

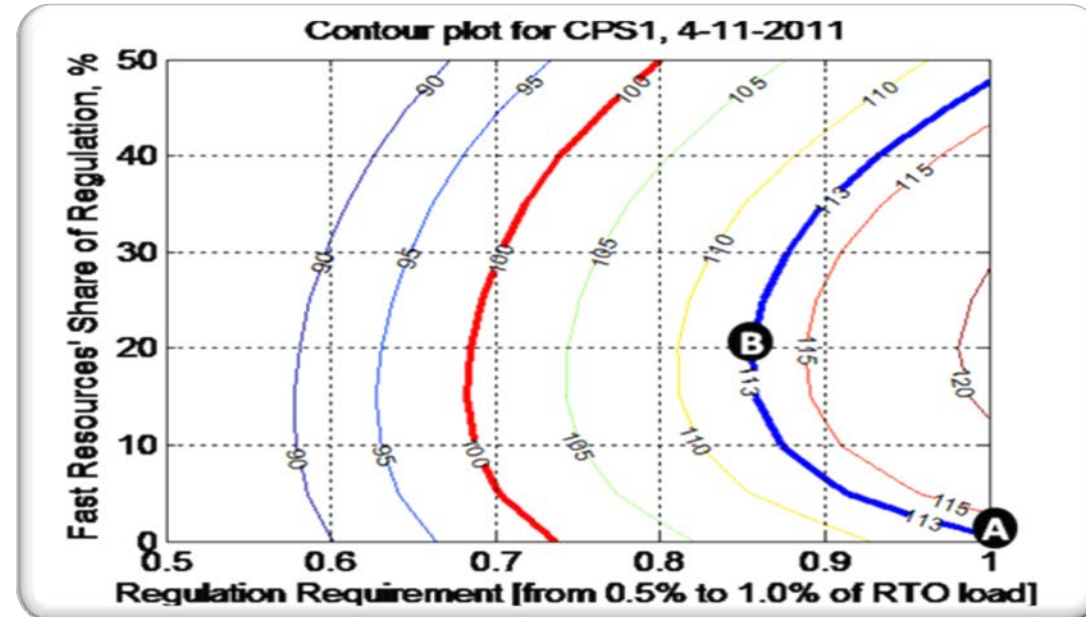
Benefits Factor and the “Effective” MW

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July 1st, 2015

- 2011 KEMA Study on Dynamic Regulation
- Benefits Factor Curve Formulation
- Performance Based Regulation
- Performance Score Calculation Engine (PSCE)
- Settlement Considerations

- In Summer 2011, PJM commissioned KEMA to study the impact on system control by simulating two variables of dynamic signal following resources
 - Increasing dynamic resource participation
 - Lowering regulation capability requirement

- Finding 1
 - Some fast is better than none
- Finding 2
 - Found an inflection point where adding additional dynamic regulation caused CPS1 scores (System Reliability) to decrease



What it is

- Simulation of perfect RegD vs lagging RegA
- 4 representative seasonal weeks
- 2-second interval Power Flow vs Unit Commitment

