Model Maintenance: When, how and how to avoid it

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Outline

- Introduction to Model Maintenance
- Identifying the need for action
- Model updating methods
- Instrument standardization methods
- Avoiding model maintenance
- Conclusions

B.M. Wise and R.T. Roginski, "Model Maintenance: the unrecognized cost in PAT and QbD," **Chemistry Today**, Vol. 33(2), pps. 38-43, March/April, 2015.
B.M. Wise and R.T. Roginski, "A Calibration Model Maintenance Roadmap," **Proceedings of ADCHEM 2015**, Whistler, BC, Canada, pps. 260-265, June, 2015.

Definition and Goal

- Model maintenance: The on-going servicing of multivariate models to preserve their predictive abilities.
- Goal of model maintenance: Sustain (or improve) models over time and changing conditions with the least amount of cost and effort

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Why Model Maintenance?

- Numerous things can cause multivariate models to become invalid
  - samples move to a range outside original calibration
    - analyte or interferent goes beyond calibration range or occurs in unusual combination
  - new variation is introduced into the samples
    - new interferent or variation in physical parameter, *e.g.* temperature
  - a change in the sample matrix causes the relationship between analyte and measurement to change
    - change in pressure, pH, particle size, temperature
  - a change in the hardware causes the analyte-measurement relationship to change
    - instrument maintenance, fiber optic change, source replacement, etc.

Before Model Goes Online

- Develop a plan for maintenance
  - Assume that updated or new calibration models will eventually be required
  - Have a plan for how to detect the problem and what to do about it
  - Put it in the budget!
- Measure standard samples
  - Plan for registration and amplitude shifts
  - Characterize instrument in ranges important to model

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Detecting Model/Data Mismatch & Performance Degradation

- Model prediction diagnostics
  - Spectral residual Q (or similar)
  - Sample distance T^2 (or similar)
- Prediction accuracy monitored via primary reference method
  - Unlikely that change not detected by diagnostics but possible
  - Risk based approach?
- Detecting that *something* has gone wrong easier than determining *what* has gone wrong.
  - unless you are monitoring via reference method!
  - ... and why aren't you?

