Multivariate process control and real time sensors in practical use

Björn Engström, Perten Instruments AB
Torbjörn Lestander, Swedish University of Agricultural Sciences
Per Lidén, Perten Instruments AB
Henrik Sundström, TPF Management
Parameters available for process monitoring and optimization

**Raw material**
- Lab measurements
- Sensors
- Specifications

**Process**
- Automation
- Lab measurements
- Sensors
- Manual

**Process output**
- Volume
- Productivity

**Quality**
- Lab measurements
- Sensors
- Customer feedback

Production management and process operators
The BoardModel vision

NIR

forming parameters

Glue mix composition

Pre-press parameters

press parameters

thickness & weight

Real time

Raw material

Process state

Product quality

PLS Calibration Model

$k_1 \cdot \text{density} + k_1 \cdot \text{surface chips} + k_1 \cdot \text{wax core} + k_1 \cdot \text{thickness} + k_1 \cdot \text{resin core} + k_1 \cdot \text{resin surf} + k_1 \cdot \text{NIR} \cdot \text{MOR} + C_1$

$k_2 \cdot \text{density} + k_2 \cdot \text{surface chips} + k_2 \cdot \text{wax core} + k_2 \cdot \text{thickness} + k_2 \cdot \text{resin core} + k_2 \cdot \text{resin surf} + k_2 \cdot \text{NIR} \cdot \text{E module} + C_2$

$k_3 \cdot \text{density} + k_3 \cdot \text{surface chips} + k_3 \cdot \text{wax core} + k_3 \cdot \text{thickness} + k_3 \cdot \text{resin core} + k_3 \cdot \text{resin surf} + k_3 \cdot \text{NIR} \cdot \text{IB} + C_3$

$k_4 \cdot \text{density} + k_4 \cdot \text{surface chips} + k_4 \cdot \text{wax core} + k_4 \cdot \text{thickness} + k_4 \cdot \text{resin core} + k_4 \cdot \text{resin surf} + k_4 \cdot \text{NIR} \cdot \text{TSW} + C_4$
y = 0.767x + 3.4627
R² = 0.8288
SEP = 0.946

Parameters used in the calibration:
- NIR on core chips before resin addition
- thickness
- density
- resin load surface/core layers
- surface/core ratio

Std error for MOR in duplicates ~ 0.5 MPa
# Modulus of rupture

<table>
<thead>
<tr>
<th>Source of error</th>
<th>Lab</th>
<th>PLS</th>
<th>Inpendent/Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample preparation</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Precision in lab measurement</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Sample homogeneity</td>
<td>X</td>
<td>X</td>
<td>No</td>
</tr>
<tr>
<td>Std dev in process parameters</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Time lag for process tags</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Spectrometer stability</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Calibration error</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The BoardModel vision

Time series, MOR
external data set collected during 10 weeks
Implementation

Drivers

• Optimal quality
• Increase productivity
• Optimal raw material use
• Reduce rejects/claims

Challenges

• Technical performance
• Relevant parameters
• Certificates
• Will it be used in the control room at 1 a.m.?
  – Company culture
  – Incentive systems
  – Trust – resistance
Reduction of standard deviation

![Graph showing reduction of standard deviation with two curves for Reference and BoardModel™. The 5% percentile is indicated.]
Savings achieved

In €/m³ when optimizing a particleboard mill with the BoardModel™ system

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th></th>
<th>BoardModel™</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MOR (MPa)</td>
<td>IB (MPa)</td>
<td>MOR (MPa)</td>
<td>IB (MPa)</td>
</tr>
<tr>
<td>Average</td>
<td>21,263</td>
<td>0,674</td>
<td>20,483</td>
<td>0,664</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>1,092</td>
<td>0,044</td>
<td>0,649</td>
<td>0,034</td>
</tr>
<tr>
<td>Lower 5%</td>
<td>19,431</td>
<td>0,599</td>
<td>19,395</td>
<td>0,608</td>
</tr>
<tr>
<td></td>
<td>n=60</td>
<td></td>
<td>n=53</td>
<td></td>
</tr>
</tbody>
</table>

Reduced resin consumption: 7.07%
Reduced dry wood consumption: 2.60%
Savings: 2,82 €/m³
### Moisture wood pellets

NIR method: 2 repacks, 2 repeats

*The sample is packed two times and scanned twice per repack.*

*This gives in total 4 spectra that are averaged to give one measured value*

**Evaluation of 85 samples**

<table>
<thead>
<tr>
<th>Method</th>
<th>r²</th>
<th>Std dev/SEP</th>
<th># Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIR Repeat</td>
<td>0,999</td>
<td>0,016</td>
<td>0</td>
</tr>
<tr>
<td>NIR Repack</td>
<td>0,972</td>
<td>0,099</td>
<td>4</td>
</tr>
<tr>
<td>NIR Repack</td>
<td>0,930</td>
<td>0,145</td>
<td>0</td>
</tr>
<tr>
<td>Owen moisture duplicate samples</td>
<td>0,953</td>
<td>0,145</td>
<td>0</td>
</tr>
<tr>
<td>NIR- Owen moisture</td>
<td>0,918</td>
<td>0,160</td>
<td>3</td>
</tr>
<tr>
<td>NIR- Owen moisture</td>
<td>0,905</td>
<td>0,203</td>
<td>0</td>
</tr>
</tbody>
</table>
# Moisture wood pellets

<table>
<thead>
<tr>
<th>Source of error</th>
<th>Owen</th>
<th>NIR</th>
<th>Independent/Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weighing sample twice</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Owen temperature</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Particle size and shape</td>
<td>X</td>
<td>X</td>
<td>No</td>
</tr>
<tr>
<td>Sample homogeneity</td>
<td>X</td>
<td>X</td>
<td>No</td>
</tr>
<tr>
<td>Spectrometer stability</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Sample distance</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Calibration error</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Repeats

\[ y = 1.0052x - 0.0348 \]
\[ R^2 = 0.999 \]

Repack

\[ y = 1.0141x - 0.0947 \]
\[ R^2 = 0.9723 \]

Owen duplicates

\[ y = 0.9598x + 0.2802 \]
\[ R^2 = 0.953 \]

Owen - NIR

\[ y = 0.899x + 0.6971 \]
\[ R^2 = 0.9185 \]
Formaldehyde

Perten DA7400

\[ y = 1.1743x - 0.5693 \]
\[ R^2 = 0.9062 \]
\[ SEP = 0.231 \]

- A good lab can have Std error for perforator of 0.13 mg/100 g
Formaldehyde

**ASTM D6007- NIR cross validation result, 85 samples**

- A good lab can have Std error for ASTM D6007 0,007 ppm
## Formaldehyde

<table>
<thead>
<tr>
<th>Source of error</th>
<th>ASTM D 6007</th>
<th>NIR</th>
<th>Inpendent/Additive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample age</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Collection of formaldehyde</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Determination of formaldehyde</td>
<td>X</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>Sample homogeneity</td>
<td>X</td>
<td>X</td>
<td>No</td>
</tr>
<tr>
<td>Spectrometer stability</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Side of board scanned</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
<tr>
<td>Calibration error</td>
<td></td>
<td>X</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Summary

• Process modelling with PLS is doable
  – Calibration works but is a challenge
  – Implementation – main challenge

• Comparing calibrated data with reference values
  – Sources of error are independent and additive

• Formaldehyde NIR calibrations
  – Calibrations with SEP compared Std error of reference method are now available
Thank you!