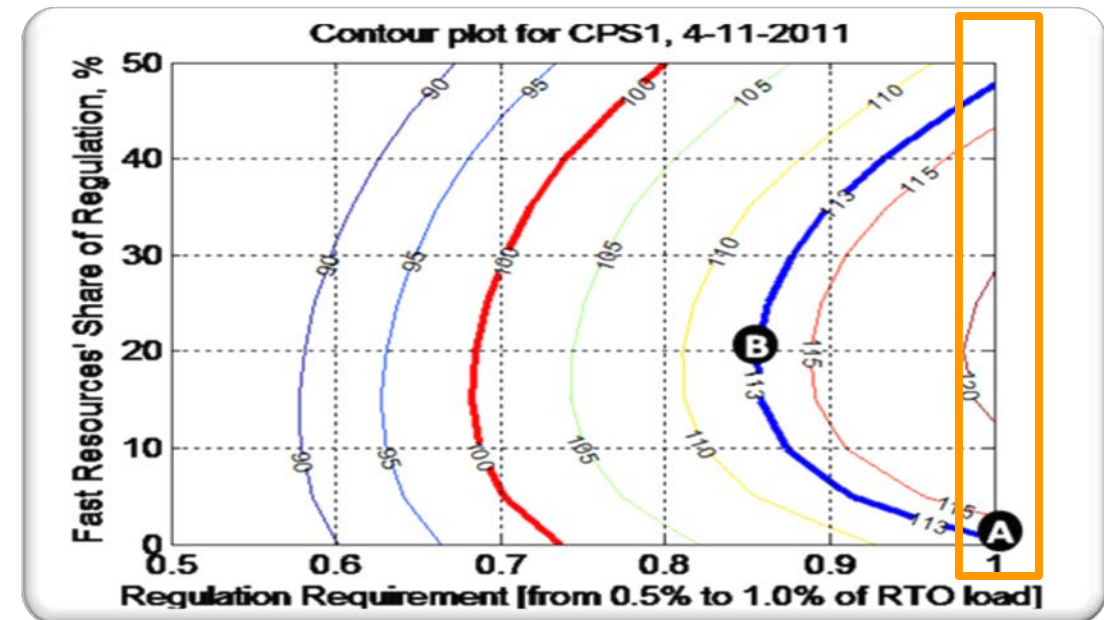
What it is not

- Analysis of actual resource performance
- Determination of relation to seasonality
- Source of Benefits Factor Curve

The Benefits Factor:

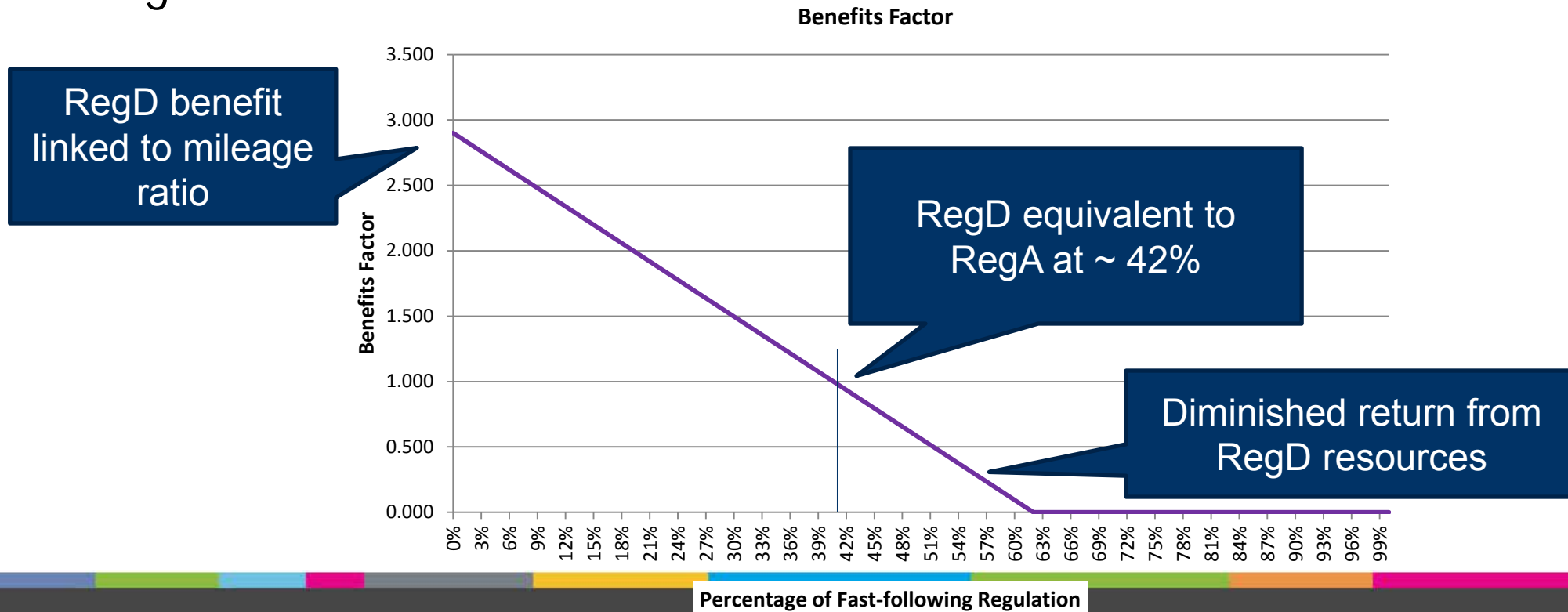
- Models the rate of substitution between traditional (RegA) and dynamic (RegD) resources
- Enables the market to translate fast moving resource's regulation MW into traditional MW, or effective MW
- Adjusts RegD resource's offer price

- Averaged the CPS-1 results for the 4 simulated weeks
- For a constant requirement,
 - From A, each additional RegD resource improves reliability
 - At ~ 42%, reliability is the same as no RegD at all, so the benefit is 1.0.
 - Beyond 42%, each additional RegD harms reliability, so the benefit should be < 1 to zero.