Diagnostics Limits

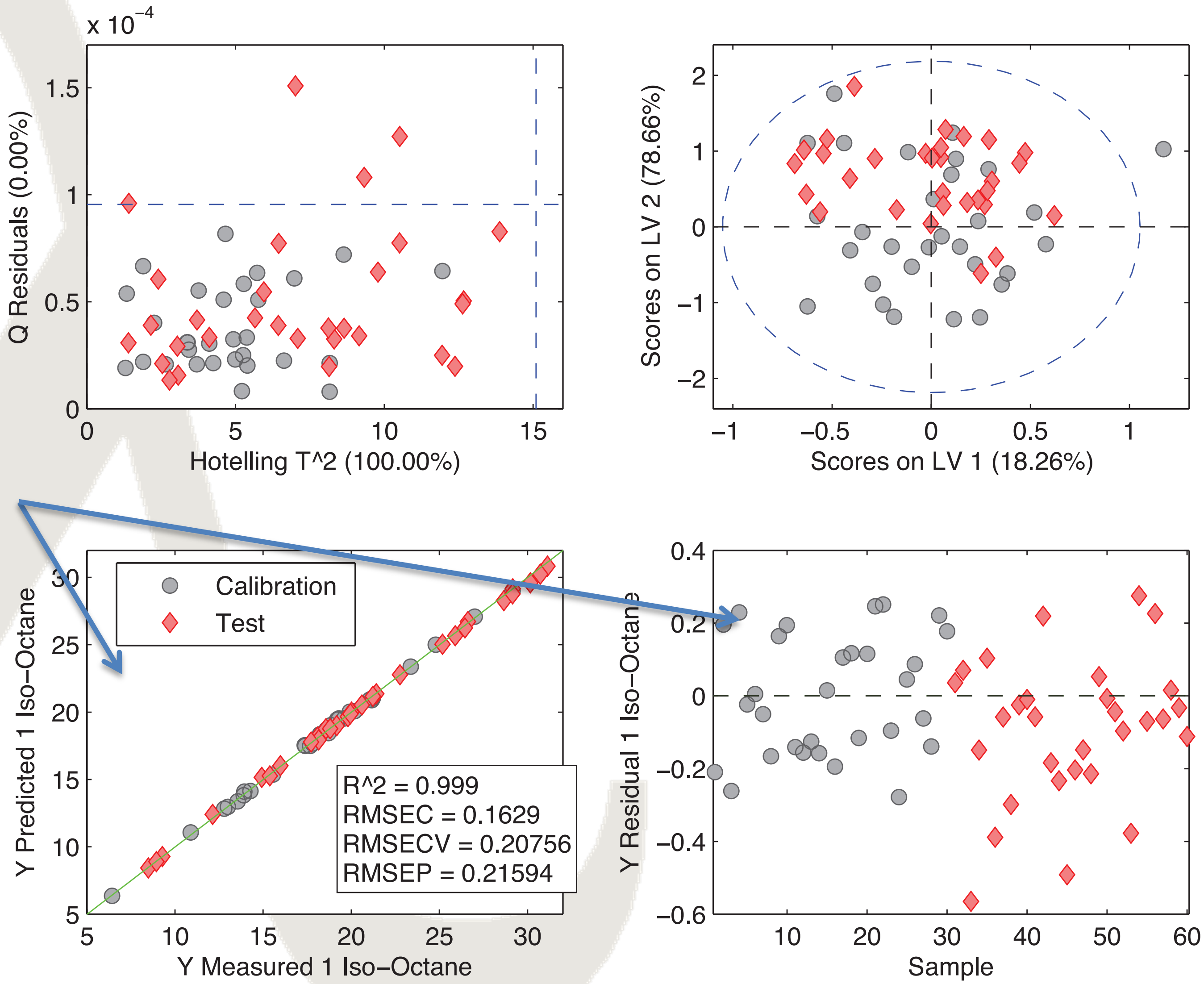
- By default, limits for Q and T^2 are generally provided based on some type of confidence limit
  - These limit values are statistically based
- Meaningful limits require knowledge of the process or measurement
  - Observations are needed that represent
    - “bad” states
    - out of spec product
    - failing sensor(s) or analyzer*

