Modular Approach for High Volume Data Analysis – Modelling, Visualization and Reporting

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Motivation

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- high volume data analysis is often a time consuming challenge – different analysis tools must be configured and applied for different analysis tasks
- there exists a gap between off-line and on-line analysis; in most cases the off-line designed algorithms can't be established one-to-one in the production in on-line systems, the adaption of the algorithms is time consuming and error prone during rollout
- the implementation of new, highly sophisticated algorithms in standard analysis tools is difficult and often not possible at all
- recurrent tasks like data acquisition, pre-processing, validation, notification and storage are usually implemented individually in different ways and several systems

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Objective and Setup

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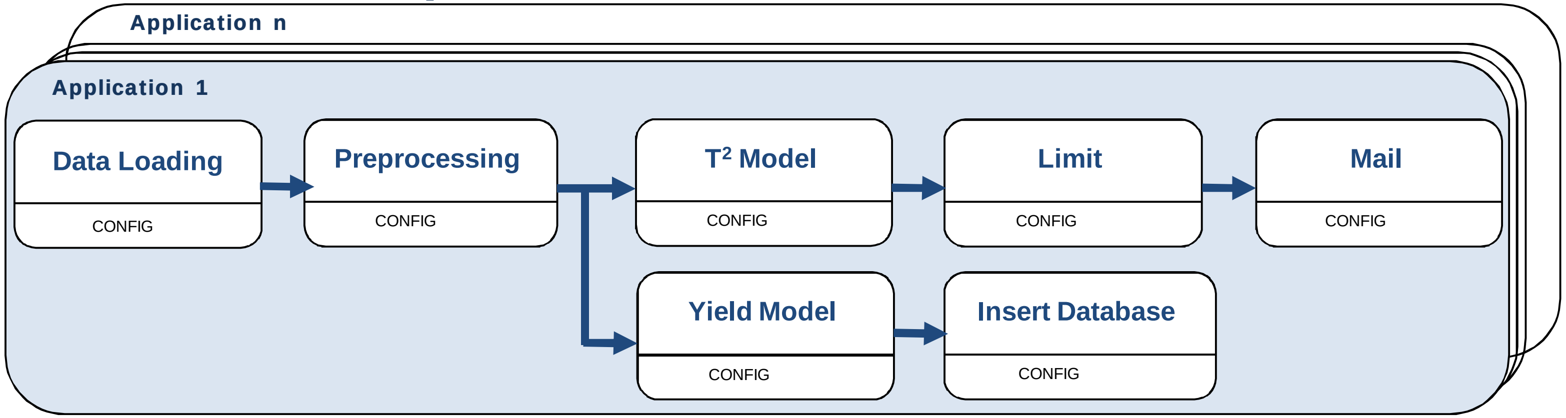
- provide easy to use MATLAB® based modular and expandable construction kit for high volume data analysis and modeling
- the same code implementation is used for off-line and on-line



- several modules for data acquisition, data pre-processing, regression analysis, and multivariate adaptive T^2 can be combined to form a well tailored application
- powerful Data and Configuration classes enable a reliable and fast application development
- MATLAB architecture enables a fast prototyping for implementations and testing of new algorithms

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Architecture

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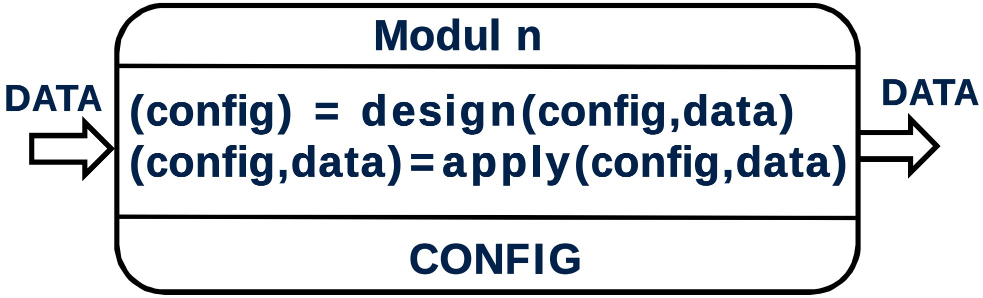
- each module uses an abstracted configuration, implements stateless code and provides fixed interfaces which enable a free arrangement:

design: this method implements a GUI for off-line design based on historical data and provides a configuration; the configuration stores all model parameters and model states.



apply: this method applies the model to the data under consideration of the stored parameters and states within the configuration.