Benefits Factor Curve in Market Clearing

- Provides a sliding scale that makes RegD resources more desirable until the optimal resource mix of 30-45%. It translates a RegD MW into a RegA MW.
- Ranges from 2.9 to 0.01



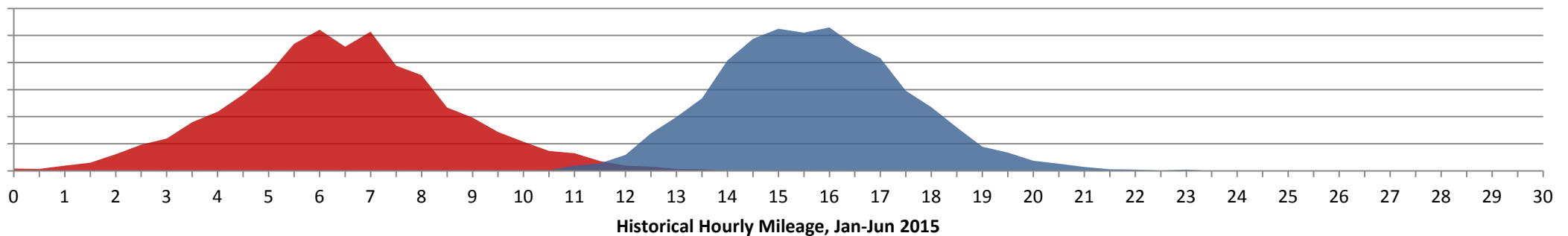
- The Regulation Market should incentivize
 - Accuracy – following a shape
 - Timeliness – reduce delay in response
 - Precision – provide ACE correction
- Objective uniform scoring methodology
 - Signal vs. Response
- Resource's *Performance Score* [0..1] should capture these characteristics

- 1) **Accuracy** – the correlation or degree of relationship between control signal and regulating unit's response
 - 5 minute rolling correlation with 10 second granularity
 - Re-calculated with a 10 second time shift up to 5 minutes
 - 2) **Delay** – the time delay between control signal and point of highest correlation from Step 1.
 - Up to 5 minutes
 - 3) **Precision** – The instantaneous error between the control signal and the regulating unit's response.
- **Performance Score = $A [\text{Score}_A] + B [\text{Score}_D] + C [\text{Score}_P]$**
 - A, B, C are scalars from [0..1], total to 1. Currently 0.333 each
 - Produces a weighted average of component scores

- Mileage is the absolute sum of movement of the regulation signal in a given time period

$$\begin{aligned}
 \text{Mileage}_{\text{RegA}} &= \sum_{i=0}^n |\text{RegA}_i - \text{RegA}_{i-1}| \\
 \text{Mileage}_{\text{RegD}} &= \sum_{i=0}^n |\text{RegD}_i - \text{RegD}_{i-1}|
 \end{aligned}$$

- Resources following the dynamic signal will move much more than those on traditional signal



For each resource, calculate

$$\text{Adjusted Total Offer Cost (\$)} = \underbrace{\left(\begin{array}{c} \text{Adjusted} \\ \text{Regulation} \\ \text{Capability} \\ \text{Cost} \\ (\$) \end{array} \right)}_{\text{Capability Payment}} + \underbrace{\left(\begin{array}{c} \text{Lost} \\ \text{Opportunity} \\ \text{Cost} \\ (\$/\text{MW}) \end{array} * \text{Capability} \right)}_{\text{Capability Payment}} + \underbrace{\left(\begin{array}{c} \text{Adjusted} \\ \text{Performance} \\ \text{Cost} \\ (\$) \end{array} \right)}_{\text{Performance Payment}}$$

$$\text{Rank Price} = \frac{\text{Adjusted Total Offer Cost (\$)}}{\text{Capability (MW)}}$$

