Peter Terwiesch
Chief Technology Officer
ABB

Industrial Automation: Situation and Trends

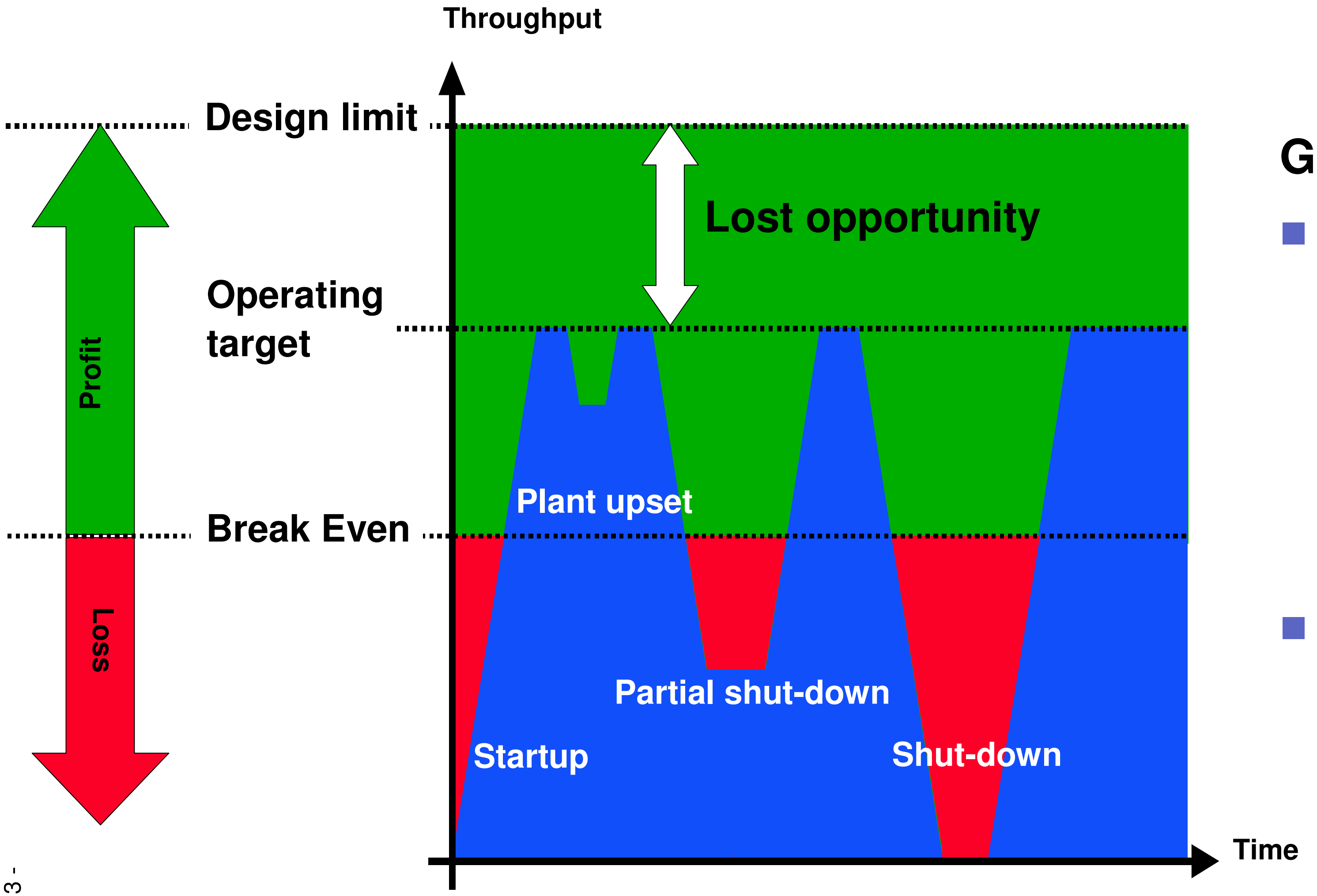
IFAC 50th Anniversary
Heidelberg
September 15, 2006

© ABB Group - 1 -
26-Aug-06

Overview

- Industry needs
- A visual history of industrial automation system evolution
- Industrial application examples
- Summary and outlook