*these may be challenging to obtain

Example of detecting model/data mismatch

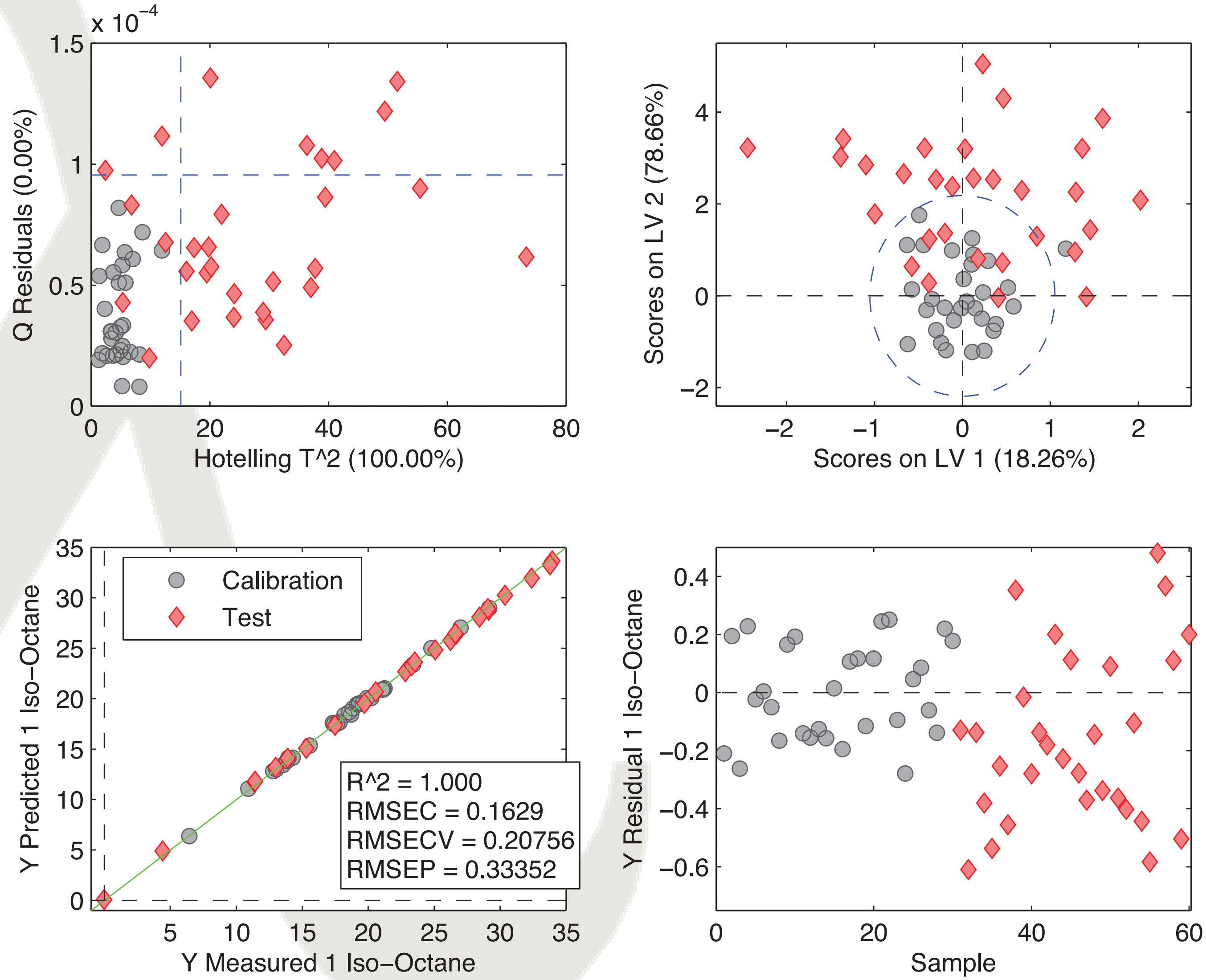
- Semi-synthetic example to illustrate change detection issues
- NIR measurement of iso-octane interferents (heptane, toluene, decane and eventually also xylene)
- CLS model to generate data along with a structured noise model from original data