Order resources by rank price, clearing by Effective MW

$$\text{Regulation Requirement MW} \leq \sum_{i=1}^n \left[\text{Capability MW}_i * \text{Benefits Factor}_i * \text{Historic Performance Score}_i \right]$$

Historical Formula pre-PBR

$$\text{Adjusted Regulating Capability Cost (\$)} = \frac{\left(\text{Capability Offer } \left(\frac{\$}{\text{MW}} \right) \right)}{\left(\text{Benefits Factor of Offered Resource} \right)} \cdot \frac{\left(\text{Capability (MW)} \right)}{\left(\text{Historic Performance Score} \right)}$$

Dynamic resources use scaled factor, traditional uses 1.0

Average of last 100 hours of performance scores

30 day average of historical mileage

$$Adjusted\ Performance\ Cost\ (\$) = \frac{\left(\begin{matrix} Performance \\ Offer \\ (\$/MW) \end{matrix} \right) * \left(\begin{matrix} Historical\ Mileage \\ of \\ Offered\ Resource\ Signal\ Type \end{matrix} \right)}{\left(\begin{matrix} Benefits\ Factor \\ of \\ Offered\ Resource \end{matrix} \right) * \left(\begin{matrix} Historic \\ Performance \\ Score \end{matrix} \right)} * \left(\begin{matrix} Capability \\ (MW) \end{matrix} \right)$$

