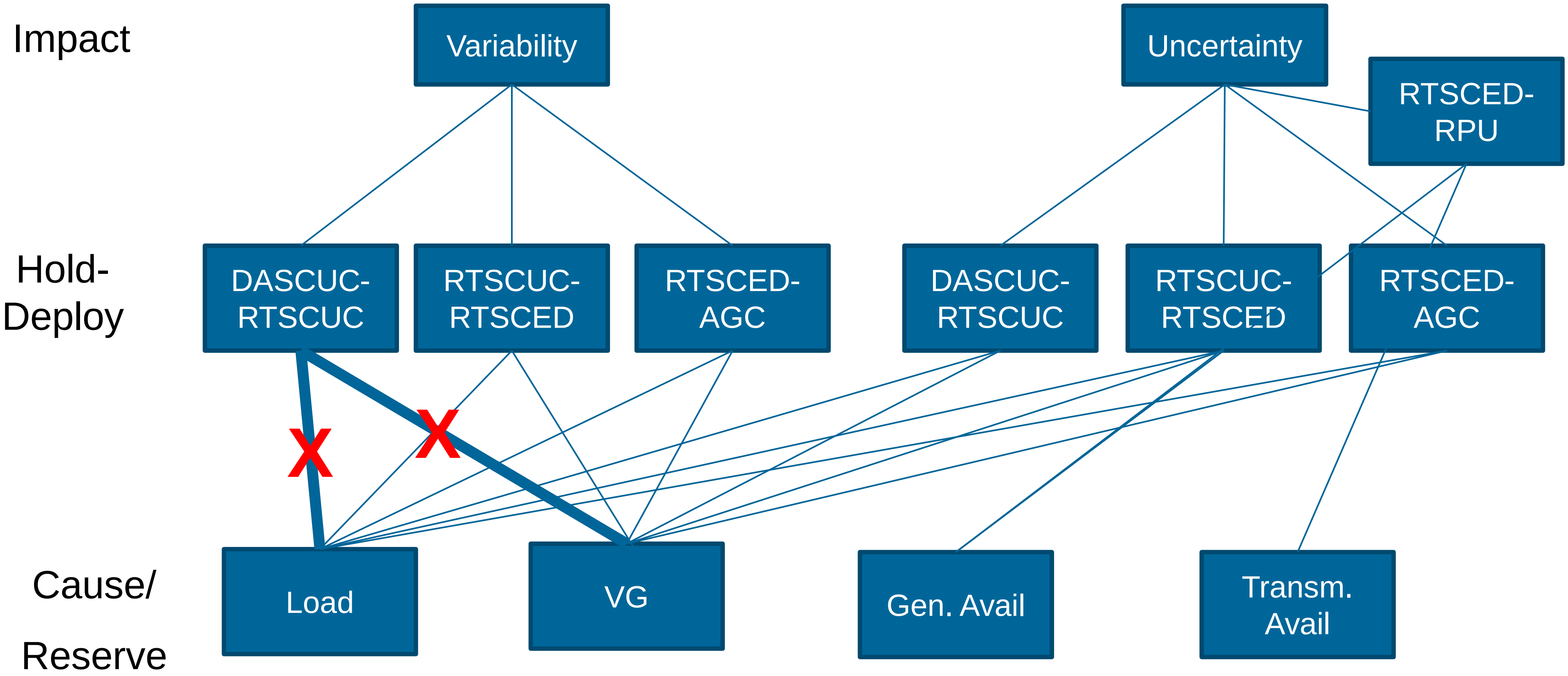
Example Definitions

			Variability		Uncertainty			
Current Name	Cycle held	Need	Inter	Intra	Inter	Intra	Made available for consumption in cycle	Explicit Representation
Regulation	RTSCED	Net load ramping		✔		✔	AGC	Stochastic scenarios at 4 second resolution
Contingency	RTSCED	Outages			✔	✔	RPU	Stochastic scenarios with generation failure
FlexiRamp Constraint	RTSCUC	Net load ramping		✔			RTSCED	Multi period at 5 minutes with ramp rates and commitment constraints enforced
FlexiRamp Constraint	RTSCUC	Net load uncertainty				✔	RTSCED	Stochastic multi period at 5 minutes with ramp rates and commitment constraints enforced
N/A	RTSCUC	Net load ramping	✔				RTSCUC	Multi period dispatch with ramp rates (**already done**)
LFU/LFD	RTSCUC	Net load uncertainty			✔		RTSCUC	Stochastic multi period dispatch with ramp rates
FlexiRamp Product	DASCUC	Net load ramping		✔			RTSCUC - RTSCED	Multi period dispatch at 5/15 minutes with ramp rates and commitment constraints enforced
FlexiRamp Product	RTSCUC	Net load uncertainty		✔		✔	RTSCED	Stochastic multi period dispatch at 5 minutes with ramp rates and commitment constraints enforced
FlexiRamp Product	RTSCED	Net load ramping	✔		✔		RTSCED	Stochastic Multi period dispatch with ramp rates

Advanced Scheduling Strategies

Need	Approximation	Explicit representation
Variability anticipated in the future	Reserve Requirements (e.g., flexible ramping reserve)	Time-coupled multi-period dispatch
Variability occurring at faster time resolutions than the scheduling model	Reserve Requirements (e.g., regulation reserve)	Shorter scheduling intervals
Uncertainty of future conditions	Reserve Requirements (e.g., contingency reserve)	Stochastic or robust unit commitment and dispatch
Frequency responsive reserve	Reserve Requirements (e.g., spinning reserve)	Explicit PFR characteristics scheduled


Impact
Variability
Uncertainty
RTSCED-RPU
Hold-Deploy
DASCUC-RTSCUC
RTSCUC-RTSCED
RTSCED-AGC
DASCUC-RTSCUC
RTSCUC-RTSCED
RTSCED-AGC
Cause/ Reserve
Load
VG
Gen. Avail
Transm. Avail