Normal Operation

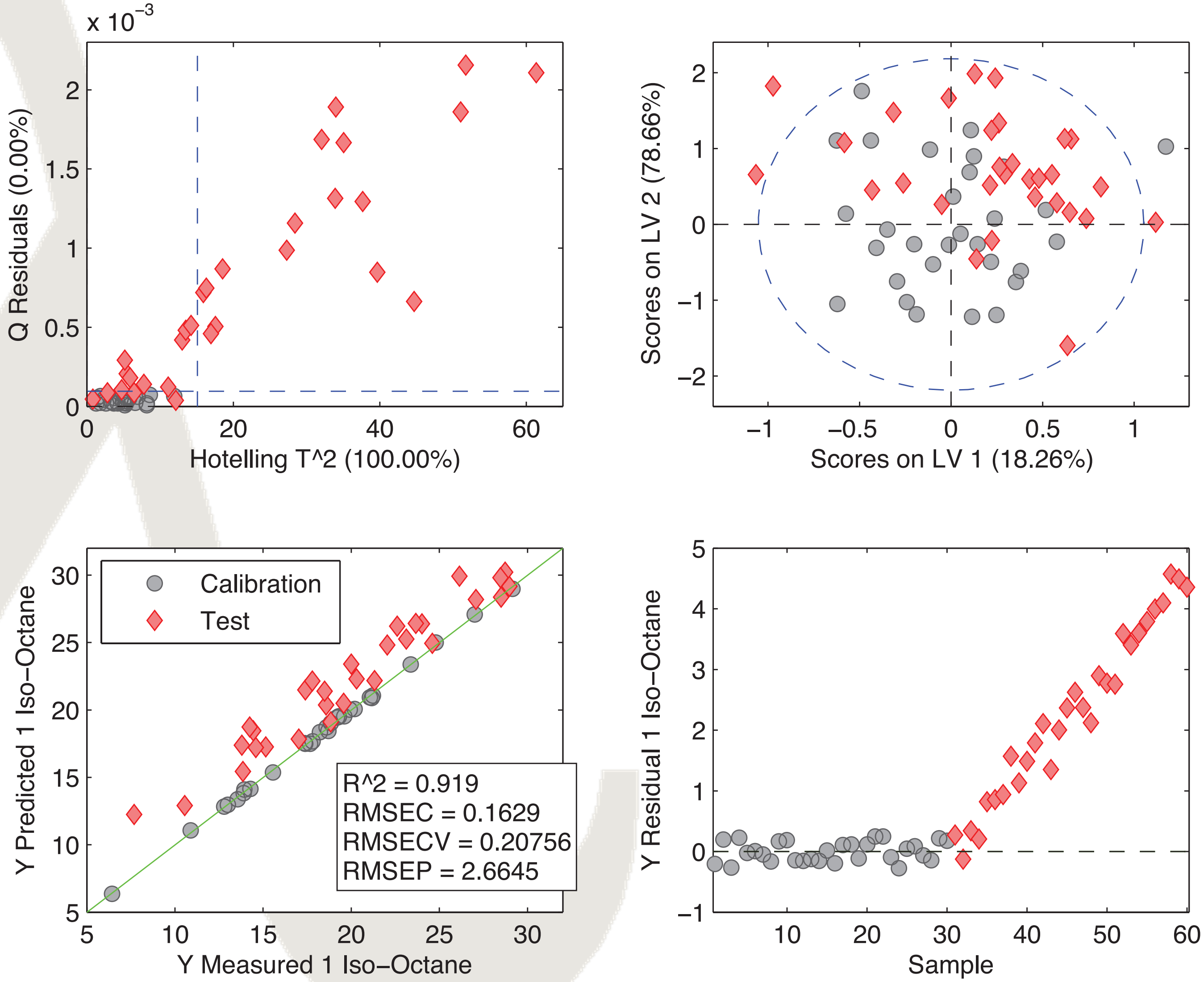


Only available from reference method

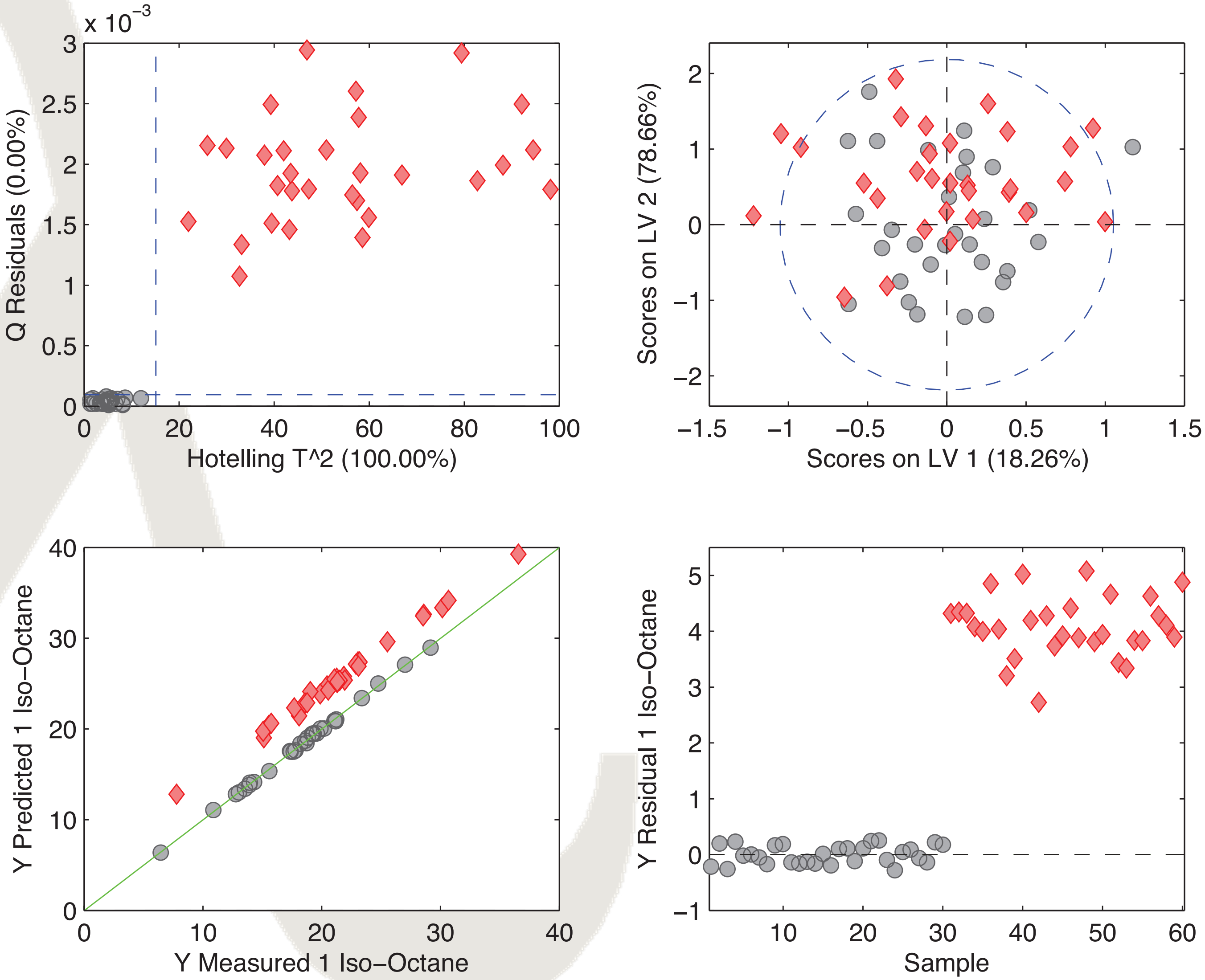
Out of Range Samples



New Interferent



Instrument Registration Shift



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Determining the cause of the problem

- Might not be obvious from model diagnostics
- Measurement by reference method helpful
- Standard samples can pin down cause unambiguously
- Then what?
  - Expand calibration set
  - Slope and bias correction
  - Instrument standardization

Adding Samples to Calibration Set

- Out of range and new interferent problems can usually be solved by adding samples to existing calibration set
- Problem: might take more than a few samples to “balance” calibration
- Solution: upweighting of new samples

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Slope and Bias Correction

- Simple to do
- May be appropriate for a constant shift
- Not to be used over and over!
  - Indicates problem is variable interferent or something else
- Automated model updating?