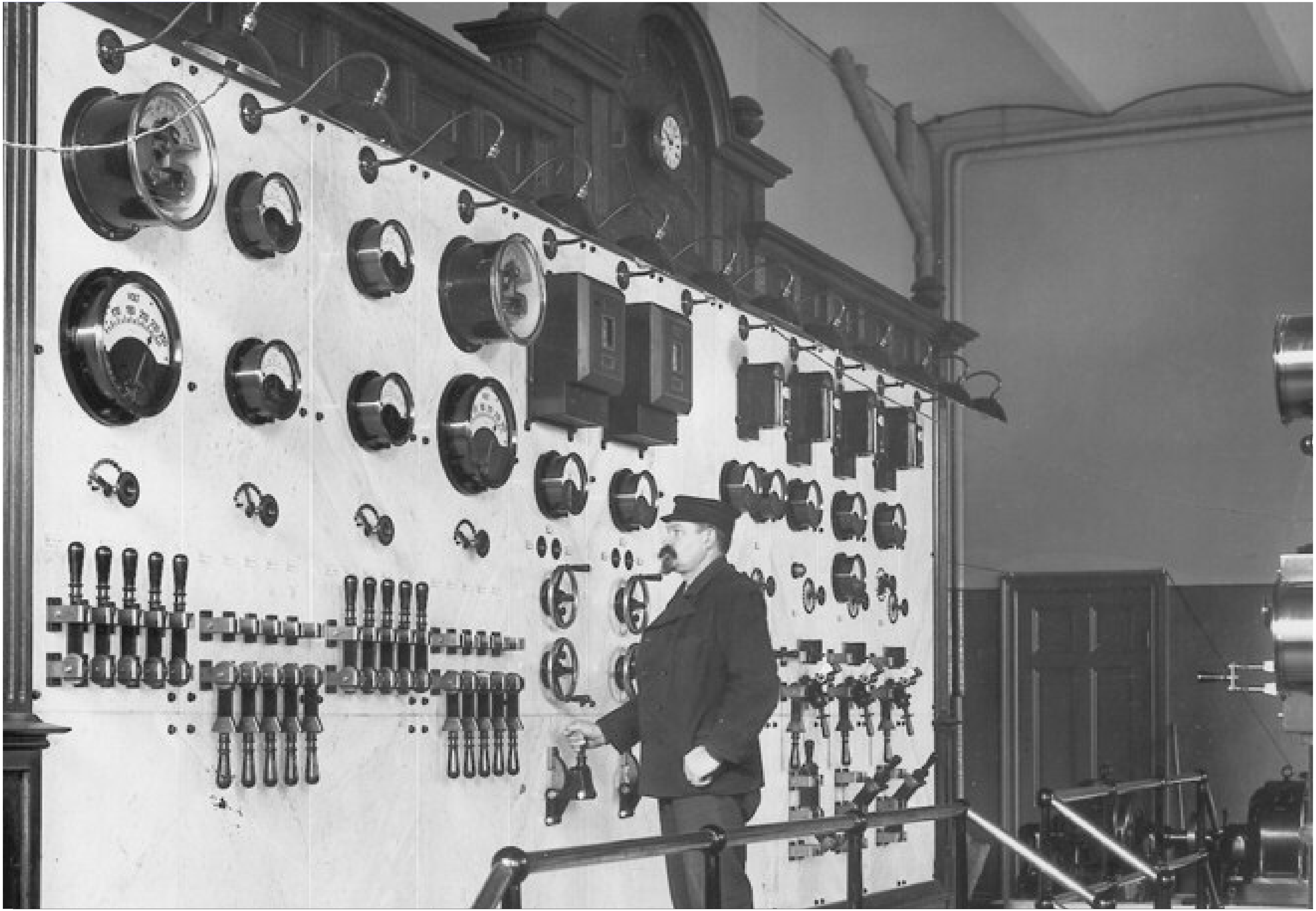
Industry Needs

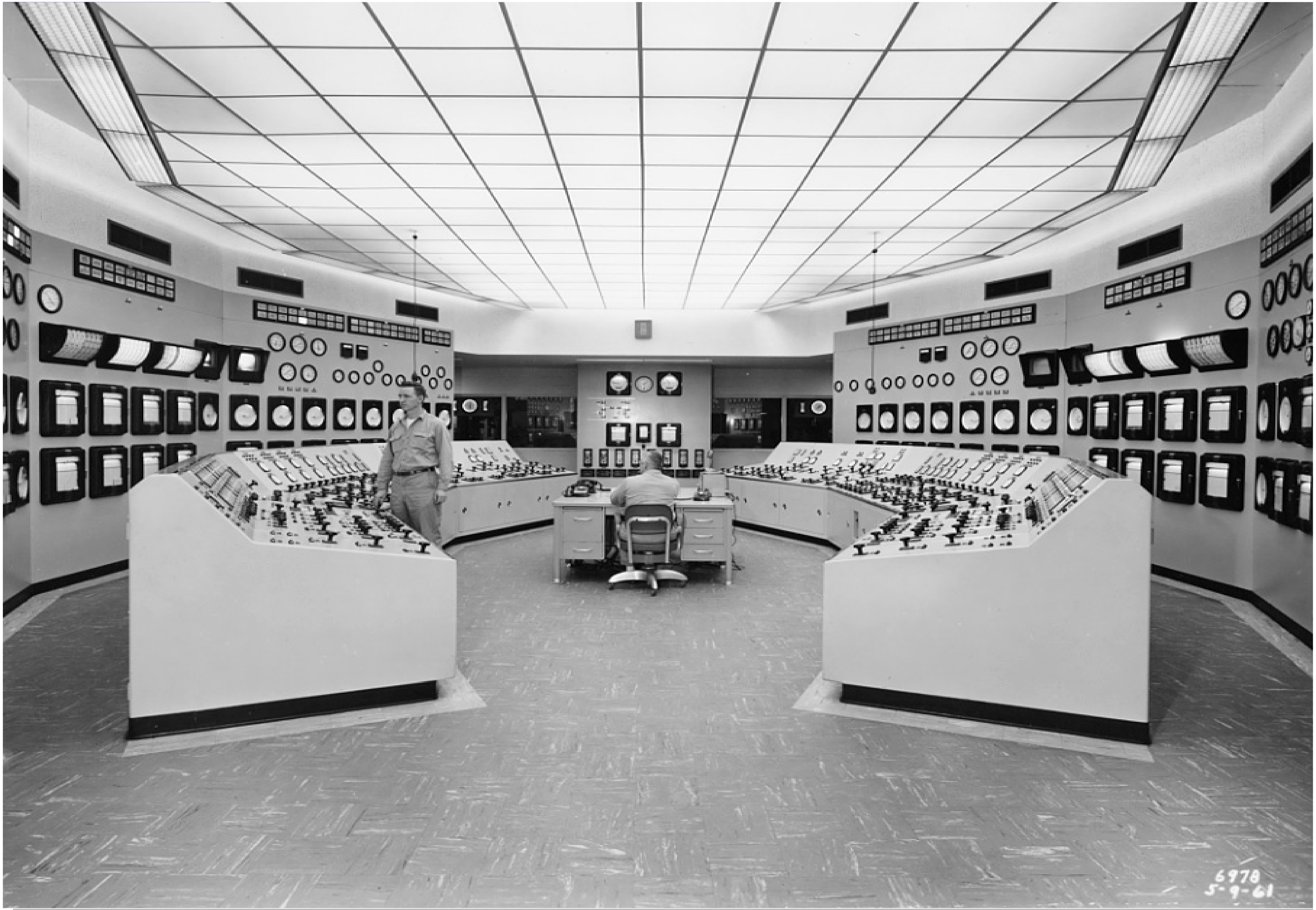


Global competition:

- Improve productivity
  - Deliver flexibly, better, more …
  - … with less: economically, and ecologically
- Focus capital spending, improve asset utilization

ABB



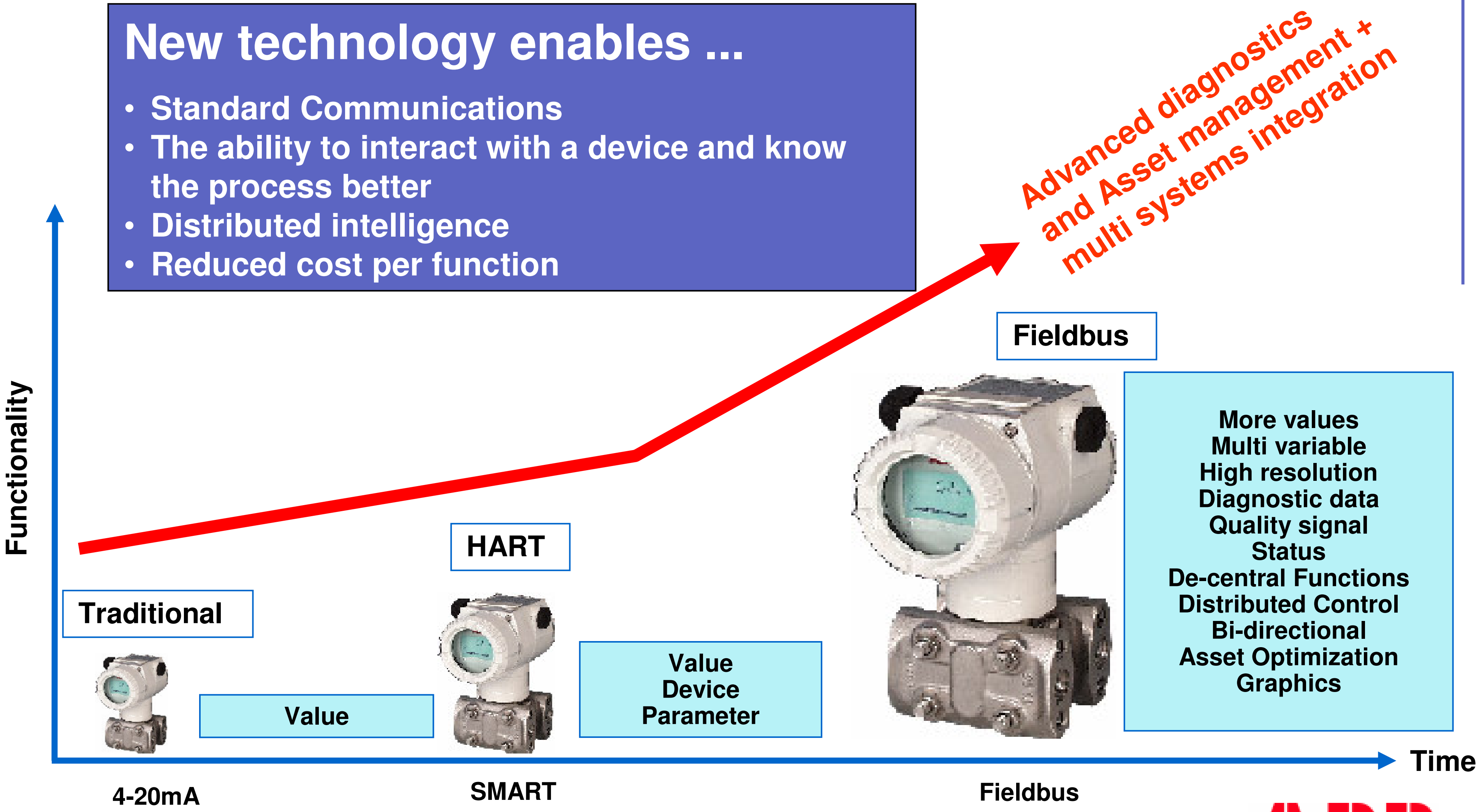

6978
5-9-61


2004-11-04 14:41
ABB
Feed In
Sand
Iron Ore
Bauxite
Prehomo
E.P. Heating / Compressor
Central Air Supply
Silo Discharge / Homogen
Aux.Drive For Mill Motor
Raw Mill Trns. Aeropol
Raw Mill Transport
Separator and Circulation
Waste Gas Fan
Electrostatic Precipator
Hot Gas Generator
Mill Motor
Mill Feeding
Lubrication
Discharge
Kiln Feed
Feed Out
2004-11-04 14:41:19
ABB

Intelligent Field Devices

New technology enables ...

- Standard Communications
- The ability to interact with a device and know the process better
- Distributed intelligence
- Reduced cost per function



ABB

Automation Industry Consolidation

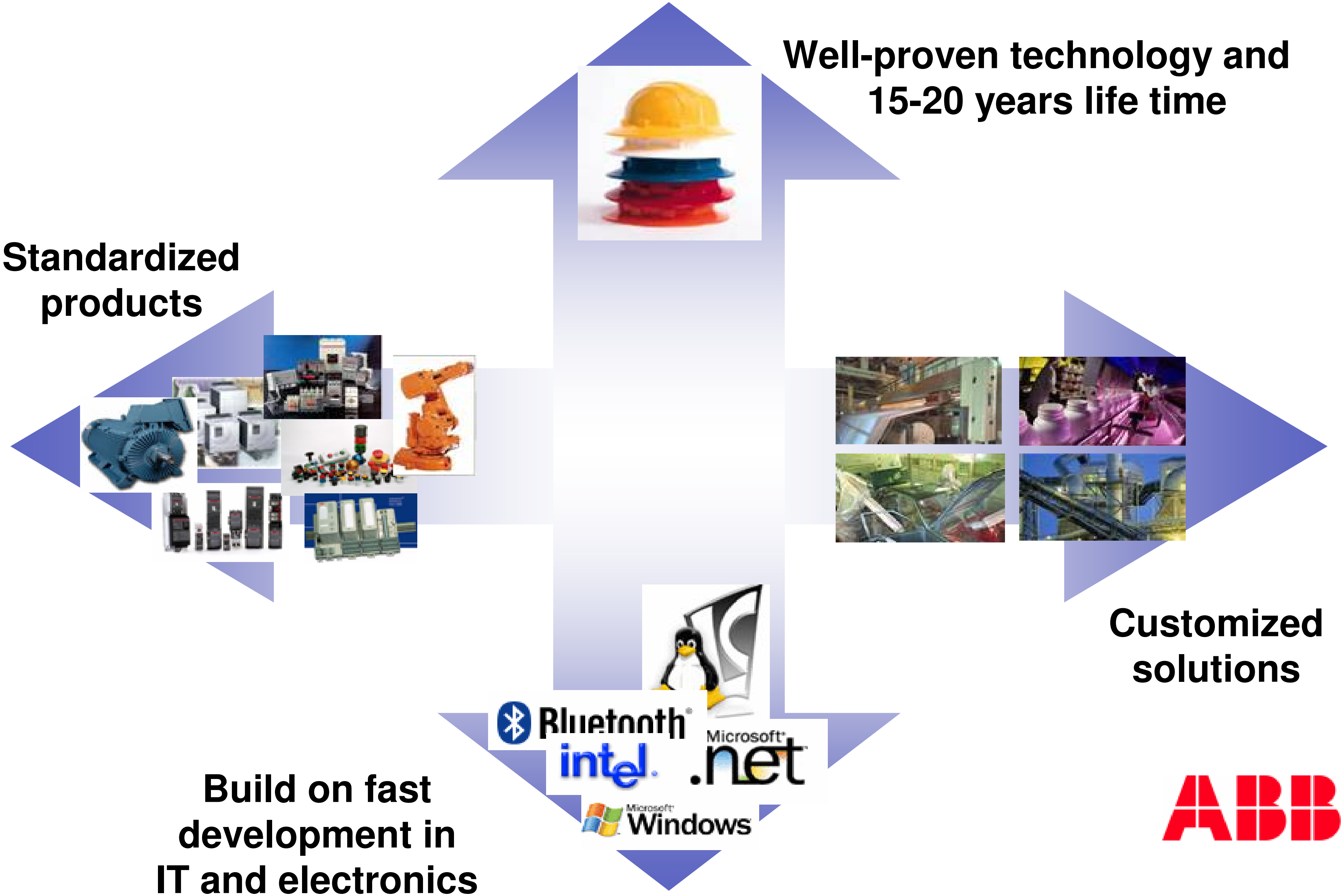
FISCHER & PORTER
BOMEM
Alfa Laval
eutech
entrelec
etsi
Hartmann & Braun
K-Flow
Kent
BBC BROWN BOVERI
ASEA
Strömberg
Bailey
Taylor
TOTALFLOW
AccuRay
SENSYCON