- a DATA Class for storage and merging all relevant data (wafer based parameter, time resolved data, site data (e.g. metrology measurement), high resolved sensor data (OES)) was established
- the DATA Class is used to pass all data from module to module

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Architecture

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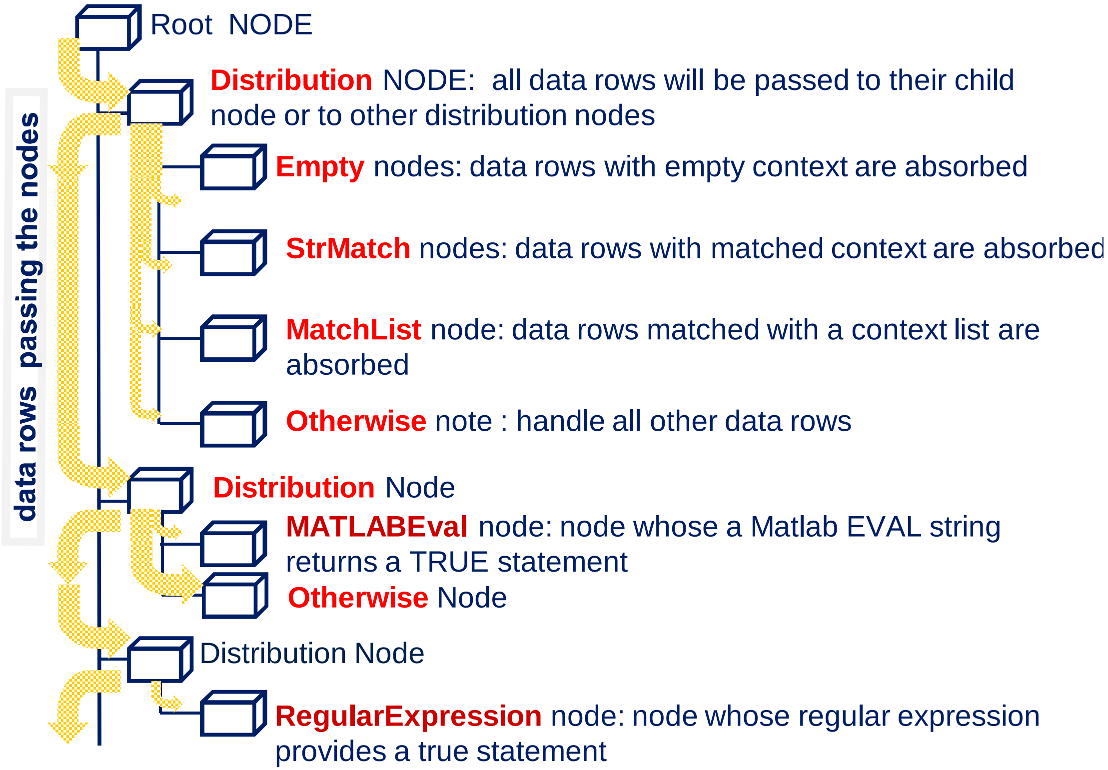
- a CONFIGURATION Class for context sensitive storage of model parameter and states was developed, each module stores it's own configuration in a well defined way within a unique schema

- the Configuration class was implemented as a tree oriented structure

- each data set is tested against the node condition, if the data context matches with the specified condition, all parameters and states from the node will be assigned to this data set

- the Configuration can be applied to single data sets in on-line cases as well as to high volume data in off line cases



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Use Case 1: Tool Health Monitoring

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- a THM Module was designed based on Hotelling T^2 statistic
- in contrast to univariate SPC, Hotelling T^2 allows the detection of error states in multivariate parameter space
- challenge in production:
  - parameter drifts in static T^2 models lead to drifts in the T^2 value – adaption of means is necessary
  - maintenance actions typically yield to a change of correlation structures, the adaption of the covariance matrix after such influences must be possible
  - T^2 models strongly depend on different logistics contexts
  - typical problems with missing values
  - Drill-Down from T^2 value to the root cause is a big challenge

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Use Case 1: Tool Health Monitoring