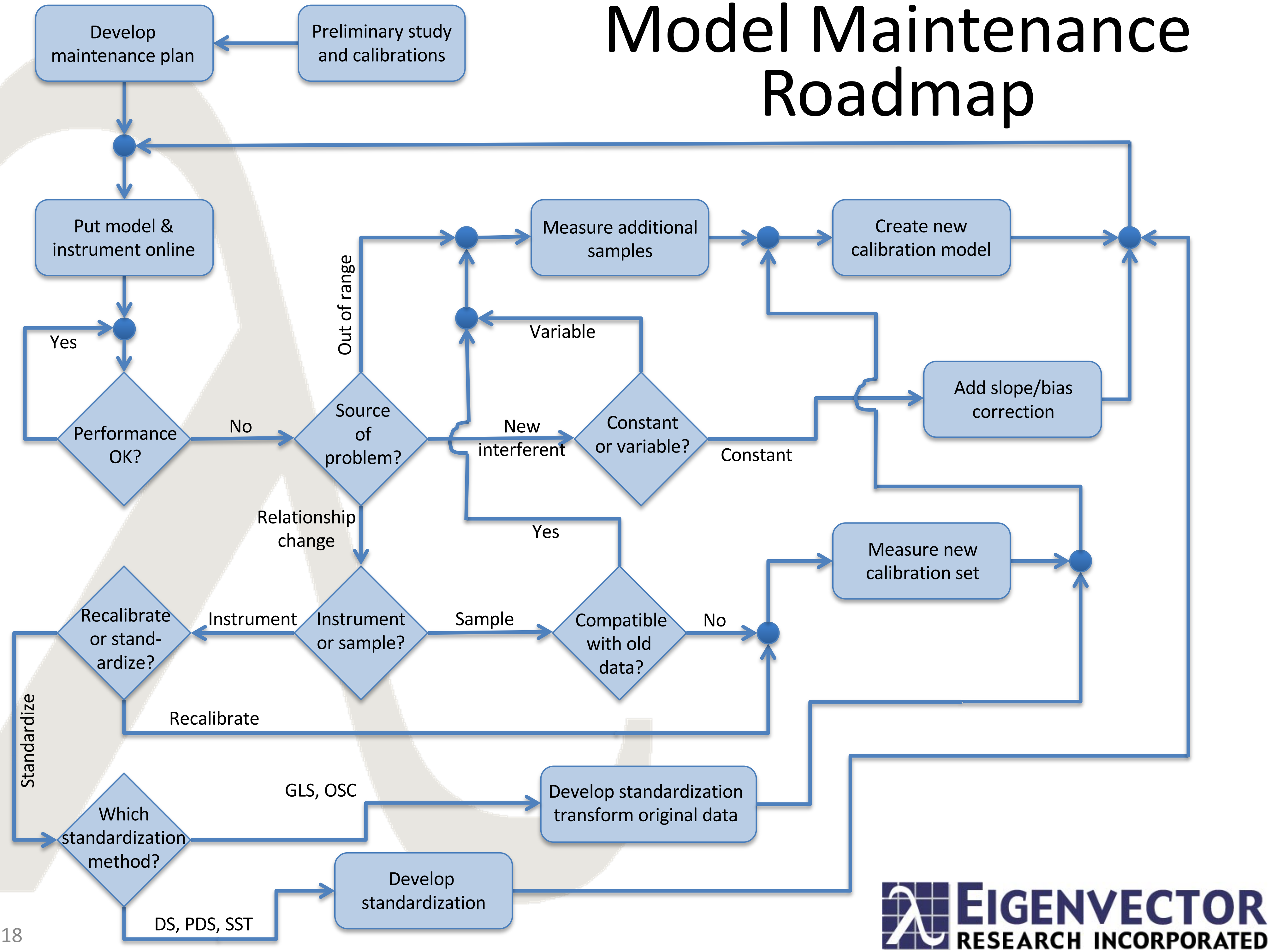
Standardization Methods

- Many methods available to estimate the response of the standard instrument from a different or changed instrument
- My favorites
  - Direct Standardization (DS)
  - Piecewise Direct Standardization (PDS)
  - Subspace Standardization Transform (SST)
  - Generalized Least Squares Preprocessing (GLS)
  - Orthogonal Signal Correction (OSC)

Putting it all together

- Have covered the pieces
  - Detecting change and performance degradation
  - Identifying the problem
  - Methods for updating/correcting models
  - Standardization methods
- How does this all fit together?