ABB

IT: Challenge and Opportunity

Well-proven technology and 15-20 years life time

Standardized products

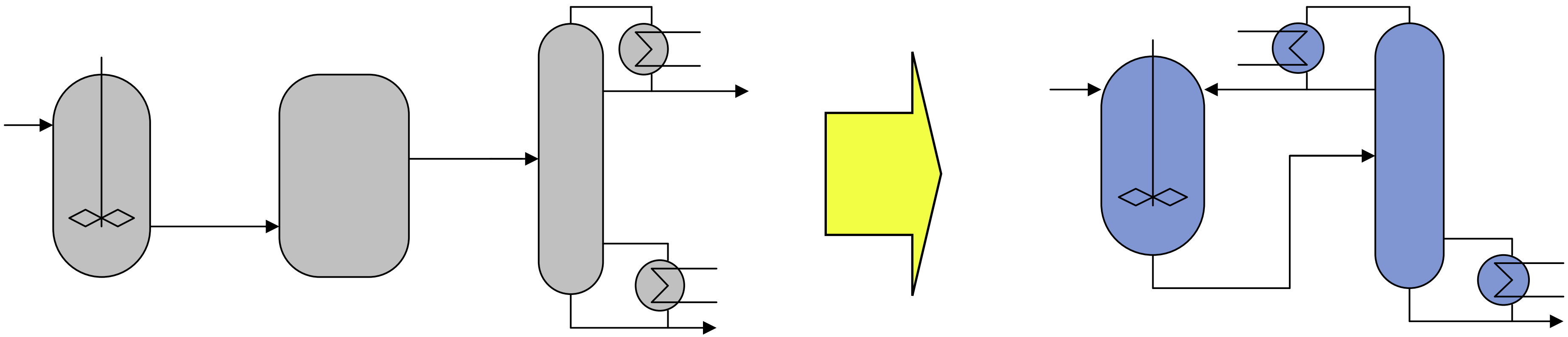


Customized solutions

Build on fast development in IT and electronics

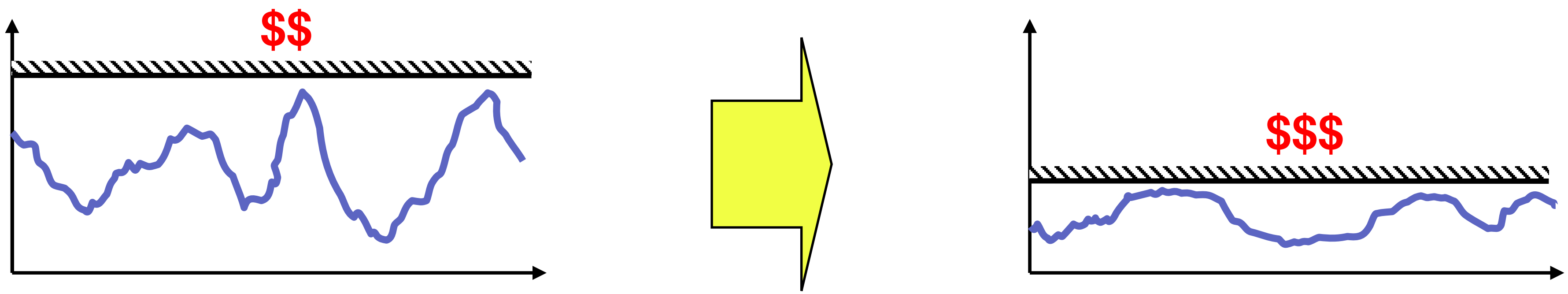
Process trends: increased integration

Process buffers at all levels get trimmed: supply chain, company, site, plant, unit

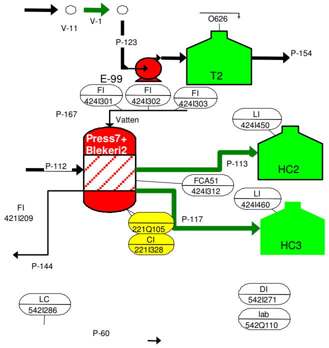


Process trends: tightening constraints

Constraints and boundaries tighten, consequences of violation become increasingly severe