Strategy: Model DASCUC at fifteen minute resolution rather than hourly

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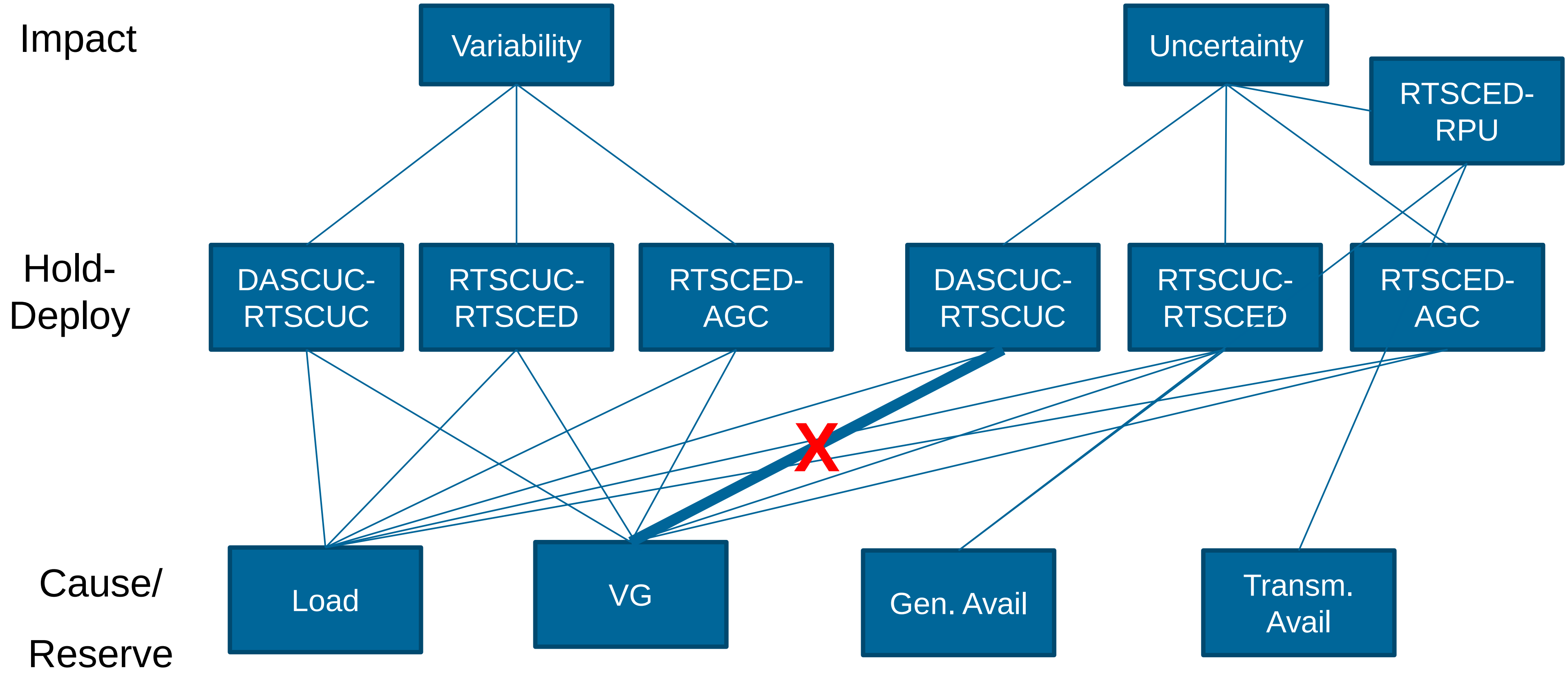
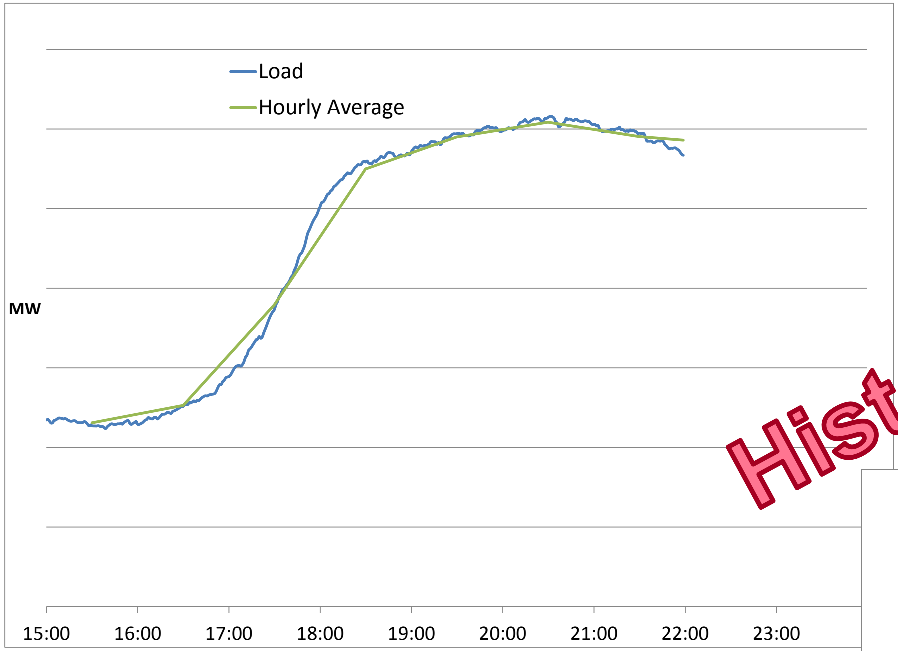


Strategy: Model potential VG scenarios using stochastic DASCUC

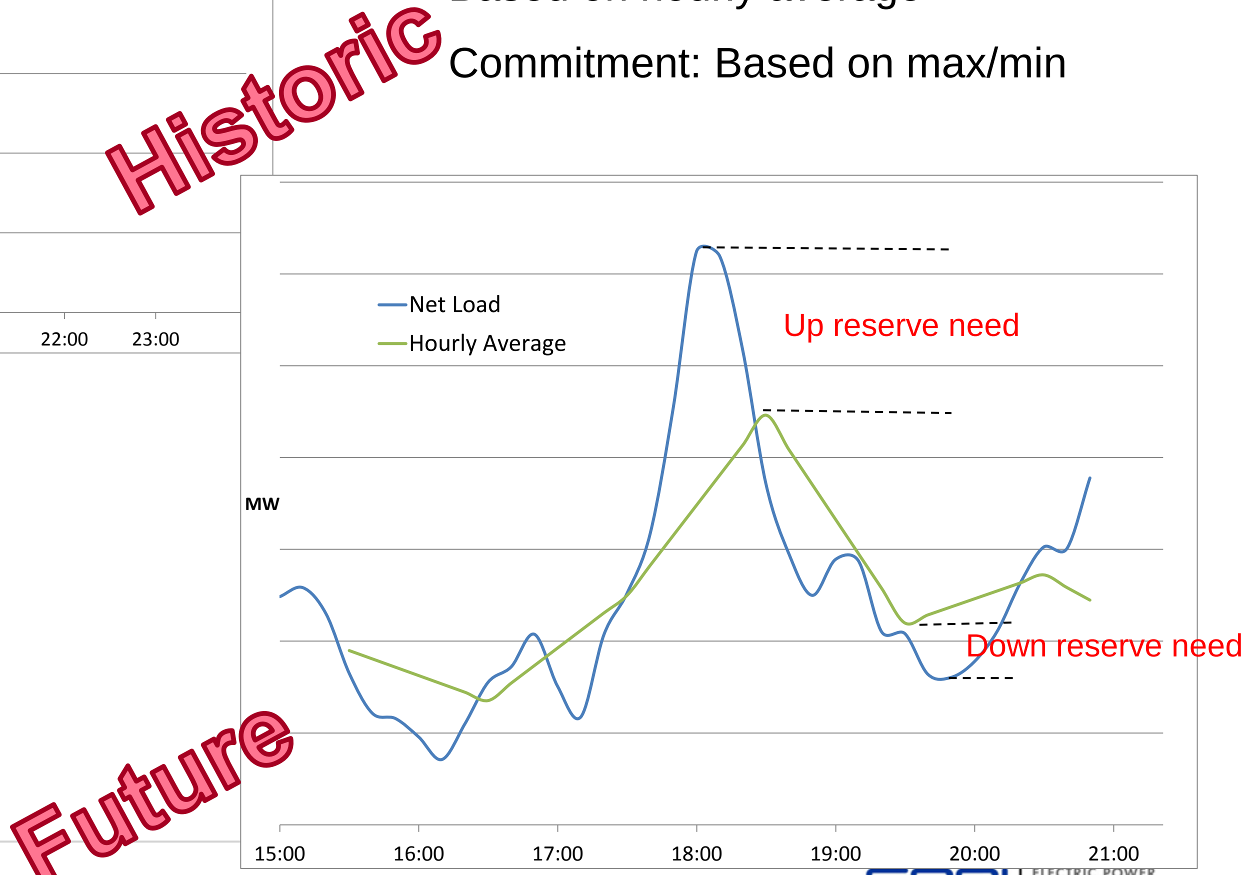
Following Reserve



No longer a linear trending net load, may need reserve capacity within the scheduling interval

