Machine Learning in Process Modeling and Decision Making for the IC Sector

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Semiconductor Process Control

Advanced Process Control
- Statistical Process Control (SPC)
- Fault Detection and Classification (FDC)
- Run to Run Control (R2R)

Applied Materials Industry 4.0 Process Control *
- Computational Process Control (CPC)

* Tech Design Forum, Paul Dempsey, March 2017
Statistical Process Control (SPC)

Post Process Measurement data is plotted on a chart and specific Western Electric rules are applied to the data to see if we are out of control.

What do we do if we are? We put the equipment down and put the lot on hold and begin a corrective action path.

Why do we put the lot on hold if we are still IN SPEC? Because spec limits don’t mean good product!
Run to Run Control (R2R)

Run-to-run (R2R) control is a form of adaptive model-based process control that can be tailored to environments where the process is discrete, dynamic, and highly unobservable; this is characteristic of processes in the semiconductor manufacturing industry. It generally has, at its roots, a rather straightforward approach to adaptive model-based control such as a first-order linear plant model with moving average weighting applied to adapt the (zeroth-order) constant term in the model.

Most of the complexity of R2R control science lies and will continue to lie in extensions to support practical application of R2R control in semiconductor manufacturing facilities of the future; these extensions include support for weighting and bounding of parameters, run-time modeling of a large number of disturbance types, and incorporating prediction information such as virtual metrology and yield prediction into the control solution.

James Moyne, Run to Run Control in Semiconductor Manufacturing, November 2014
Fault Detection and Classification (FDC)

- Deals with process alarm conditions
- Not all alarms are interesting
- Not all alarms are cost effective
- Faults may be analog in nature and require profiles to be recognized as faults
- Conditions leading to an alarm need to be modeled and clearly understood
- Is the anomalous condition a root cause or a symptom?
- Root cause conditions must be identified, characterized and alarms weighted and justified

FDC is based on the idea that you can detect changing conditions within equipment and use that knowledge to improve process.
Computational Process Control (CPC)

Applied Materials is developing an evolution in supervised process control that uses Industry 4.0 advanced data analytics techniques combined with modeling data, metrology data, virtual metrology data, process data and domain knowledge into a next generation process control model.

A comprehensive knowledge network is essential to drive good die out
Common Weak Points?

- Current Process Control functionality assumes much, and requires deep domain expertise to be effective.
- Process Control relies heavily on post-processing measurements
- Each method sub-optimizes processing steps in the workflow

- You must know the interesting questions before you can ask them

This said, the foundations provided by existing process control methodologies are crucial to the success of a Digital Twin approach to Analytics Based Process Control.
Analytics Based Process Control

Only possible with predictive analytics that includes modeling and data based analytics across the factory
The **Digital Thread** ties all of your data together, from requirements through design all the way to manufacturing and the field.

The **Digital Twin** allows us to simulate the entire supply chain, from requirements collection and design to factory layout, capacity, scheduling, processing, manufacturing and the field.

**Shift-Left** and fail before committing physical assets, or catch real problems as early in the process as possible.
Accelerating the Innovation Velocity
Leveraging Analytics to Transform Your Business

**Descriptive**
What happened?

**Diagnostic**
Why did it happen?

**Predictive**
What happens next and when?

**Prescriptive**
When this happens, take these steps.

- Fast Contextual Search
- Performance Analytics
- Advanced Data Visualization

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- Performance Analytics
- Advanced Data Visualization
- Predictive Learning
Introduction: Predictive Analytics

What is Predictive Analytics?
• Systems or applications used for predicting the likelihood of certain events happening in future from analyzing historical data

How does Predictive Analytics Work?
• Historical data is analyzed, patterns are exploited, models are trained
• Models are used to predict an outcome based on new data

Why Predictive Analytics?
• This is the future trend of big data analytics and will gain a lot of potential market in the manufacturing domain
Predictive Analytics General Data Analysis Flow

Data Collection → Data Preparation → Building Models → Validate Models → Deploy Models

Data Visualization → Model Visualization → Automated Model Selection → Update Models → Feedback

Maintain Models
Domain Knowledge is Key to Success

What you see in the data:

A

Correlates with

B

Correlates with

Correlates with

Assume you want to predict Y

Y

What you need know to solve the problem:

A

causes

combine

Y

causes

That will be the independent variable in your model

This one is irrelevant for predicting Y

B

Omneo Solution (Data Scientist)

Domain Expertise (Business User)

Omneo + Domain Expertise
Cross-Functional - Why did this fail?

Business Use Case Definition

Provide Product Insights

**Description:**
Identify patterns, which were unknown or would require huge effort to uncover, by analyzing all available data / parameters related to a specific lot.

**BUC Objective(s):**
- Reduce time-to-resolution which will avoid prolonged containment times, avoid scrap / rework and avoid production disruption

**Source system(s):**
- Test Specs
- Testing raw data
- Manufacturing Execution System (MES)
- Process Equipment Sensors

**Example:** All the in-process test are in Specs, but at final tests some items fail: Why? A pattern is discovered showing, that when test 5 & 7 are in the bottom range of the spec, it ends up with fail at final test.
Decision Making Support

- All measurements are in spec, product is not yielding as expected

**Commonalities**
- 3 high, 5 low, 7 low, 9 high FAIL
- 3 med, 5 low, 7 low, 9 med FAIL
- 3 low, 5 high, 7 med, 9 low PASS
- 3 low, 5 med, 7 high, 9 med PASS

Not enough data to make a positive correlation
Adding in Analytics, we perform Discovery on the data

Typical Data Needed for Discovery

- Measurement Specs
- Actual Measurement Data
- Process Data – sub-second data collection, as many interesting data points as possible
- FDC Data – alarms that we care about, and MIGHT care about
- SPC violations and corrective actions taken
- What Recipe was run for each specific lot with equipment settings (R2R changes)
- Facilities data - temperature, humidity, air quality, DI water quality, etc
- Equipment data - how long since PM, was it waived? What was done, etc
- Operator, training level, shift and time when the lot was run
- Modeling expectations for where we should be running in this process
- MES history of all actions on the lot and equipment

Discovery then pulls together the “I didn’t know to ask this question” results, and we use these to begin to characterize the problem.
After adding in all the extra data AND going through the Discovery results to characterize the process, here's what we found (hypothetical):

At SPEC 5, Alarm Code 2002 always occurred on the lots that failed, and never occurred on the lots that passed.

At SPEC 9, Recipe modifications from R2R process to raise results to center of spec always changed parameter X by >20% in the lots that failed.
Analytics Supported Decisions

- We have identified conditions that result in yield failures at a high enough frequency to predict future failures early.

- If we encounter these conditions in the future, at the earliest point in the process the **Activity Manager** will:
  - Predict yield loss and start a new lot to make up for the lost quantity commitments
  - Schedule a DOE (engineering support already configured) to attempt to correct the problem for the lot in process. Data will be used to refine the analytics.

- Further process control analytics will refine the correction approach as well as the process and environmental characteristics that led to the error in the first place
  - If there is a systemic equipment issue, PM or other requirements will be added to the production schedule
  - If there is a modeling or IP problem (this cell is always impacted by these conditions) then appropriate measures to limit future risk can be taken
Analytics Based Process Control

Only possible through predictive analytics that includes both modeling and simulation data as well as actual production results across the factory.

The Discovery processes must be able to run through huge volumes of data in a very short period of time.

Dell Example with Omneo: 2B rows, 250M variables, 3-4 secs
Thanks for Your Attention

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