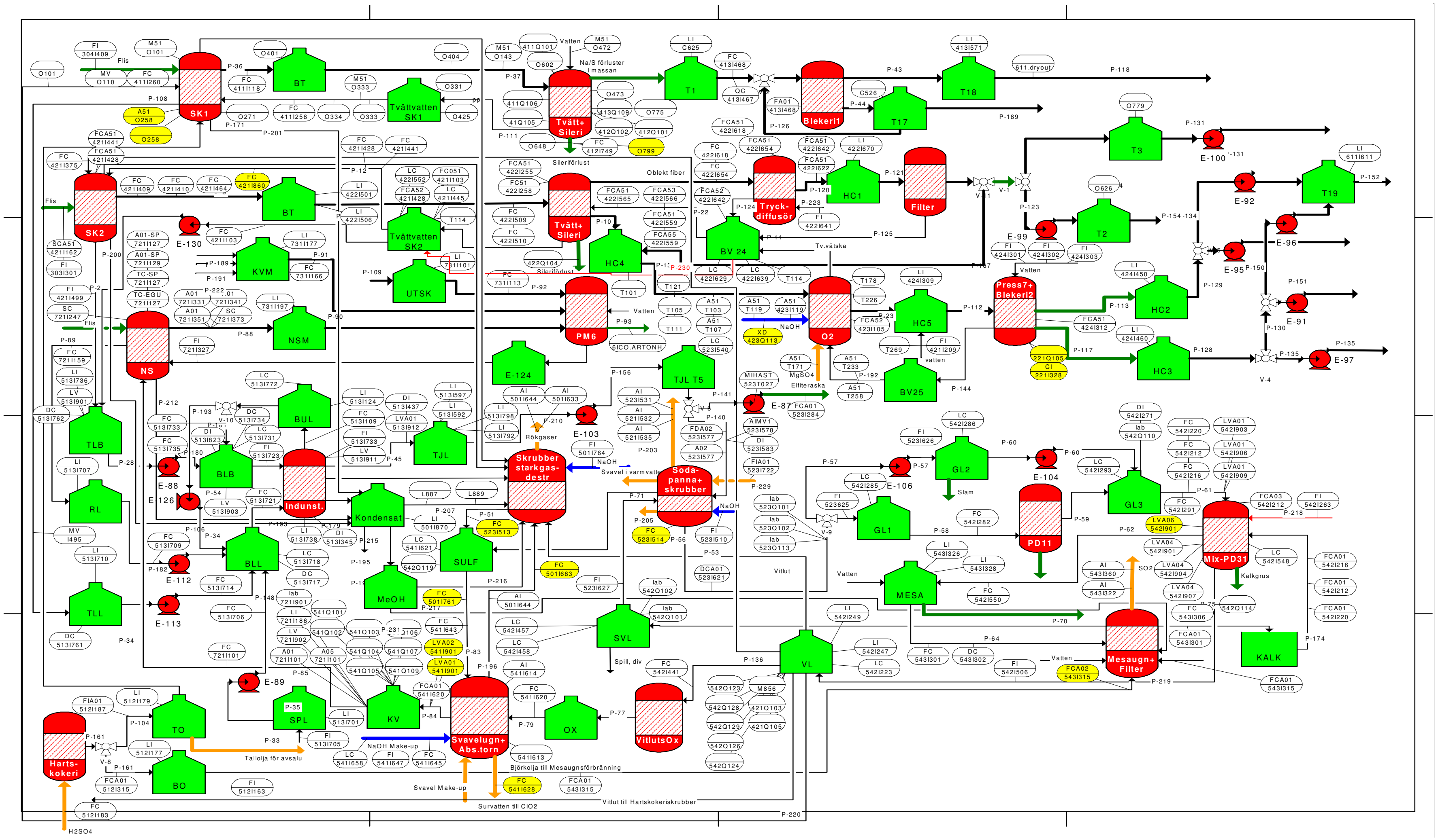


Trend: broader scope, more complex models



Example: Pulp Mill

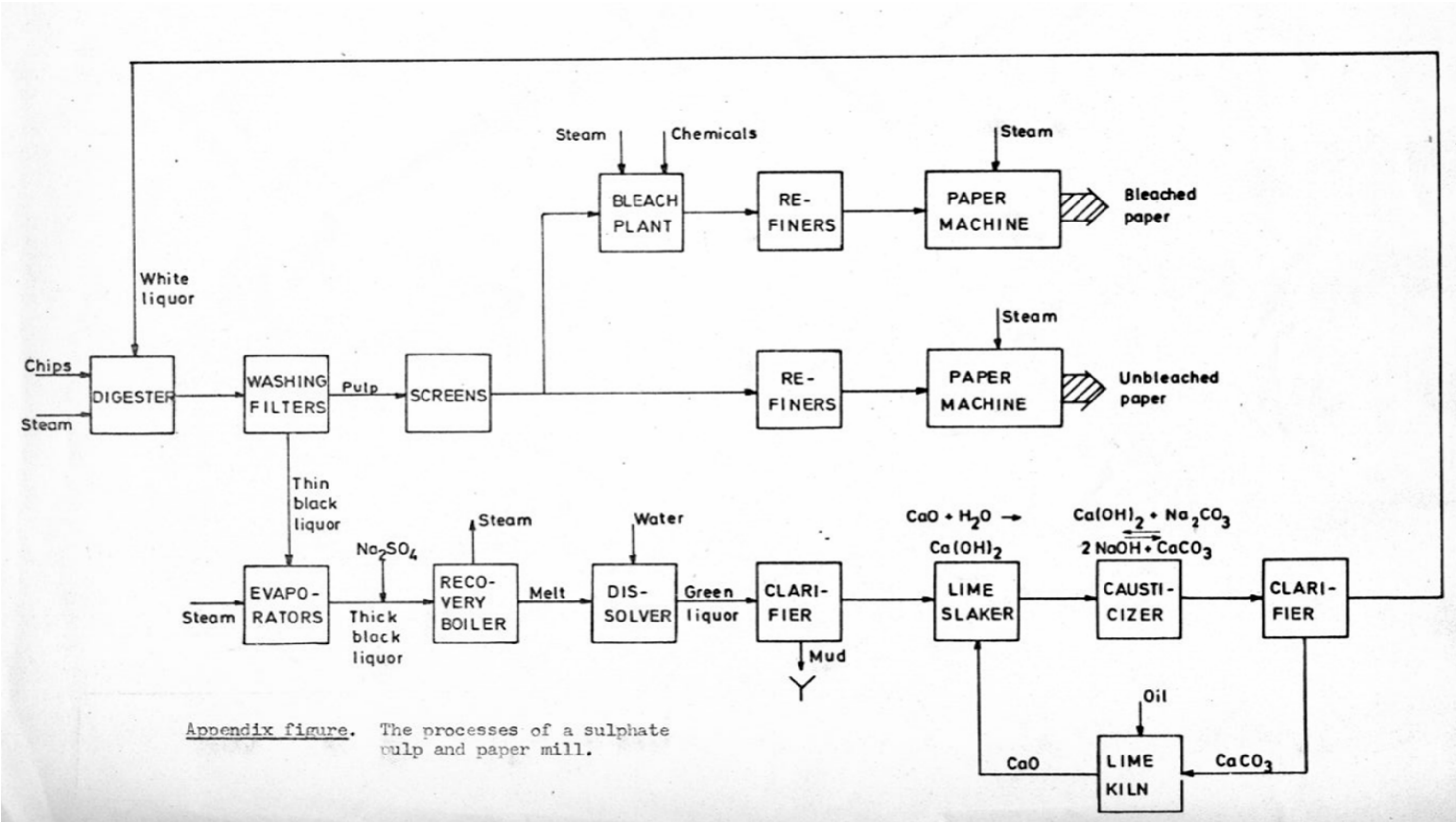
Trend: broader scope, more complex models



Example: Pulp Mill

1960s: Production optimization at Gruvön in

- Licentiate thesis by Bengt Pettersson
- Figures courtesy of Karl Johan Åström

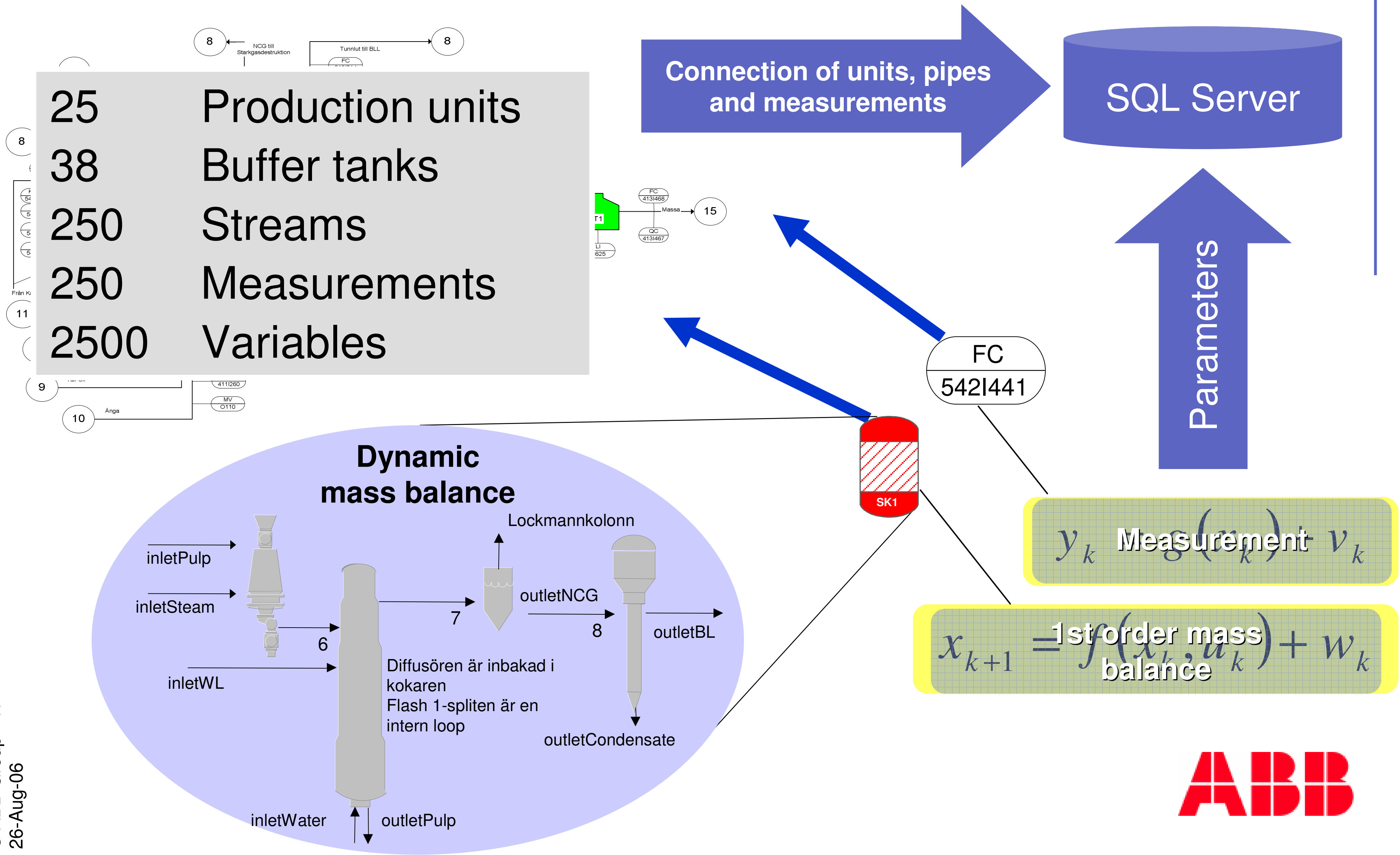


Appendix figure. The processes of a sulphate pulp and paper mill.