Prices and energy schedules: Based on hourly average

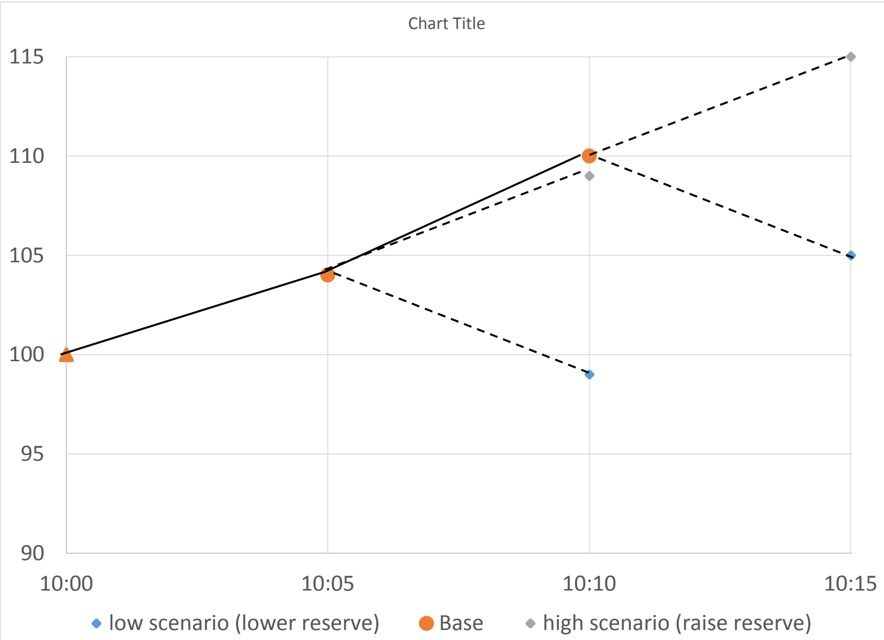
Commitment: Based on max/min



Definition of reserve through constraints

Different formulations mean different things

Importance of ramp constraints



$\sum P_{i,t}$=[100,104, 110] for {last,I1,I2}

$\sum R_{i,t} \geq 5$ (e.g., Regulation)

$$-RR_i I \leq P_{i,1} - P_{i,last} \leq RR_i I$$

$$-RR_i I \leq P_{i,t} - P_{i,t-1} \leq RR_i I$$

$$R_{i,t} \leq RR_i I$$

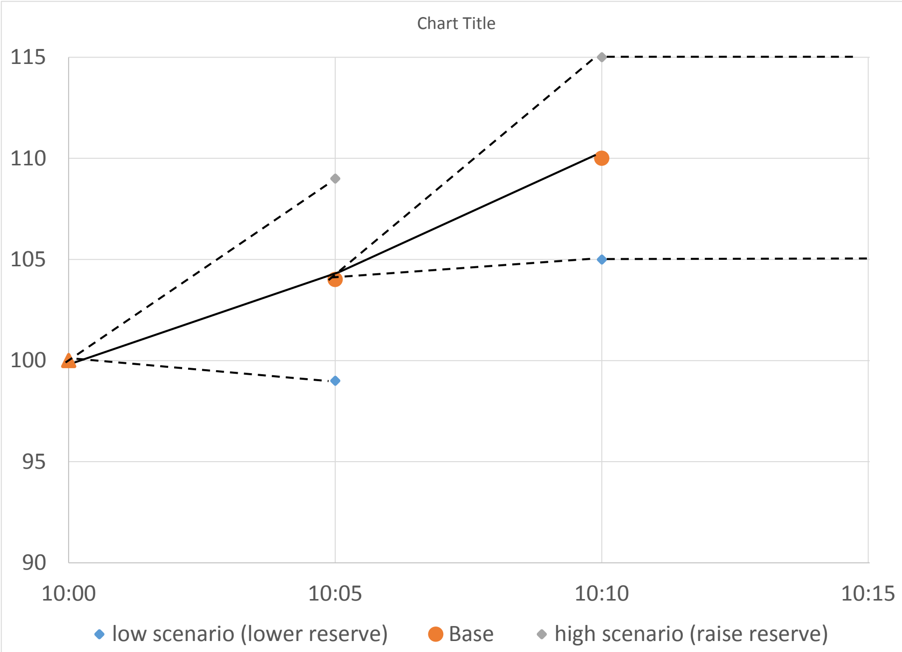
$$P_{i,t} + R_{i,t} \leq P_i^{max}$$

$$P_{i,t} - R_{i,t} \geq P_i^{min}$$

In interval1, the system is only guaranteed to meet the expected ramp. In interval 2 it is not guaranteed to meet any uncertainty above the net load.

If $\text{Load}_t > \text{Load}_{t-1} + \text{Res Rqmnt}_{t-1}$, R_t is useless

Importance of ramp constraints



$$\sum P_{i,t} = [100, 104, 110] \text{ for } \{last, I1, I2\}$$

$$\sum R_{i,t} \geq 5 \text{ (e.g., Regulation)}$$

$$-RR_i I \leq P_{i,1} - P_{i,last} \pm \mathbf{R_{i,1}} \leq RR_i I$$

$$-RR_i I \leq P_{i,t} - P_{i,t-1} \pm \mathbf{R_{i,t}} \leq RR_i I$$

$$P_{i,t} + R_{i,t} \leq P_i^{max}$$

$$P_{i,t} - R_{i,t} \geq P_i^{min}$$

The system is ready for uncertainty of 5 MW in either direction.

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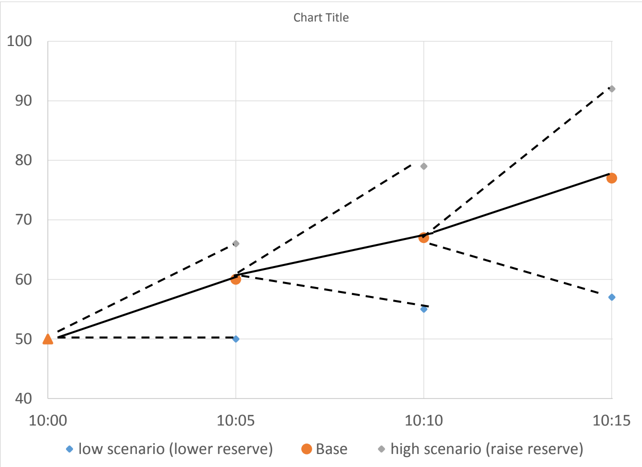
Different ways of modeling mean different things



$$P_{i,t} + R_{i,t} \leq P_i^{max}$$

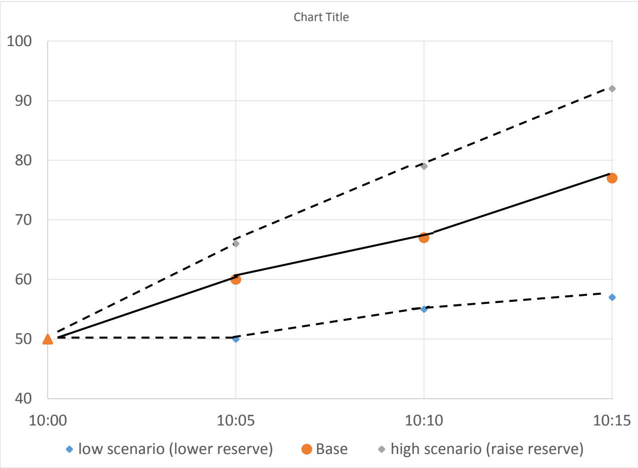
$$P_{i,1} - P_{i,last} + R_{i,t} \leq RR_i I$$

$$P_{i,t} - P_{i,t-1} + R_{i,t} \leq RR_i I$$

$$P_{i,t,s} \leq P_i^{max}$$

$$P_{i,1,s} - P_{i,last} \leq RR_i I$$

$$P_{i,t,s} - P_{i,t-1,0} \leq RR_i I$$



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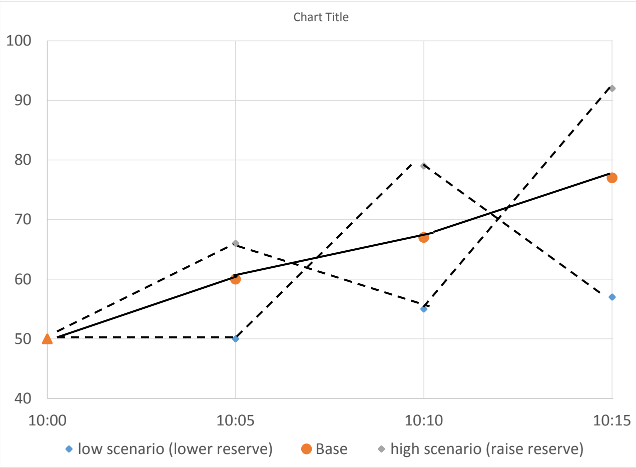