Model Maintenance Roadmap



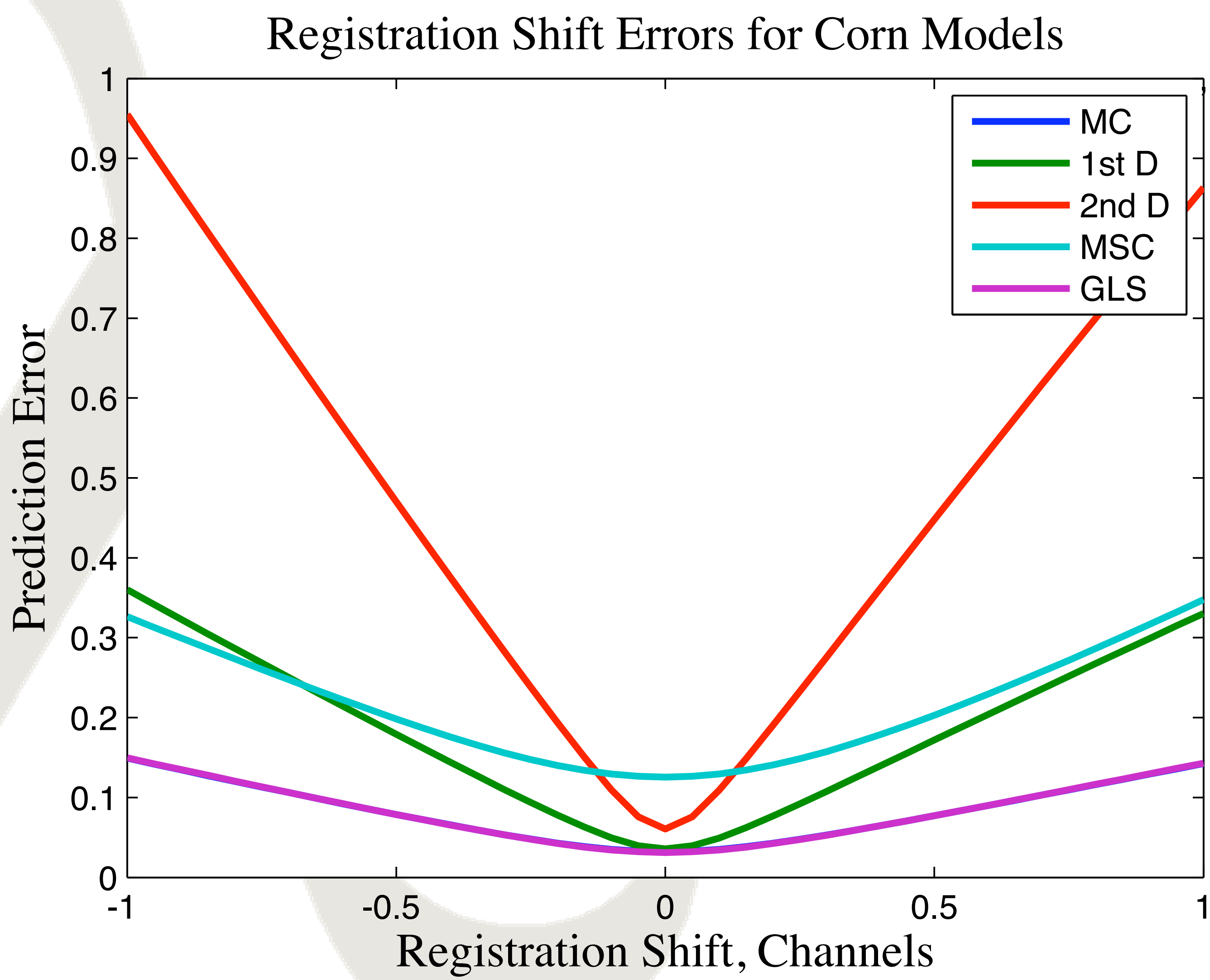
Avoiding Model Maintenance

- Some models more robust to new analytes and changes in data than others
- Highly dependent on preprocessing options and number of factors in models

Robustness Tests

- Series of functions developed to test model against system changes
  - Develop model with desired preprocessing, #LVs, etc.
  - "Perturb" test data set
  - Apply calibration model to "perturbed" data
  - Look at prediction error as function of perturbations
  - Test and compare multiple models

Shift with Preprocessing



Conclusions

- Plan and budget (!) for model maintenance
- Many elements
  - Performance monitoring
  - Problem detection and identification
  - Standardization protocols
  - Remodeling and revalidating
- Model robustness testing can help minimize the need for model updating