Example: Pulp Mill

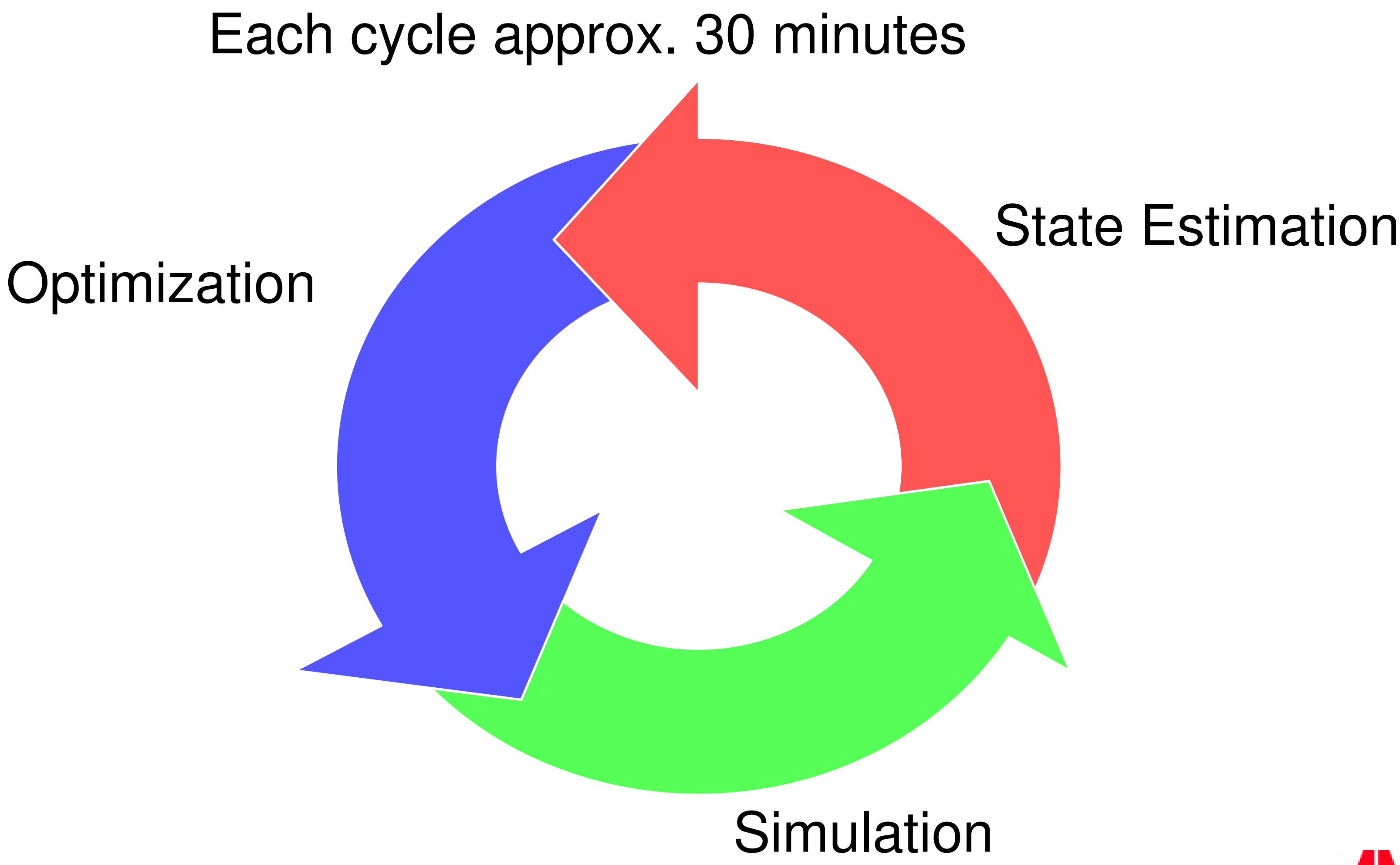
Today: Nonlinear Dynamic Model

25	Production units
38	Buffer tanks
250	Streams
250	Measurements
2500	Variables



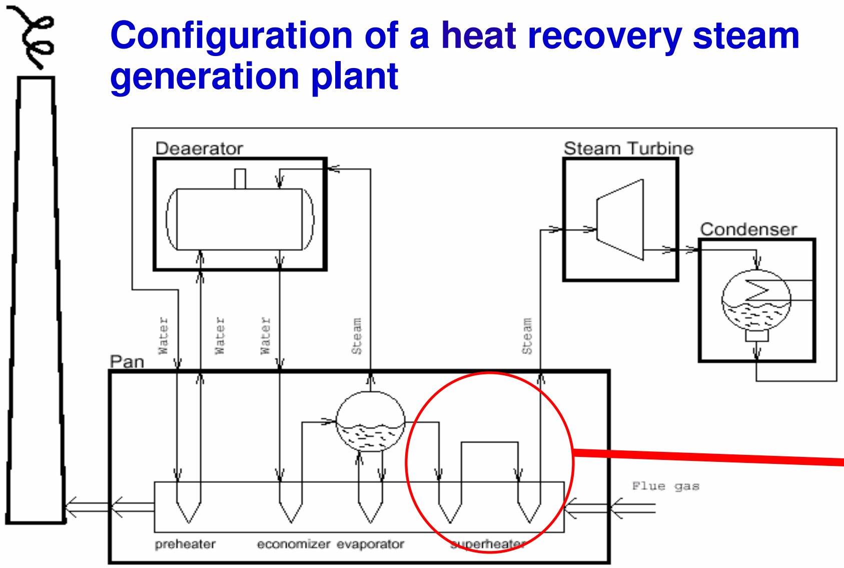
Example:
Pulp Mill

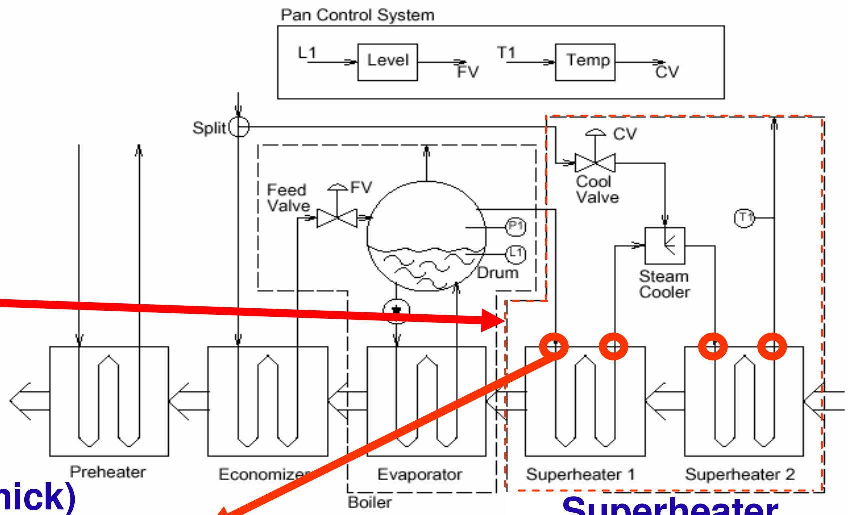
On-line operation



NMPC: Minimizing Thermal Stress at Boiler Start-up

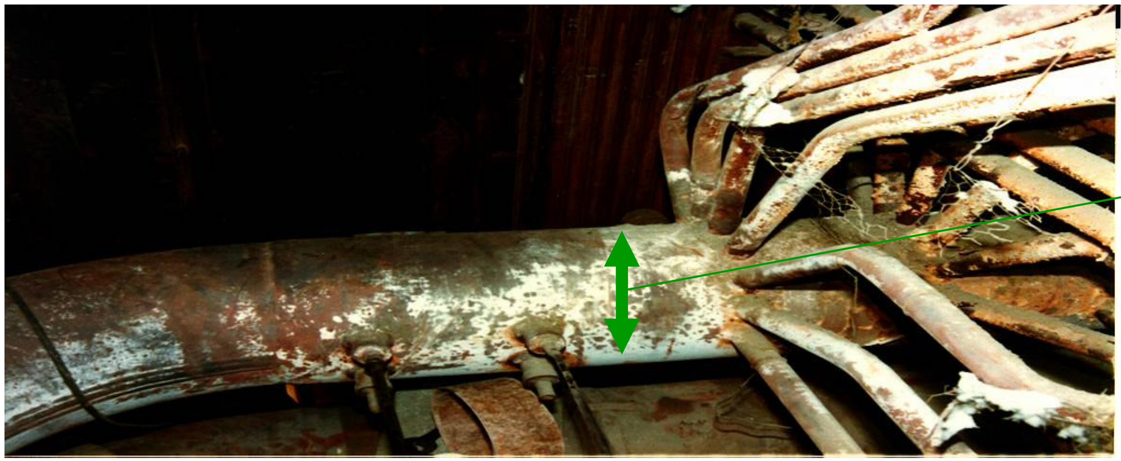
Configuration of a heat recovery steam generation plant





Superheater subsystems

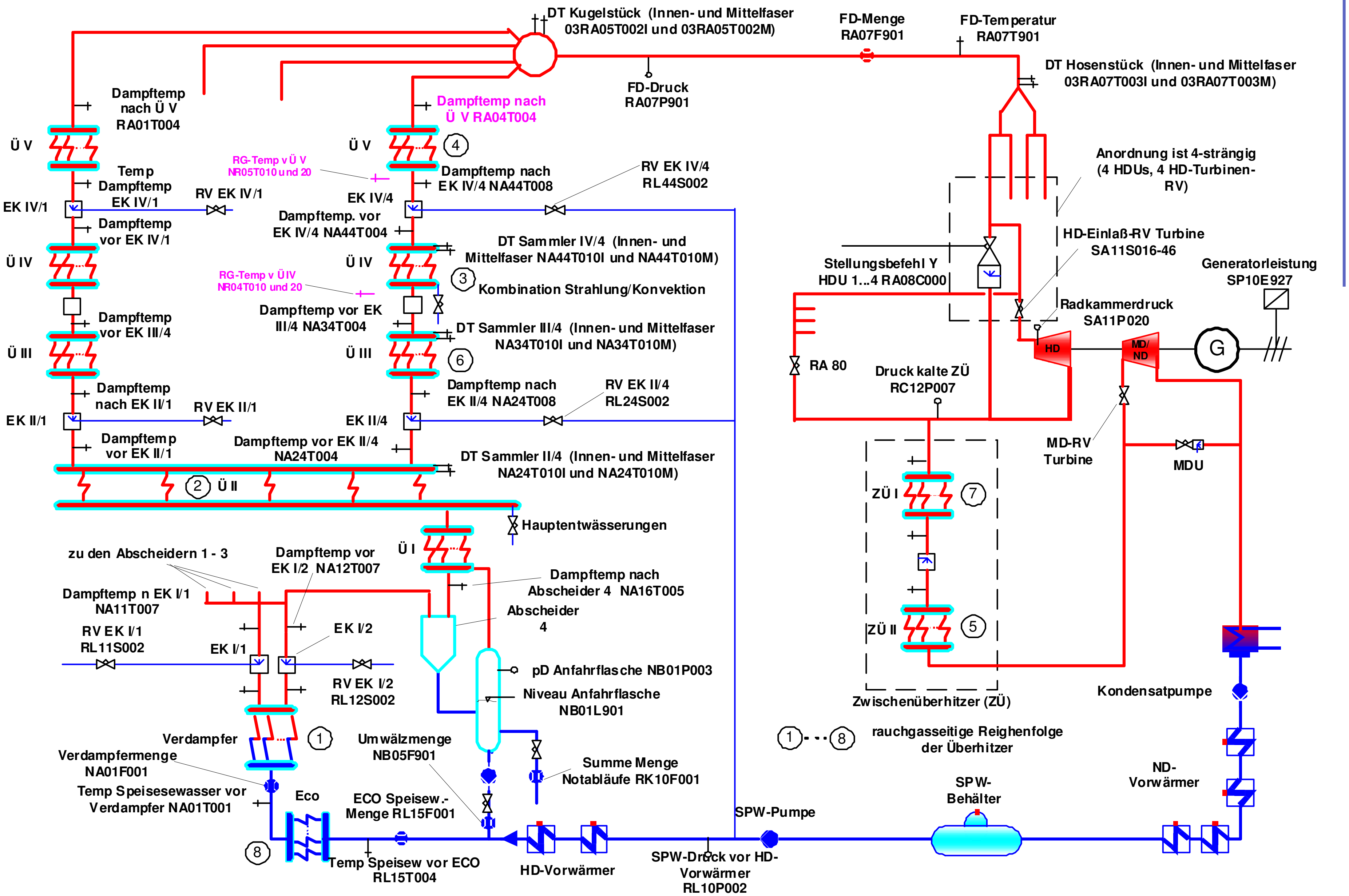
Thick-walled steam header (cylindric type, 6.4 cm thick)