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$$P_{i,1,s} - P_{i,last} \leq RR_i I$$

$$P_{i,t,s} - P_{i,t-1,\alpha} \leq RR_i I, \forall \alpha \in s$$

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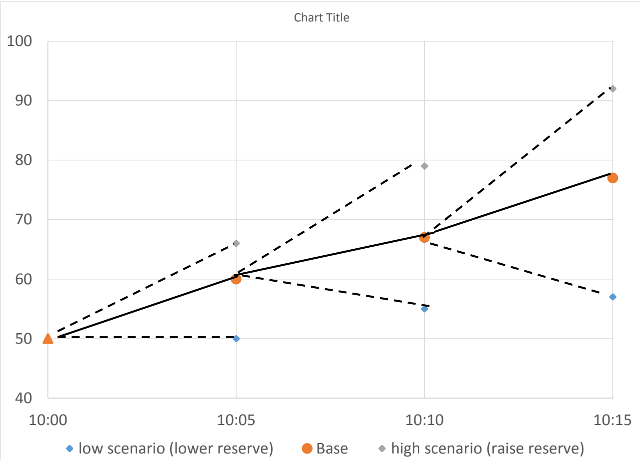

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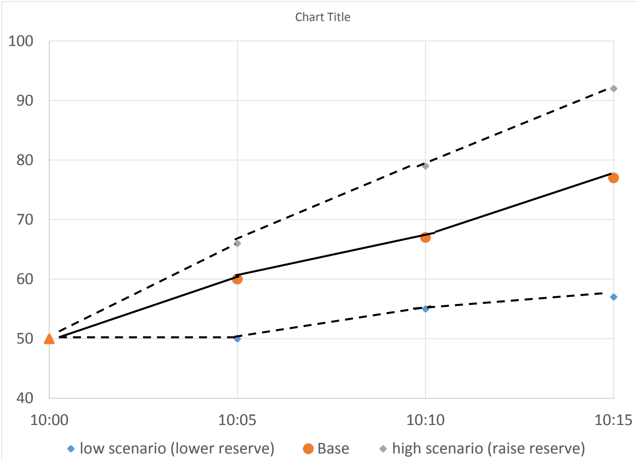

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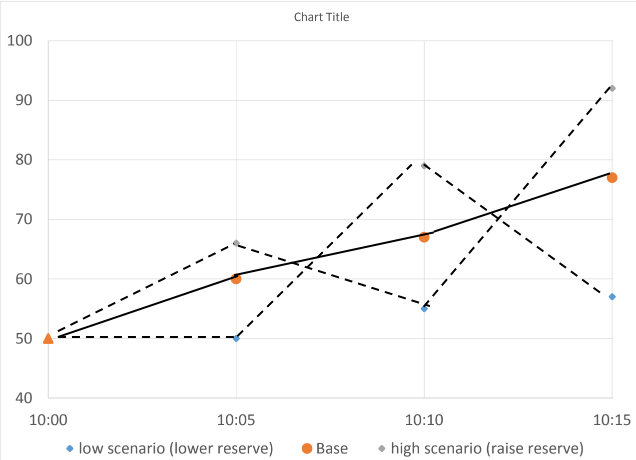

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Same

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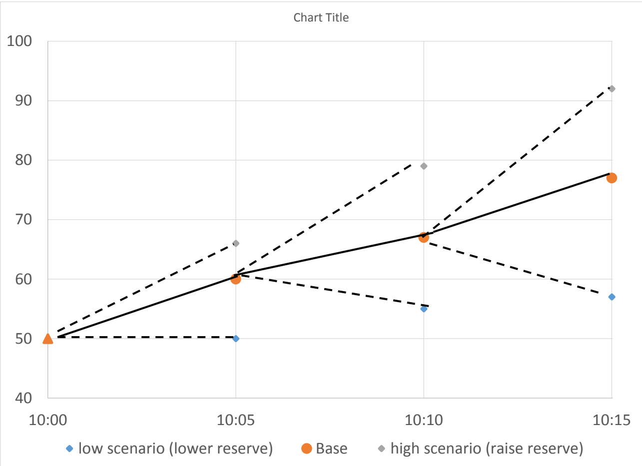
Different ways of modeling mean different things



$$P_{i,t} + R_{i,t} \leq P_i^{max}$$

$$P_{i,1} - P_{i,last} + R_{i,t} \leq RR_i I$$

$$P_{i,t} - P_{i,t-1} + R_{i,t} \leq RR_i I$$

Flexiramp

$$P_{i,t,s} \leq P_i^{max}$$

$$P_{i,1,s} - P_{i,last} \leq RR_i I$$

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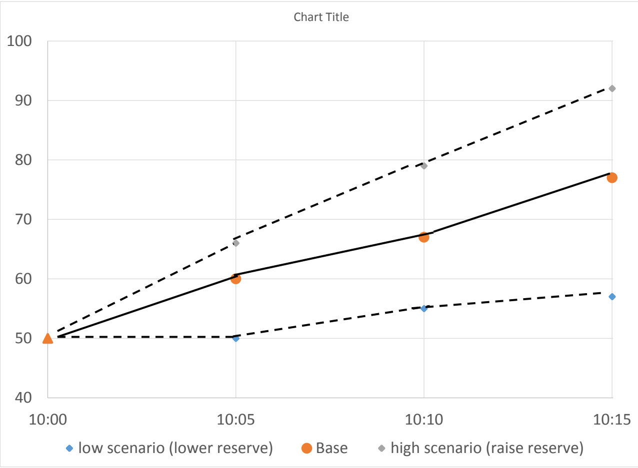

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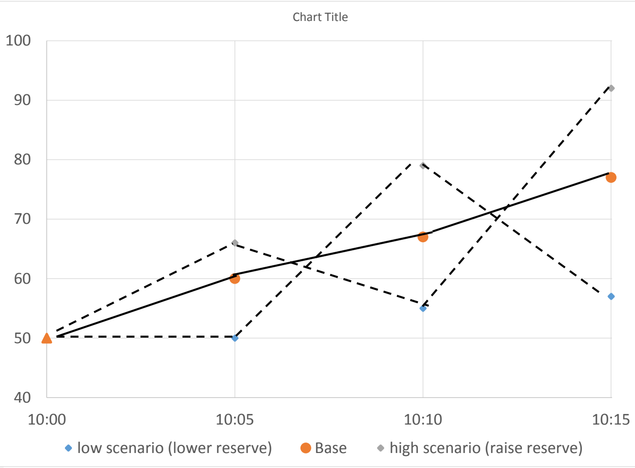
Typical Stoch. Form.

$$P_{i,t,s} \leq P_i^{max}$$

$$P_{i,1,s} - P_{i,last} \leq RR_i I$$

$$P_{i,t,s} - P_{i,t-1,s} \leq RR_i I$$



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Typical Robust Form.

$$P_{i,t,s} \leq P_i^{max}$$

$$P_{i,1,s} - P_{i,last} \leq RR_i I$$

$$P_{i,t,s} - P_{i,t-1,\alpha} \leq RR_i I, \forall \alpha \in s$$

*There are many different ways of defining these in each of the methodologies. This is a generic, simplistic assignment of formulation to model method

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Interval by Interval Reserve Analysis