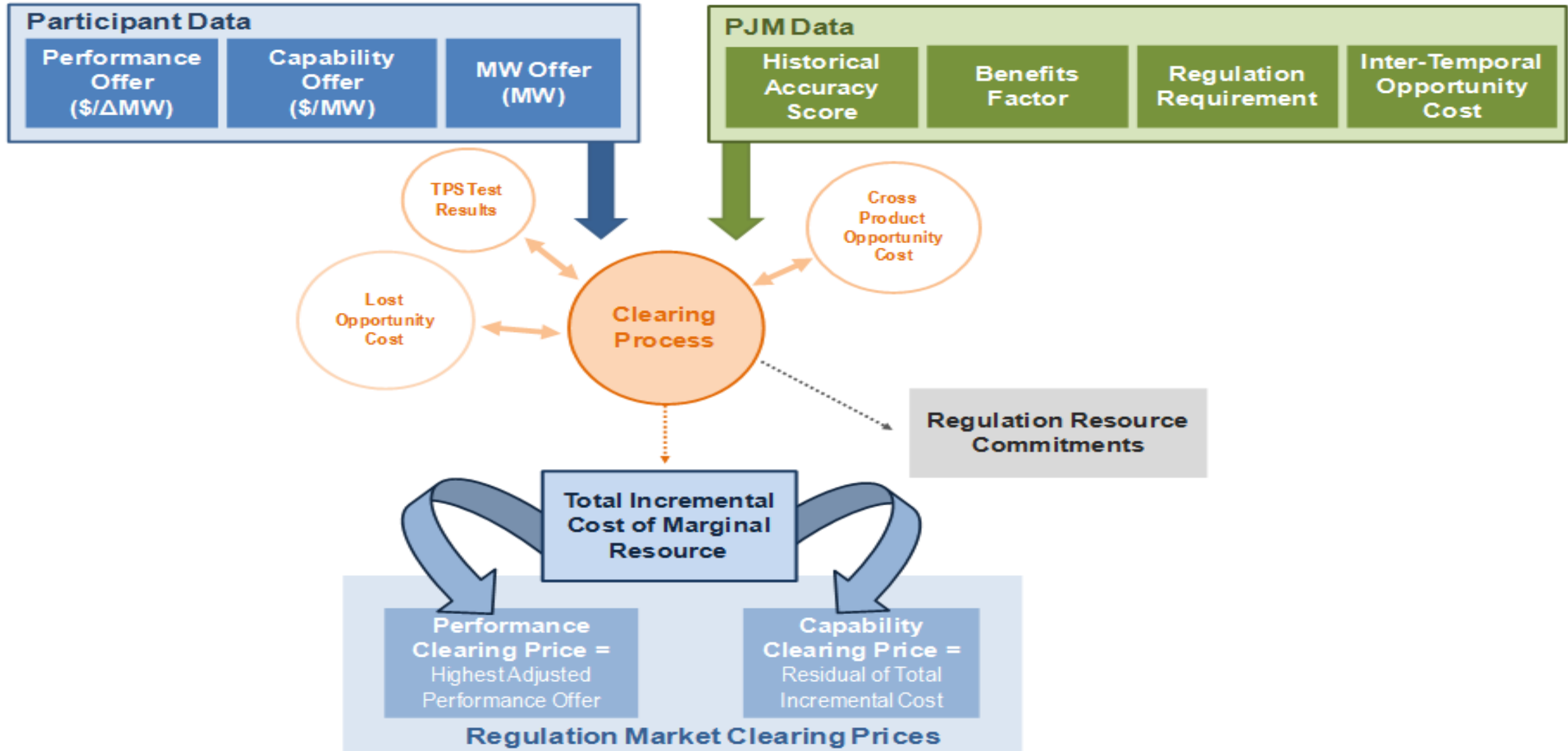
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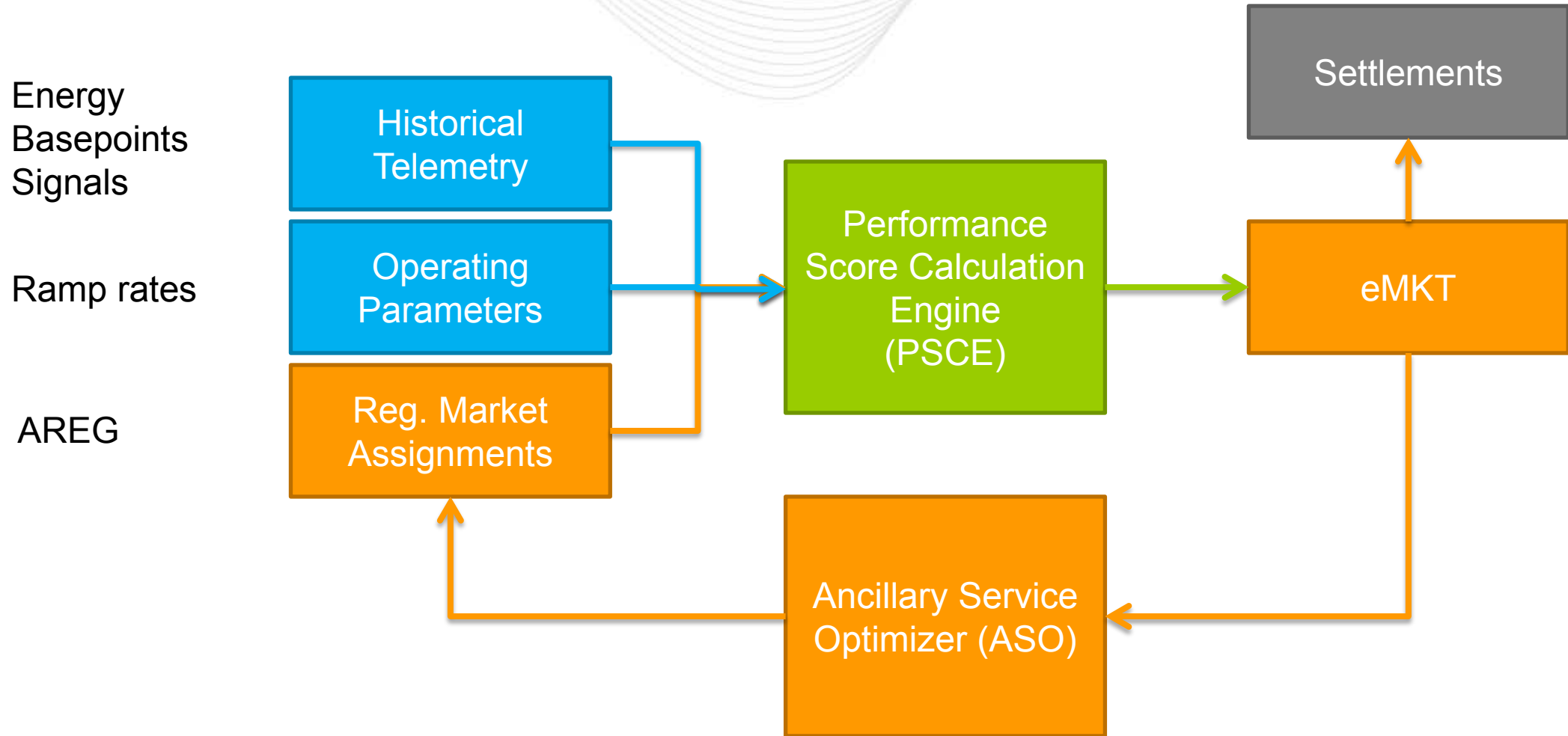
LOC is the foregone revenue or increase in costs relative to the energy market for providing regulation