Stretching of the material because of temperature gradients lead to lifetime reduction

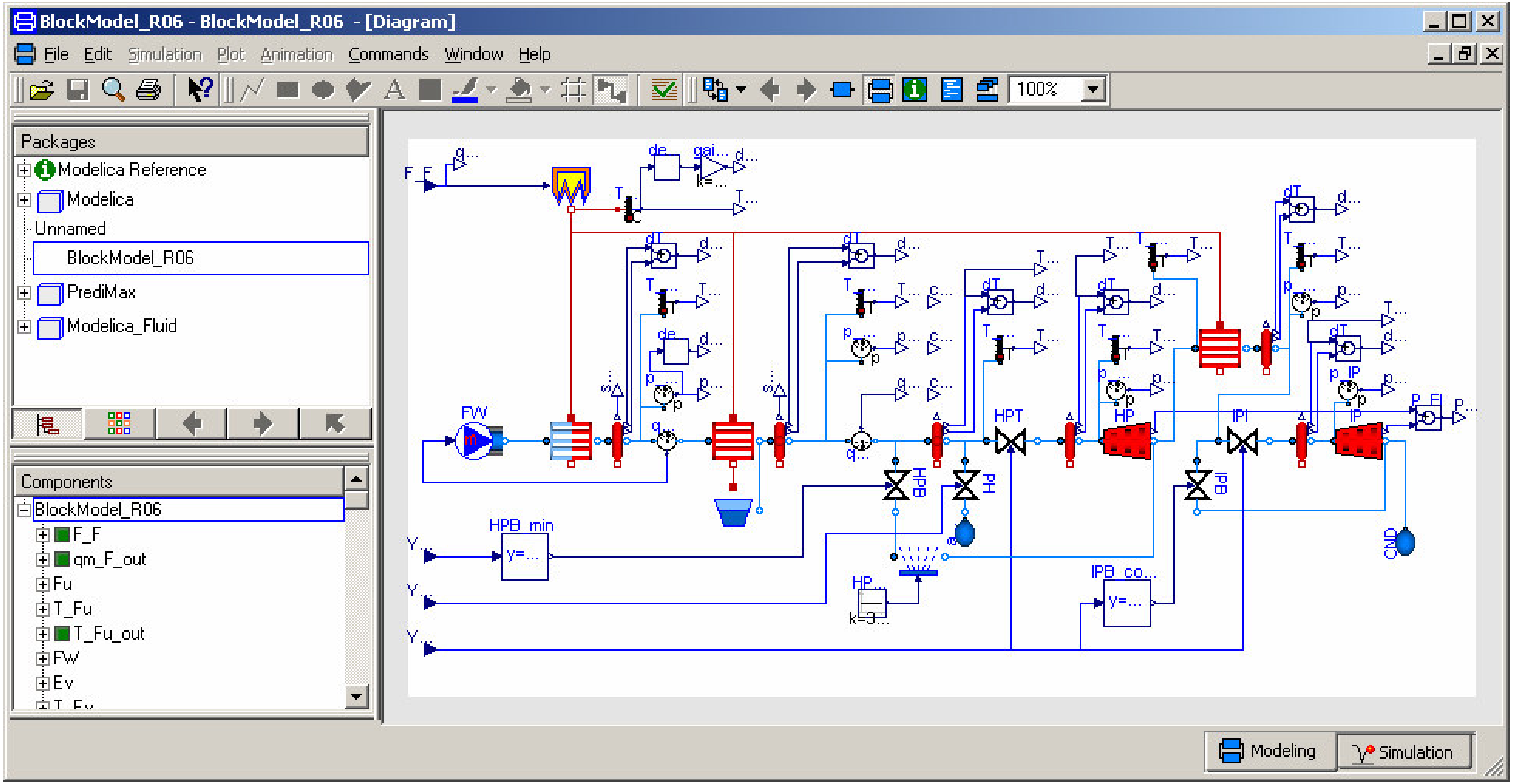
Example:
Boiler Startup

Exemplary Water-Steam Cycle



Example: Boiler Startup

Object-oriented modeling



Graphical flowsheet modeling

Combine commodity models with proprietary knowledge

Automatic generation of stand-alone executable code

Example: Boiler Startup

Dynamic optimization problem

$$J = \int_{t=0}^{t_f} \frac{[T(t) - T_{set}]^2}{w_T^2} + \frac{[p(t) - p_{set}]^2}{w_p^2} + \frac{[q_m(t) - q_{m,set}]^2}{w_{q_m}^2} \, dt \longrightarrow \min_{q_F(t), Y_{HPB}(t)}$$

$s.t.$

$$\dot{x}(t) = f[x(t), q_F(t), Y_{HPB}(t), Y_{AW}(t)], \quad x(0) = \bar{x}$$

- **Process model**

$$q_{F,\min} \le q_F \le q_{F,\max}, \quad \dot{q}_{F,\min} \le \dot{q}_F \le \dot{q}_{F,\max}$$

$$0 \le Y_{HPB}(t) \le 1$$

- **bounds on fuel**
- **bounds on valve positions**
- **thermal stresses**

$$\Delta T_{\min,i} \le \Delta T_i(t) \le \Delta T_{\max,i}, \quad i = 1, \ldots, n$$

General startup optimization problem:

Optimal transition to new operating point (T, p, q_m) subject to control bounds and state constraints (esp. thermal stresses).

© ABB Group - 22 -
26-Aug-06

ABB

Solution Approach

- Parameterize control
  $u(t) = u(u^k)$, k=0,1,…,K-1
- Convert dynamic optimization problem to discrete-time optimal control problem:

$$J = f_0(x^K) + \sum_{k=0}^{K-1} f_0(x^k, u^k) \xrightarrow{\quad} \min_{x^0, u^k}$$