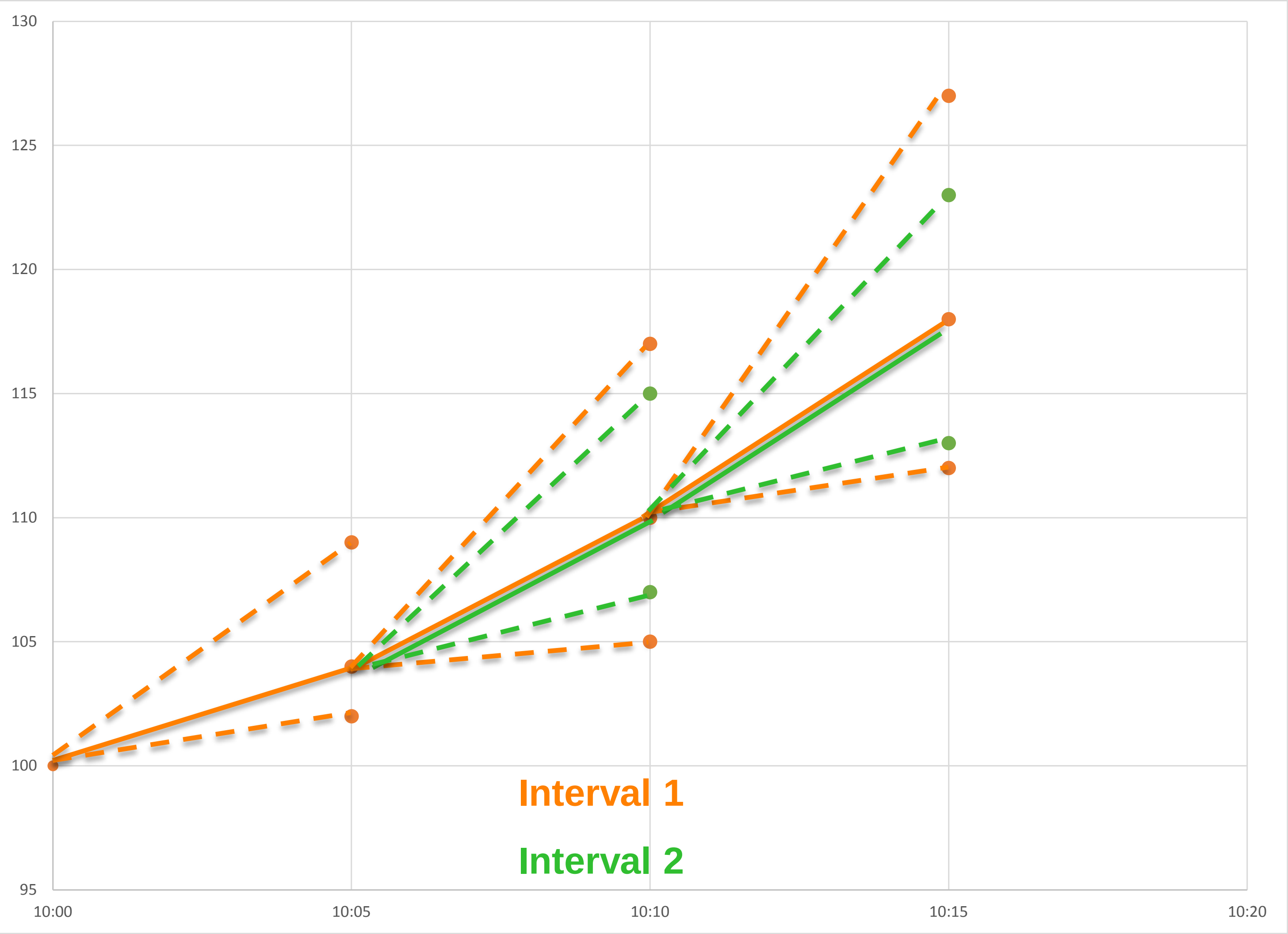
Illustrative examples on how each product is defined, held and deployed

Note: Must use in slideshow mode

Example Descriptions

- First example: No uncertainty
  - No regulation or flex deployed
  - Assumption of predictions being more certain as horizon gets closer. May not always be the case.
- Second example: Uncertainty
  - Each interval (binding and advisory) has uncertainty and so reserve products are deployed.
- In all cases, the first colored dot is actual, the second dot connected through a solid line is the binding interval, and dots beyond connected through solid lines are advisory lookahead intervals
- Dots connected through dashed lines are potential outcomes
  - E.g., they may be the upper and lower bounds within 95% confidence
  - Either through reserve product or 3-scenario stochastic model
- Assumption: The dots represent meeting the instantaneous demand. Units ramp linearly from one interval to the next.

No Uncertainty



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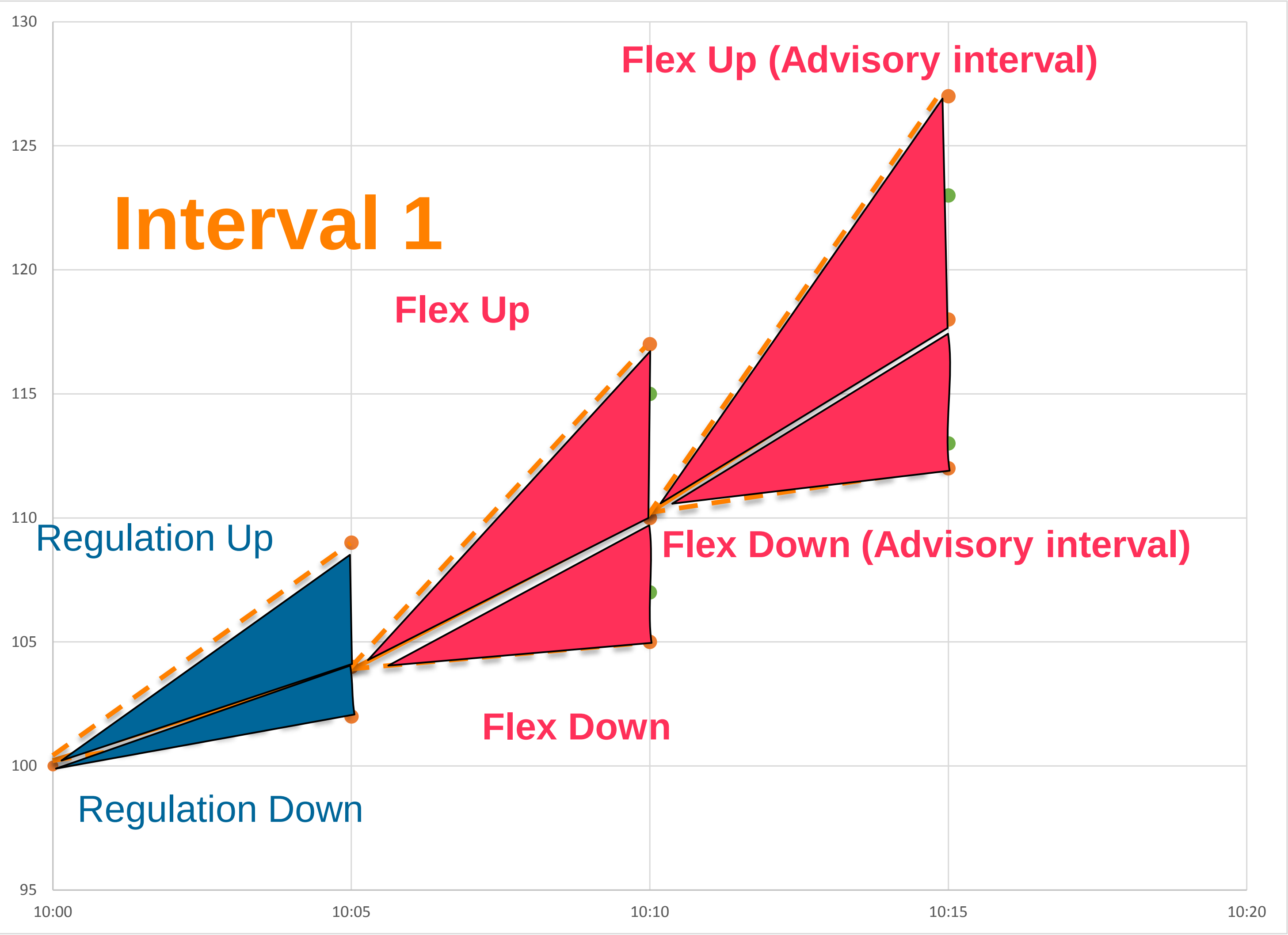
No Uncertainty