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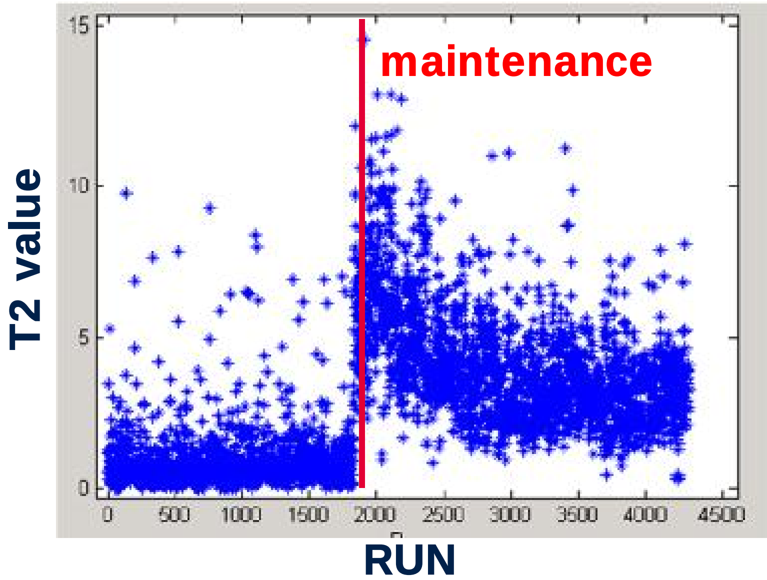
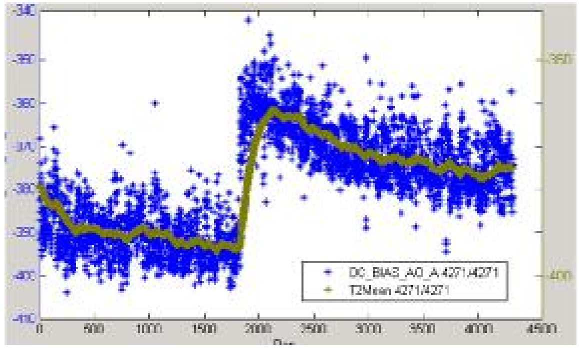
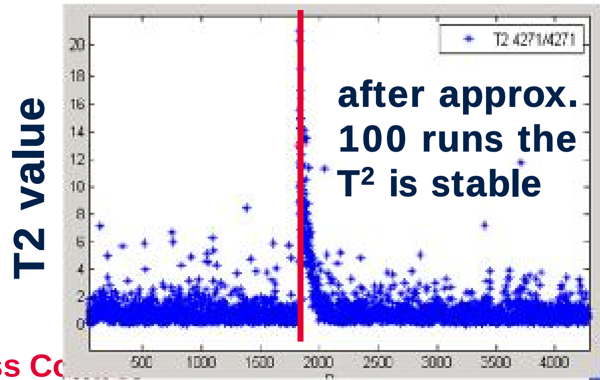
- n **Calculation of T2:** $T^2 = (\underline{x} - \underline{m})^T \cdot C^+ \cdot (\underline{x} - \underline{m}) / n = \underline{x}_0^T \cdot C^+ \cdot \underline{x}_0 / n$
  - **- Adaption of Mean:** $\underline{m}_{k+1} = g^2 \cdot \underline{m}_k + (1 - g^2) \cdot \underline{x}$
  - **- Adaption of Covariance:** $C_{k+1} = g^2 \cdot C_k + (1 - g^2) \cdot (\underline{x} - \underline{m}_{k+1}) \cdot (\underline{x} - \underline{m}_{k+1})^T$

à application of a T² model without adaption yields to a drifting T² value after maintenance actions



à adaption of means prevents drifts in T2 value (γ^2=0.99)





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Use Case 1: Tool Health Monitoring