$$s.t.$$

$$x^{k+1} = f^k(x^k, u^k), \quad k = 0, \ldots, K-1$$

$$c^k(x^k, u^k) \geq 0, \quad k = 0, \ldots, K-1$$

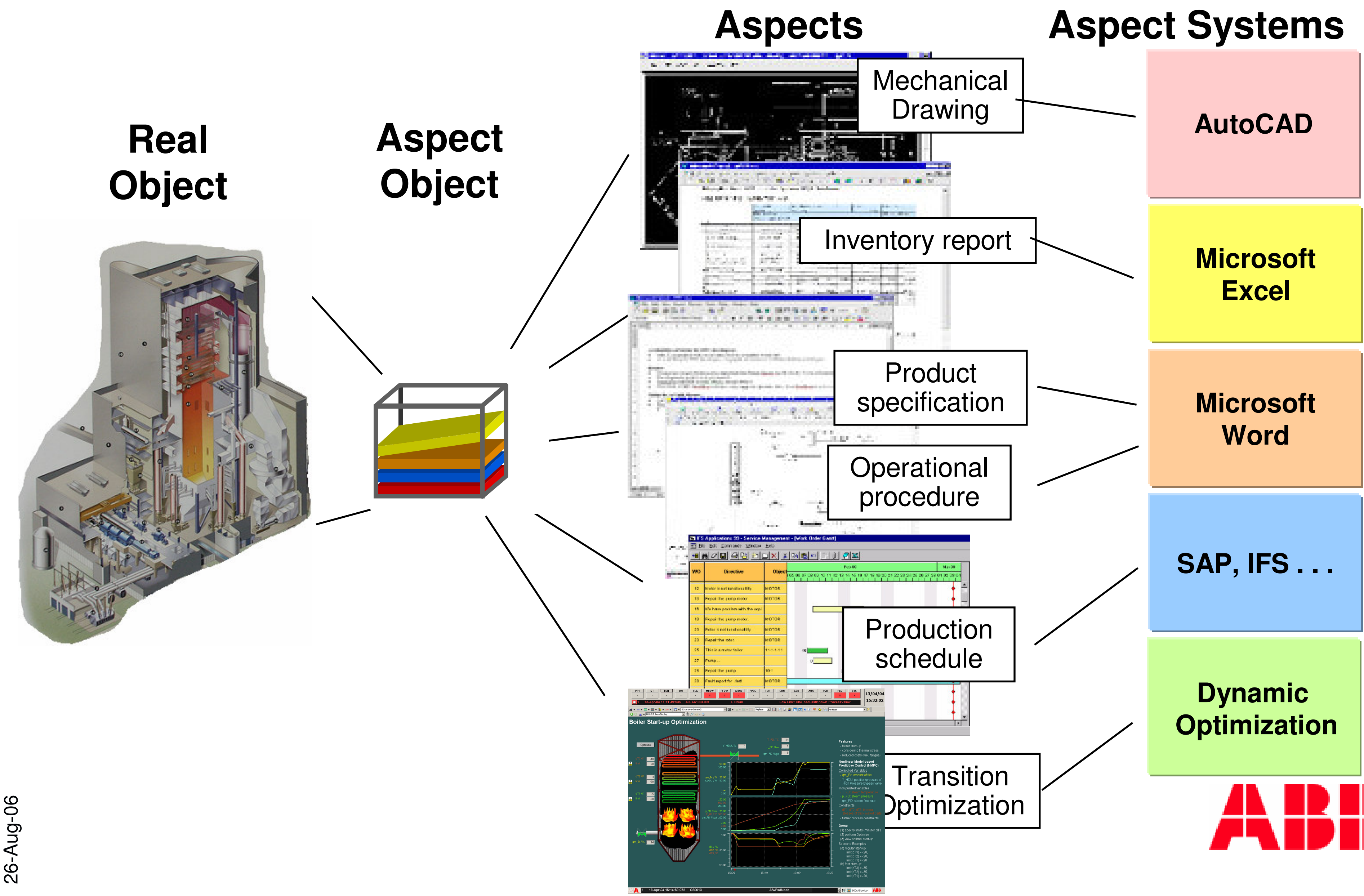
$$c^K(x^K) \geq 0$$

- Solve as large-scale nonlinear programming problem with vector of optimization variables v:

$$\breve{v} = \begin{pmatrix} u^0 \\ u^1 \\ \vdots \\ u^{K-1} \end{pmatrix} \qquad v = \begin{pmatrix} x^0 \\ u^0 \\ x^1 \\ u^1 \\ \vdots \\ x^{K-1} \\ u^{K-1} \\ x^K \end{pmatrix}$$

Example:
Boiler Startup

Organizing Information With Aspect Objects™

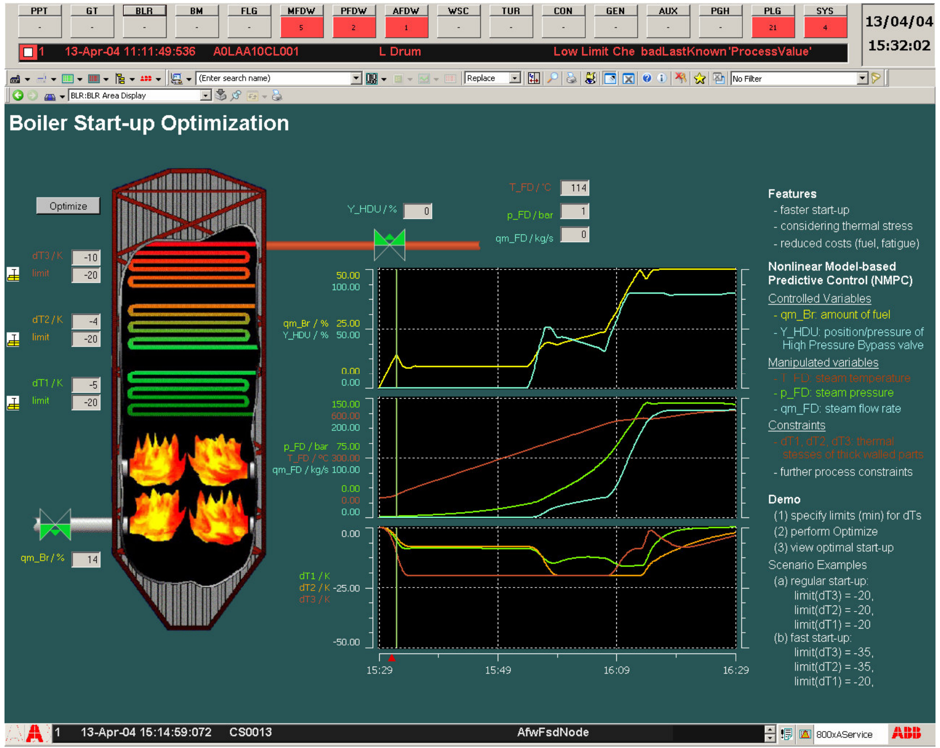


Example:
Boiler Startup

NMPC Integration with Control System

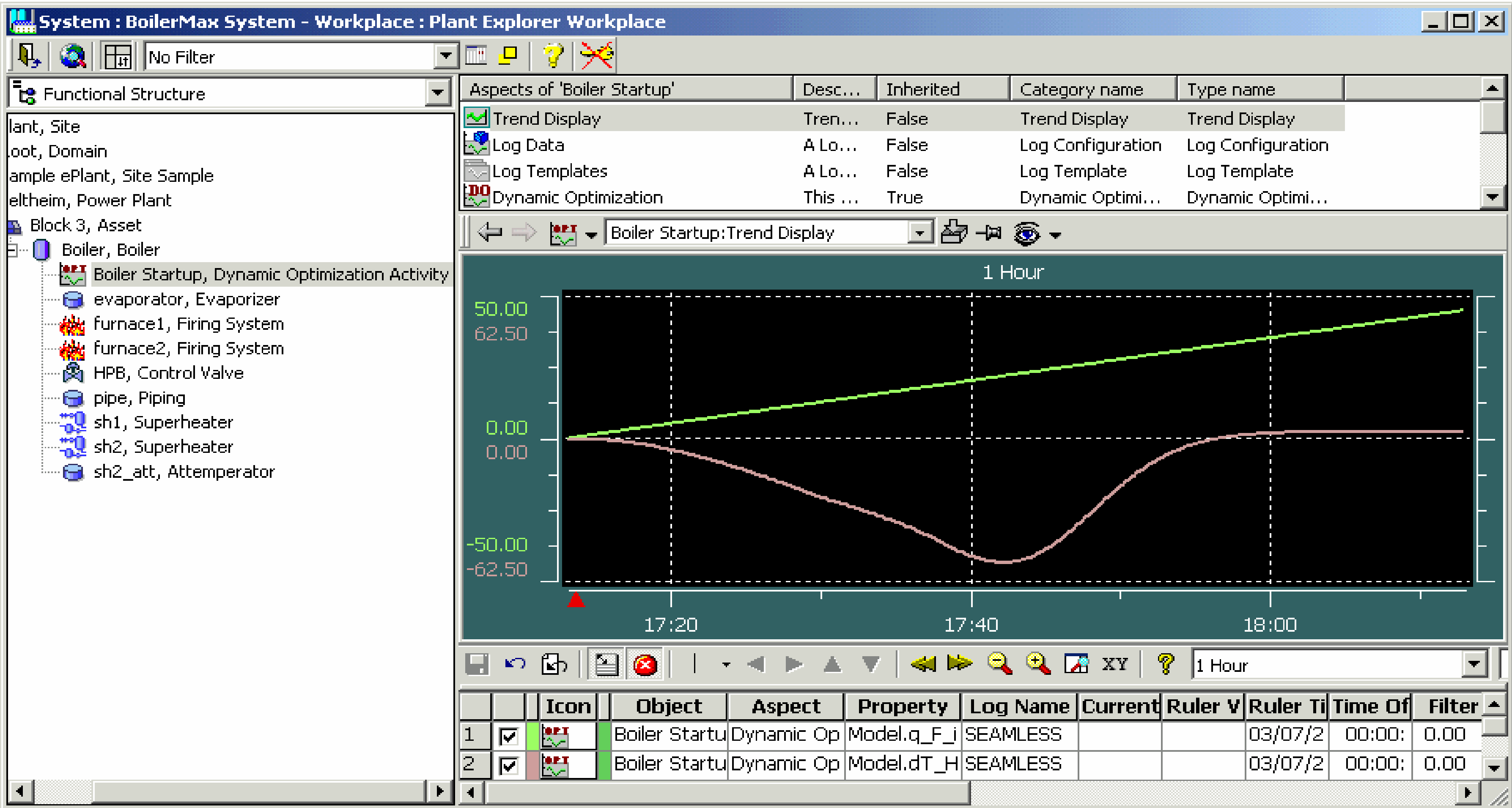
NMPC with 800xA

- Seamless integration with operator station
- Data serving (Aspect Server, Basic History)
- Connectivity to process databases
- Connectivity to major control systems
- Further synergies, e.g. alarm handling