- Calculated only for resources providing energy along with regulation service
- Calculated only for pool scheduled regulation resources
- Is \$0 for DSR, self-scheduled regulation, and Non-Energy Regulation resources
- Can only be positive, else zero
- Calculated only within Eco limit range
 - Economic Minimum to Economic Maximum range
- Co-optimized with energy in intra-hour Regulation Market Clearing Price

- Marginal resource sets Total Regulation Market Clearing Price (RMCP)
 - Performance Clearing Price (PCP) is the maximum of Adjusted Performance Cost/MW over all committed resources
 - Capability Clearing Price (CCP) is the residual, Total RMCP minus PCP
 - Marginal Benefits Factor (MBF) reported, but isn't consumed by anything



- Performance Score Calculation Engine (PSCE)
 - Calculates hourly scores for all regulating units for settlements credits
 - Calculates daily scores for ASO clearing & settlements LOC credits
 - Calculates 5-minute mileage for RMCP (-P/-C) pricing
 - Calculates hourly mileage for settlement credits
 - Calculates daily mileage for ASO clearing
- Windows Service runs continuously, User Interface on demand
... Same code behind



- Hourly Performance Scores
 - Solve at 15 min after every hour, for the previous operating hour
 - For every assigned unit, pull 10-sec telemetry from the PI Historian and blend it with market resource assignment and ramp rate data
 - 10-sec values are rolled into hourly averages
 - Detail available upon request
 - Values are loaded into markets databases

- Regulation Accounting rules are defined in [Manual 28 Section 4](#)
 - Resources are paid on capability, performance and lost opportunity
 - Payments are scaled by hourly accuracy scores
 - Dynamic resources are given additional payment as a function of hourly REGD/REGA mileage ratio
 - A dynamic resource is asked to move ~ 3 times as much as a traditional resource in an average hour
 - After-the-fact analysis of the REGA and REGD signals determines the multiplier

- “Shoulder Hour” Lost Opportunity
 - Ramping into and out of service occurs outside the operating hour
 - Is included in Clearing, as an estimate
 - Is not included in 5-minute Pricing
 - Is included in Settlements, as unit specific LOC
- Product Substitution
 - Unit-specific Benefit Factor used in Clearing
 - Unit-specific Benefit Factor used in Pricing
 - Mileage Ratio used in Settlements

- Resources' hourly credits are calculated using actual performance scores and mileage
- Marginal benefit factor will not scale payments like pricing

$$\begin{aligned}
 \text{Regulation Capability Credit} &= \left(\frac{\text{Assignment}}{\text{MW}} \right) * \left(\frac{\text{Historical}}{\text{Performance Score}} \right) * \left(\frac{\text{Capability Clearing}}{\text{Price \$}} \right) \\
 \text{Regulation Performance Credit} &= \left(\frac{\text{Assignment}}{\text{MW}} \right) * \left(\frac{\text{Historical}}{\text{Performance Score}} \right) * \left(\frac{\text{Performance Clearing}}{\text{Price \$}} \right) * \boxed{\left(\frac{\text{Mileage}}{\text{Ratio}} \right)}
 \end{aligned}$$

- After-the-fact make whole payments (LOCC) have been greatly reduced; shoulder hour logic is now primary driver

- FERC issued a Deficiency Notice during PBR development
 - Marginal Benefits Factor (MBF) not allowed in Settlements
 - Operated with a “1” multiplier until July 2013
 - PJM resettled almost a year’s billing with Mileage Ratio in Oct 2013
- Hourly Mileage Ratio = $\text{Mileage}_{\text{RegD}} / \text{Mileage}_{\text{RegA}}$
 - 2015 YTD Average ≈ 2.38
 - Mileage Ratio often larger than MBF; incentivizes more Reg D