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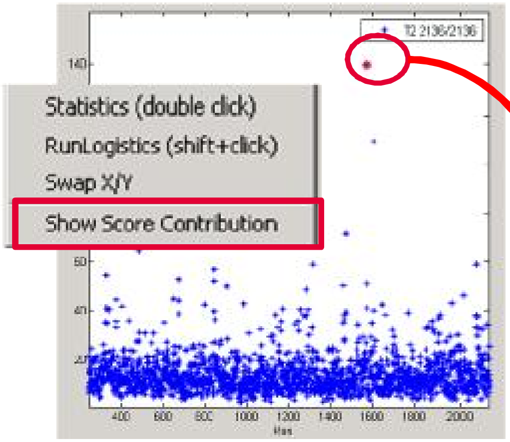
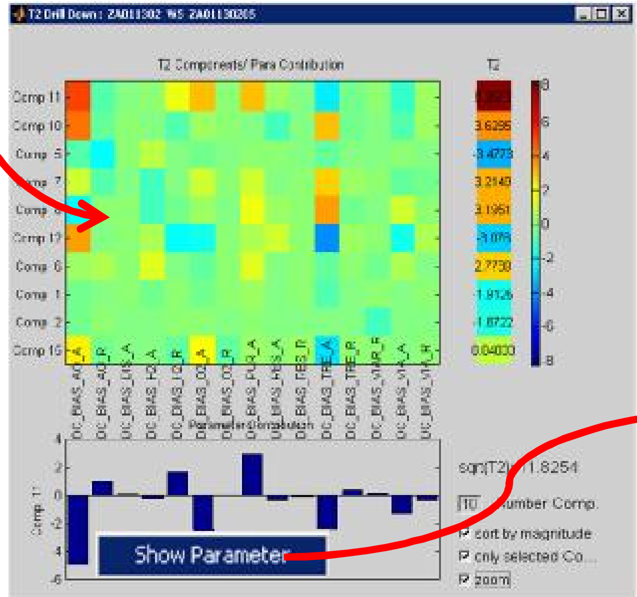
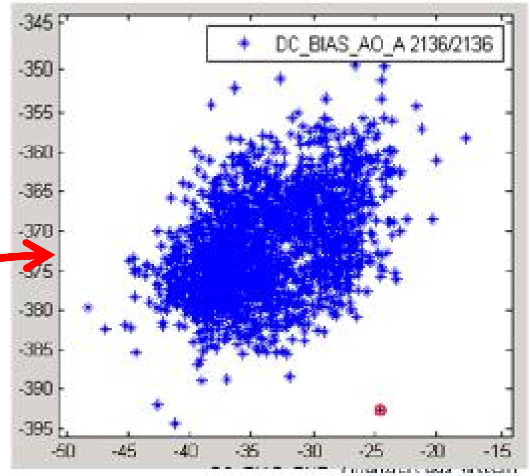
- interactive Drill Down Features are most important for the root cause analysis
- visualization of the component matrix $\underline{t} = \sum_{j=1}^{n} x_0^j \cdot v_{ij}$ enables a fast drill down to single parameters, which causes a large T^2 value



Component matrix shows the fraction of each component in the total T^2 value



Drill Down from Component Matrix to single Parameter Plot shows the outliers in a suited projection



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Use Case 2: Prediction of Inline Data

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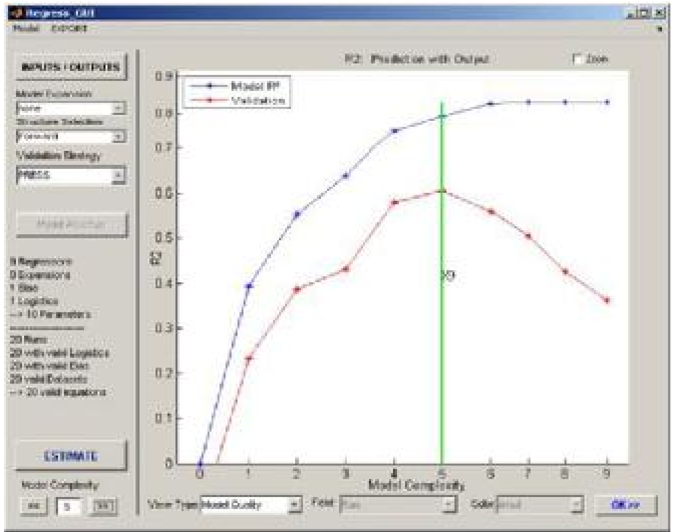
- for the analysis of influences and interactions within process data a Regression Module was designed which enables a fast model design with the following features:
  - context sensitive analysis and modelling
  - consider numerical influences (regressors) and logistical (bias)
  - model complexity tuning based on different methods (e.g. forward regression, backward regression, stepwise regression, manual regression, principal component regression)
  - different model validation techniques are provided (R^2, adjusted R^2, F-statistic and different cross validation strategies)
  - fast model explanation and application to other data
  - model storage and export



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Use Case 2: Prediction of Inline Data