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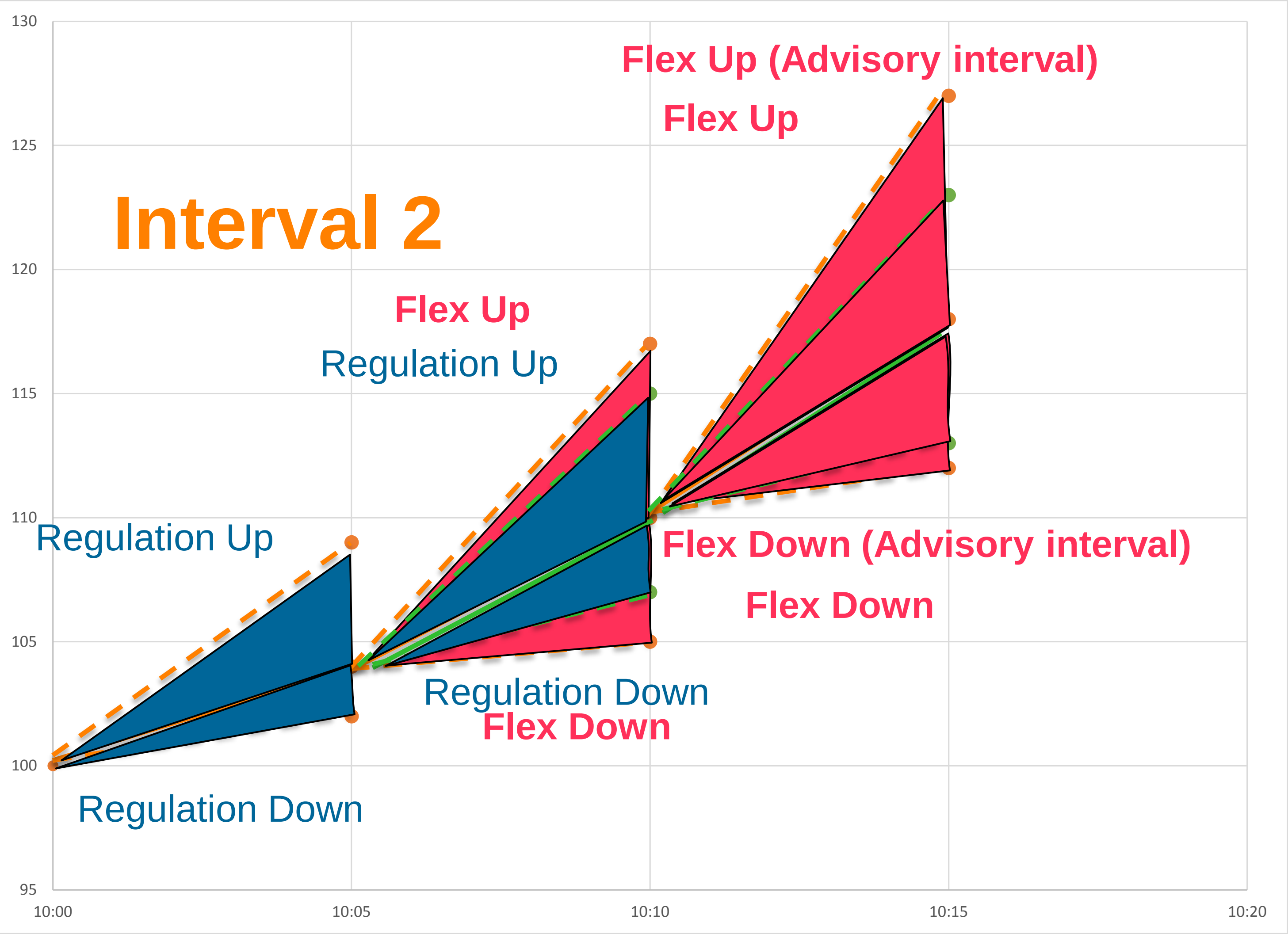
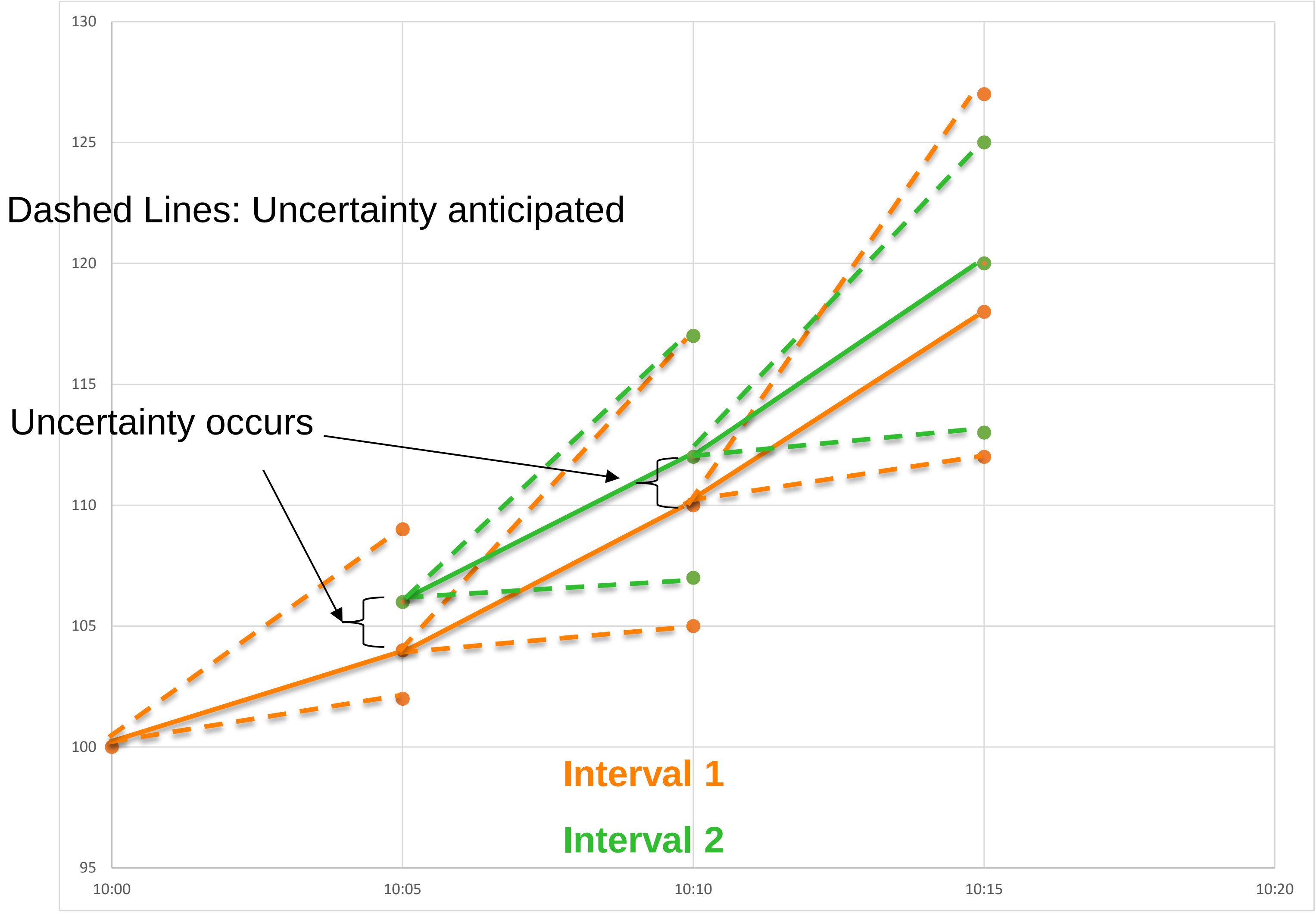
No Uncertainty