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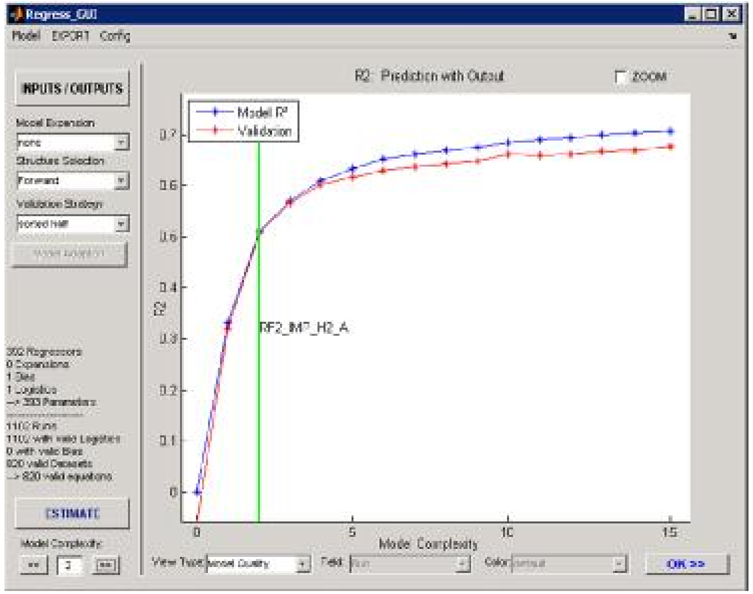
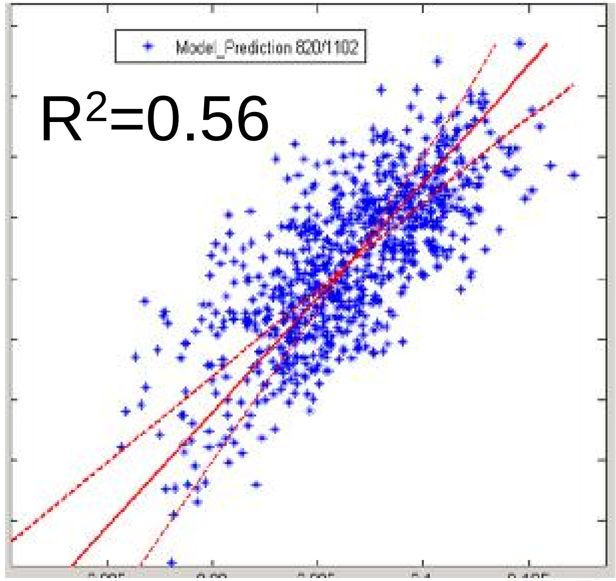
- several hundred wafer-based parameters were measured in several phases of a DUDA Etch process
- the VIA CD after the etch is only measured for sample of wafers, a prediction of the CD for all wafers is important for a reliable process control

Model Quality vs. Complexity



Prediction vs. measured CD



Predicted CD

measured VIA CD

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Use Case 3: Reporting within Wafertest

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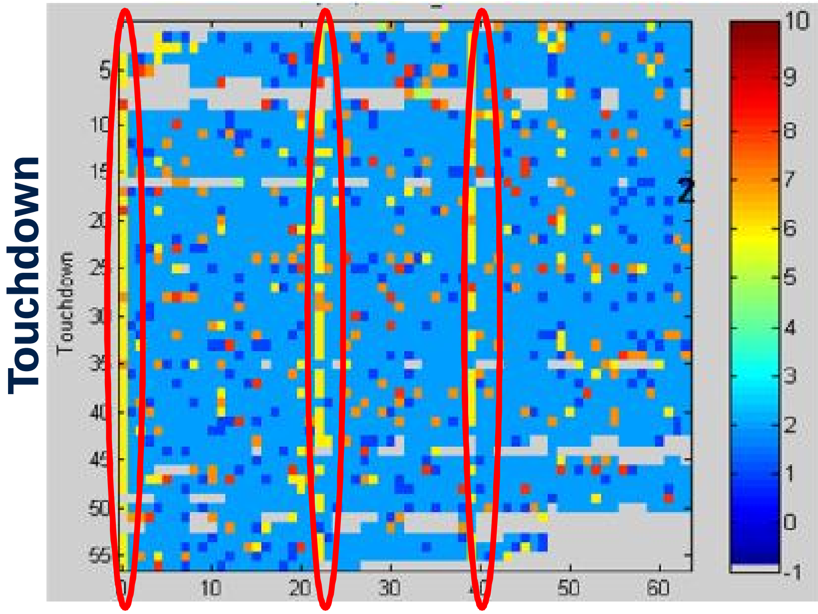
- based on HBin/SBin test results and ProbeMark Inspection Data new parameters are generated for fast identification of probecard dependent yield issues e.g. identification of contact problems or systematic wafer/probecards drifts or rotation

HBin Map – Touchdown vs. Probecard Site



Probecard Site

Example: Probecard related Yield Loss

- HBIN TouchDown Map show defect Probecard Sites
- fast identification of such systematic Probecard failures is a major issue

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Use Case 3: Reporting within Wafertest

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- daily reports, based on those data provide useful information about the stability of the test process and help to identify defect probecard sites

- several modules were provided to generate user specific reports:
  - ***Aggregation***: module to calculate aggregated parameters for free defined Logistic combinations (Pivot Tables)
  - ***Calculation:*** derive and create new computed data columns
  - ***Export:*** module to export results to e.g. Excel

Probecard related YieldLoss grouped by Probecard