Uncertainty modeled



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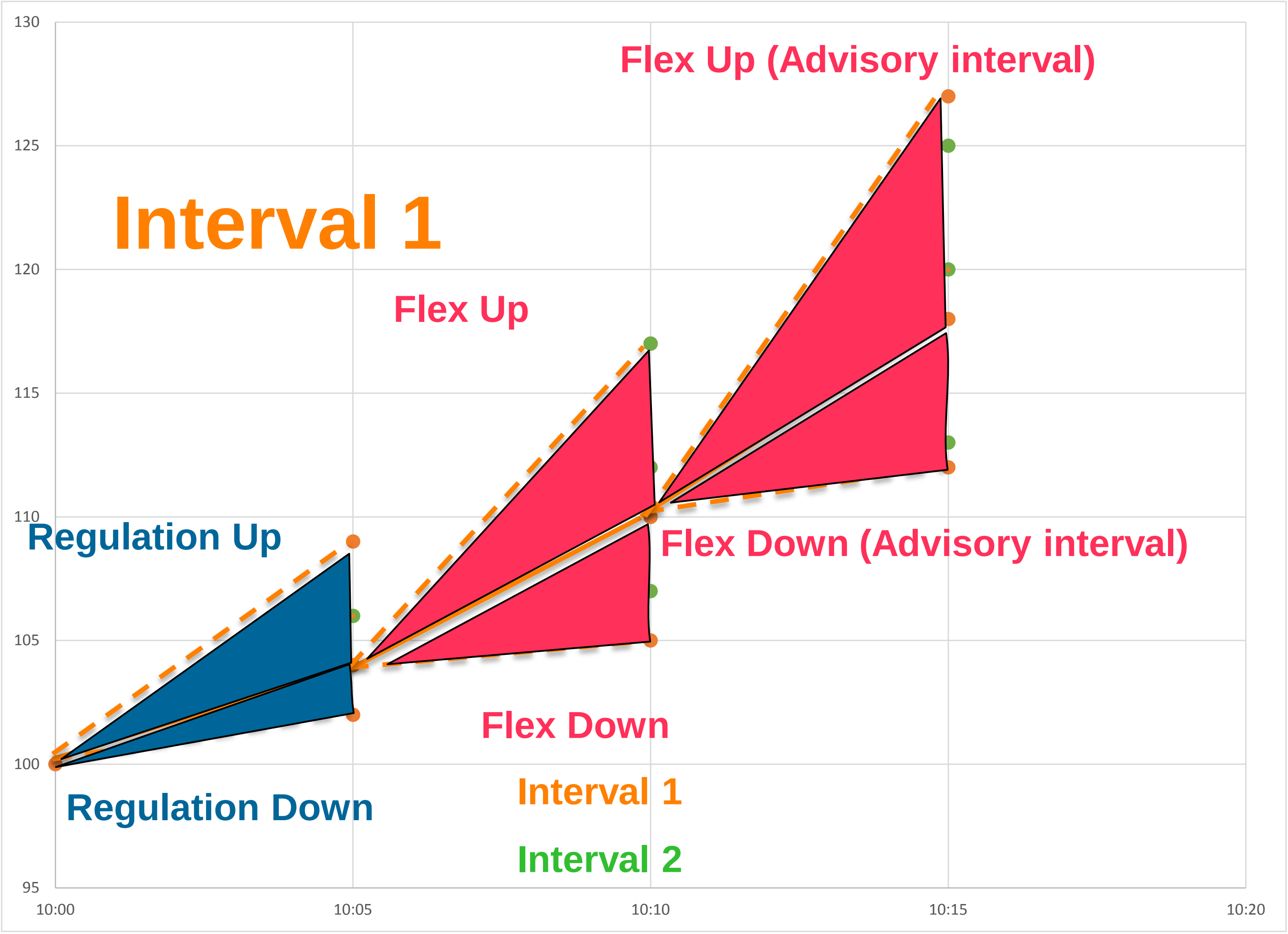
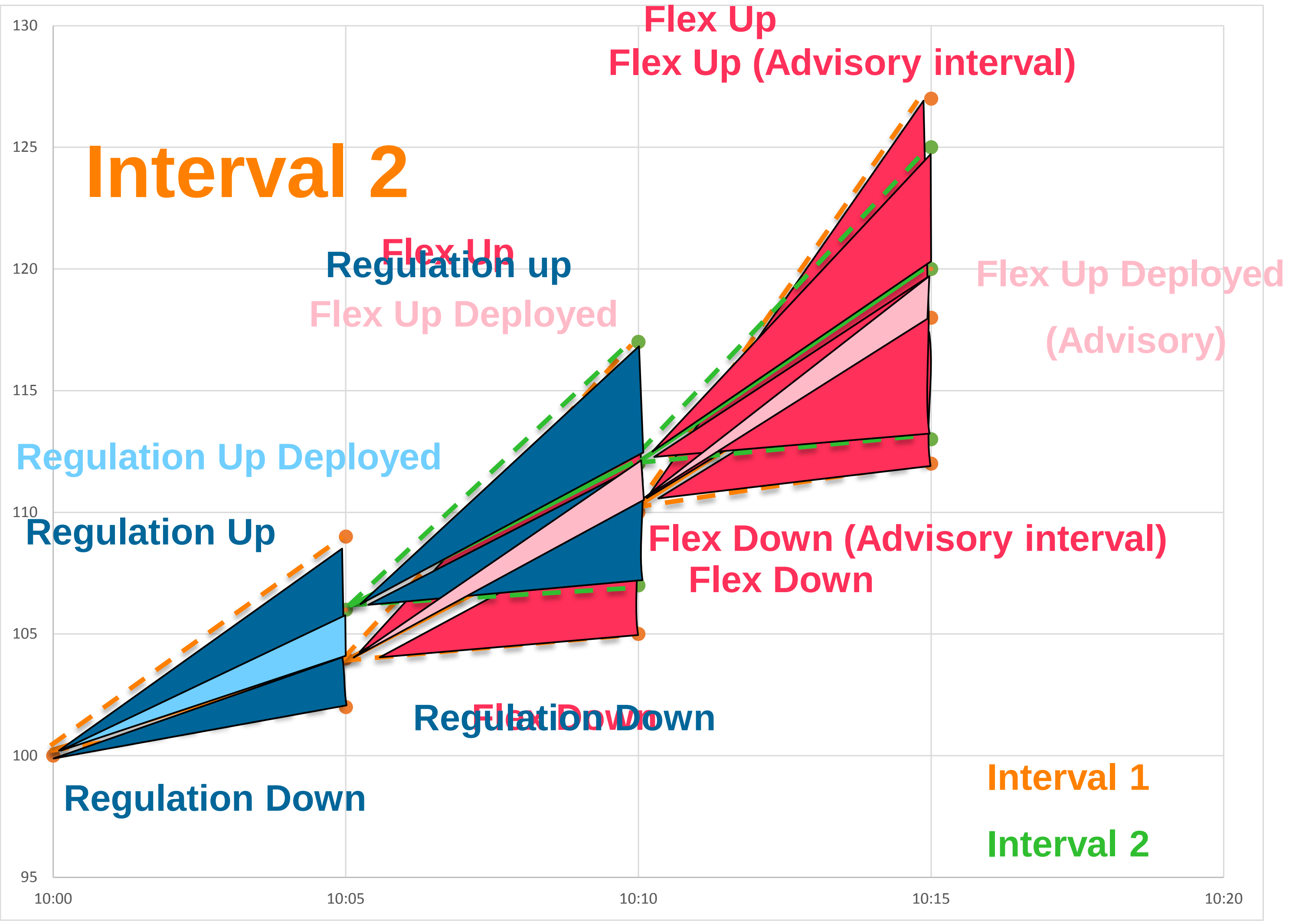
Uncertainty modeled



Uncertainty modeled



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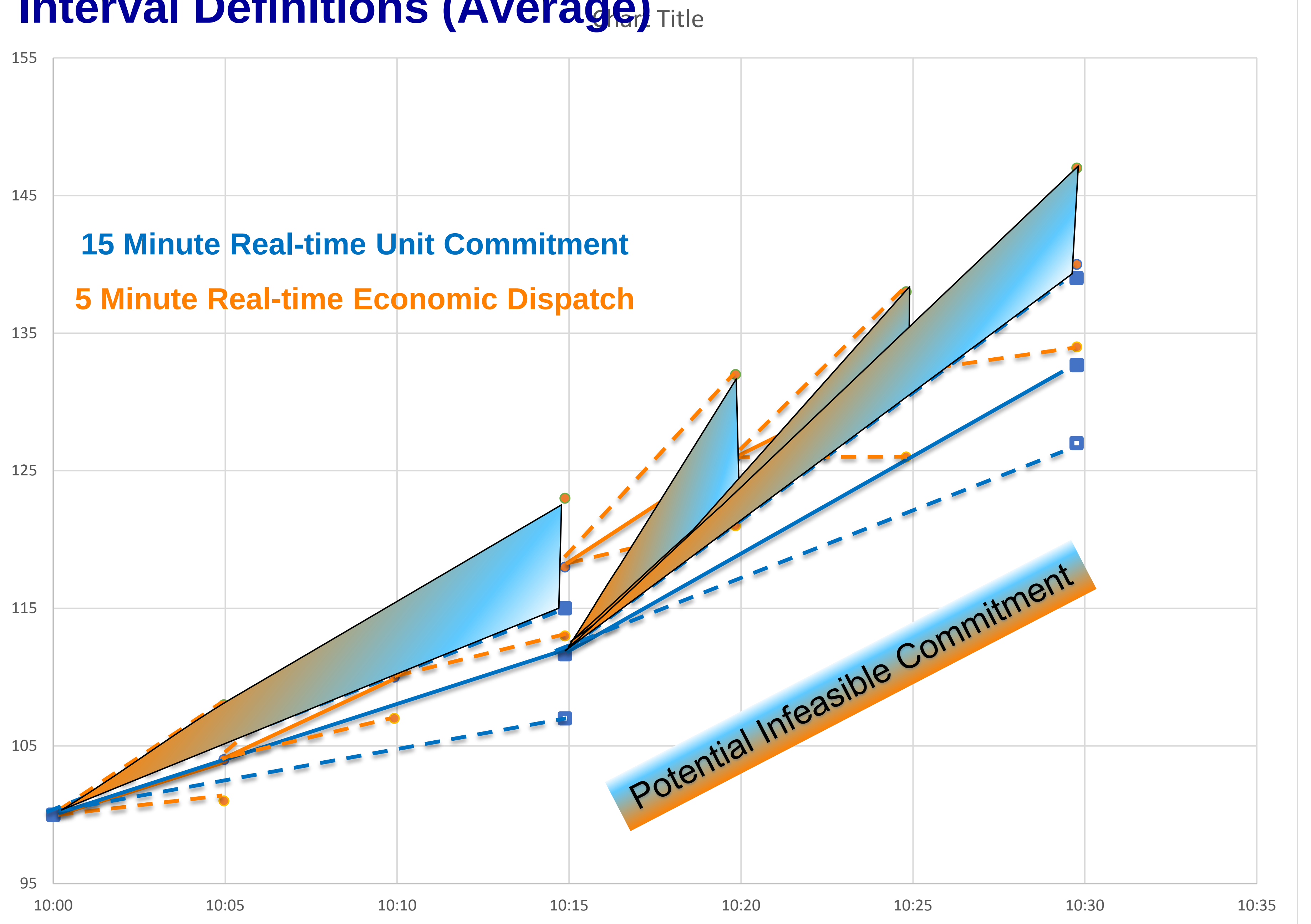
Interval Definitions

- Previous examples assume scheduling to an instantaneous load, with timestamp representing End_Interval
- If timestamp represents Beginning_Interval or Middle_Interval, results differ
- If scheduling energy to average load, rather than instantaneous, results differ

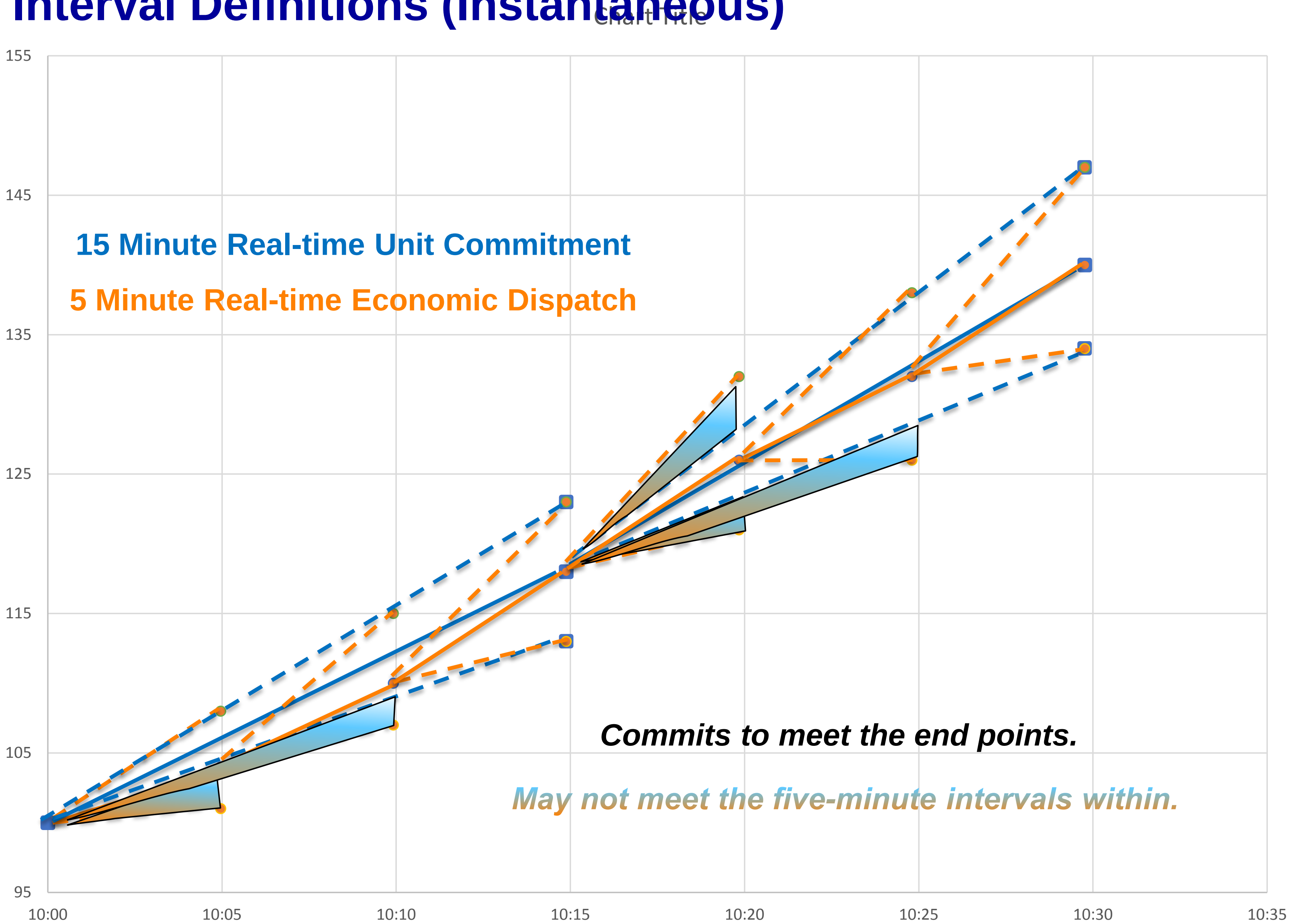
- Illustration:
  - 15-min RTUC and 5-min RTED
  - Example 1: RTUC represents average load
  - Example 2: RTUC represents instantaneous load at End_Interval

  - Note: Next examples must also be used in slideshow mode.

Interval Definitions (Average)



Interval Definitions (Instantaneous)



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Interval Definitions

- When committing for the average, but formulations are based on snapshots, the commitment may not give the dispatch a feasible solution
- Similar issues can arise with economic dispatch by itself
- It is important to understand these definitions, how they differ by region, and how they are aligned with model formulations

- Can have a big impact on reserve requirements.
  - Simple changes may drastically reduce or increase apparent reserve requirements
- Can also affect prices and economics
  - Settlements and prices should be based on averages, reserve and capacity should based on max/min

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Conclusions and Future Work

- New reserve products are being introduced
- Essential to understand the direct need for new product
- Formulation of reserve product in market software perhaps as important as quantity of reserve requirement
- Needs depend on many different factors beyond just the driving force of reserve

- Expand to many different permutations of ISO & BA formulations
- Multi-cycle, multi-timescale simulations including various permutations
- Report on final analysis

Together…Shaping the Future of Electricity