Example: Boiler Startup

Conventional ramp start-up

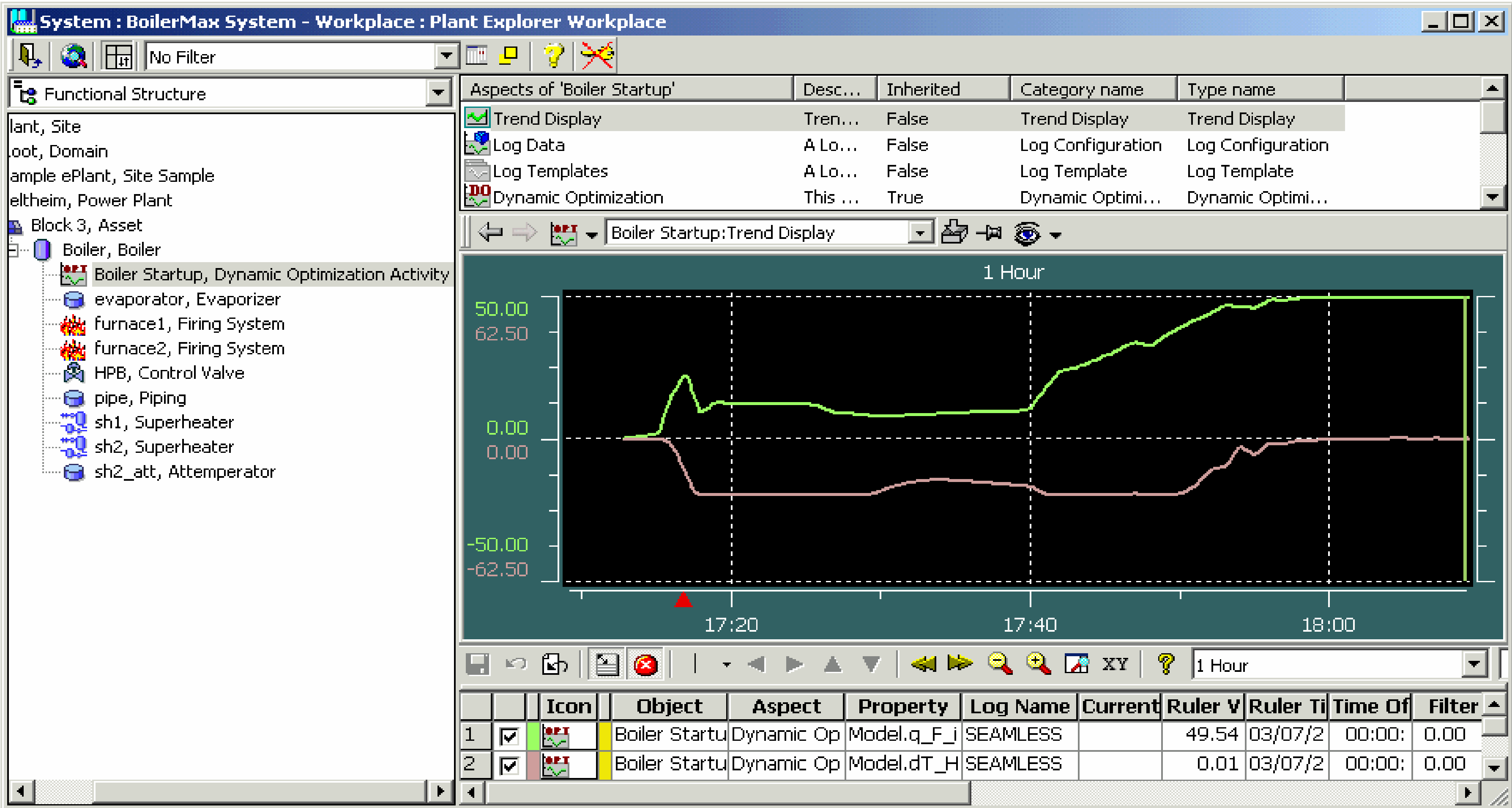


- Classical start-up: apply ramp on fuel flow rate q_F
- Thermal stress violates constraint (-60 instead of –25)

ABB

Example:
Boiler Startup

Optimized start-up

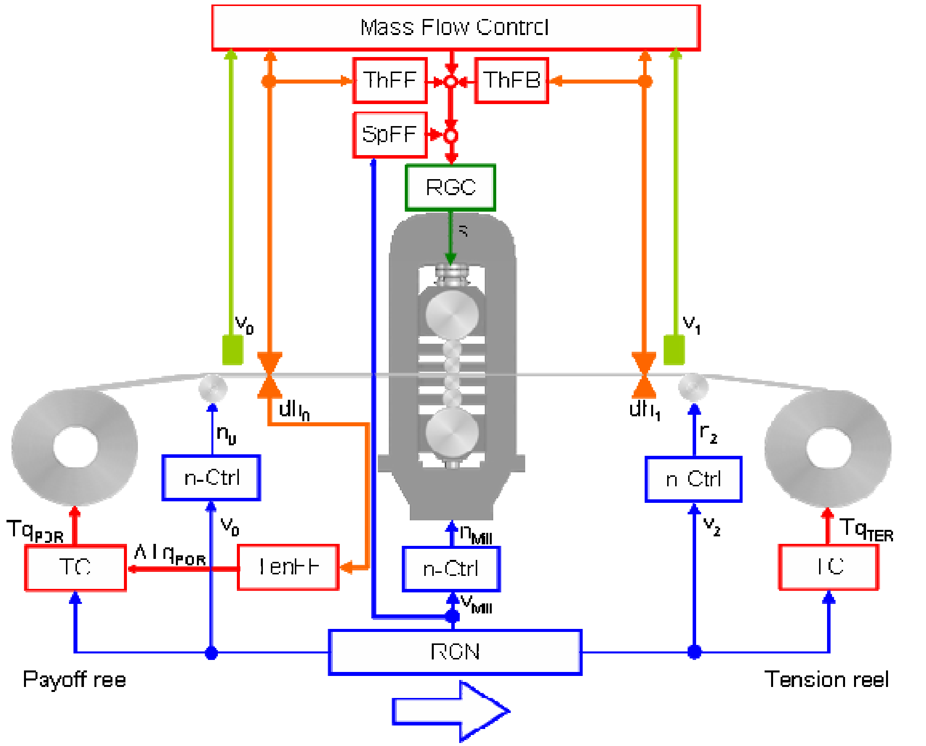


- Result: achieve faster startup and fulfill constraints
- Seamless integration with Trend&Historian subsystem

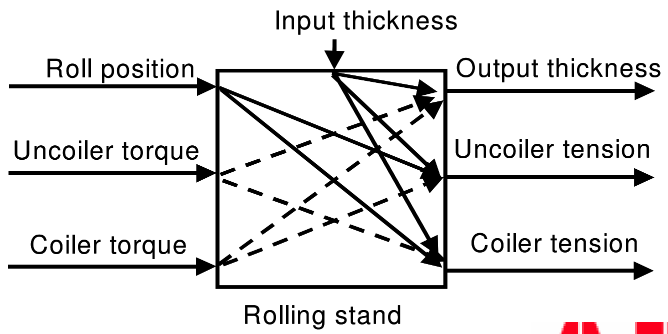
Example: Cold Rolling

Thickness Control in Cold Rolling Mills

- Conventional control:
  - Single control loops
  - Feed forward strategies
  - Limited performance



- Task and objectives:
  - Improve tolerance over the whole strip length
  - Improve quality during ramp-up / ramp-down
  - Better disturbance rejection to allow higher speed

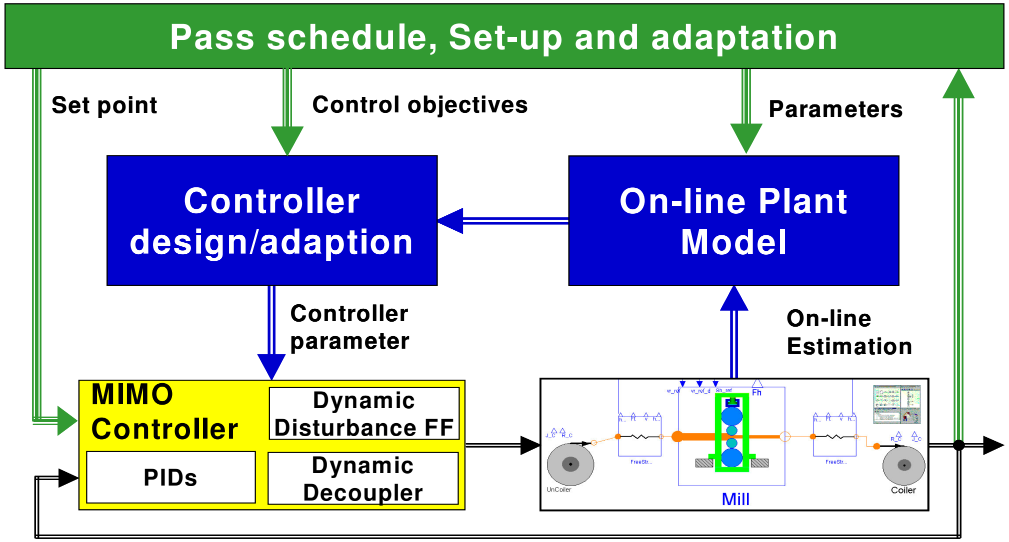


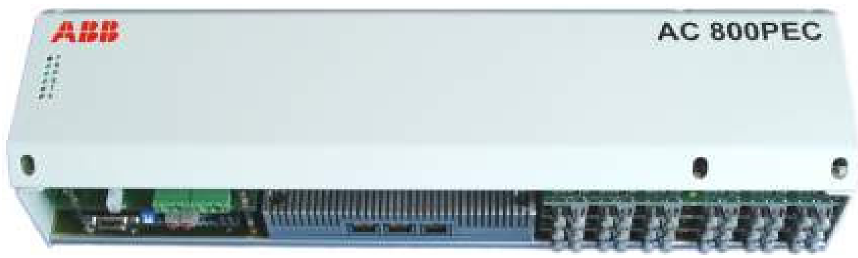
Example:
Cold Rolling

New Advanced Thickness Control

Dynamically decoupled MIMO control with

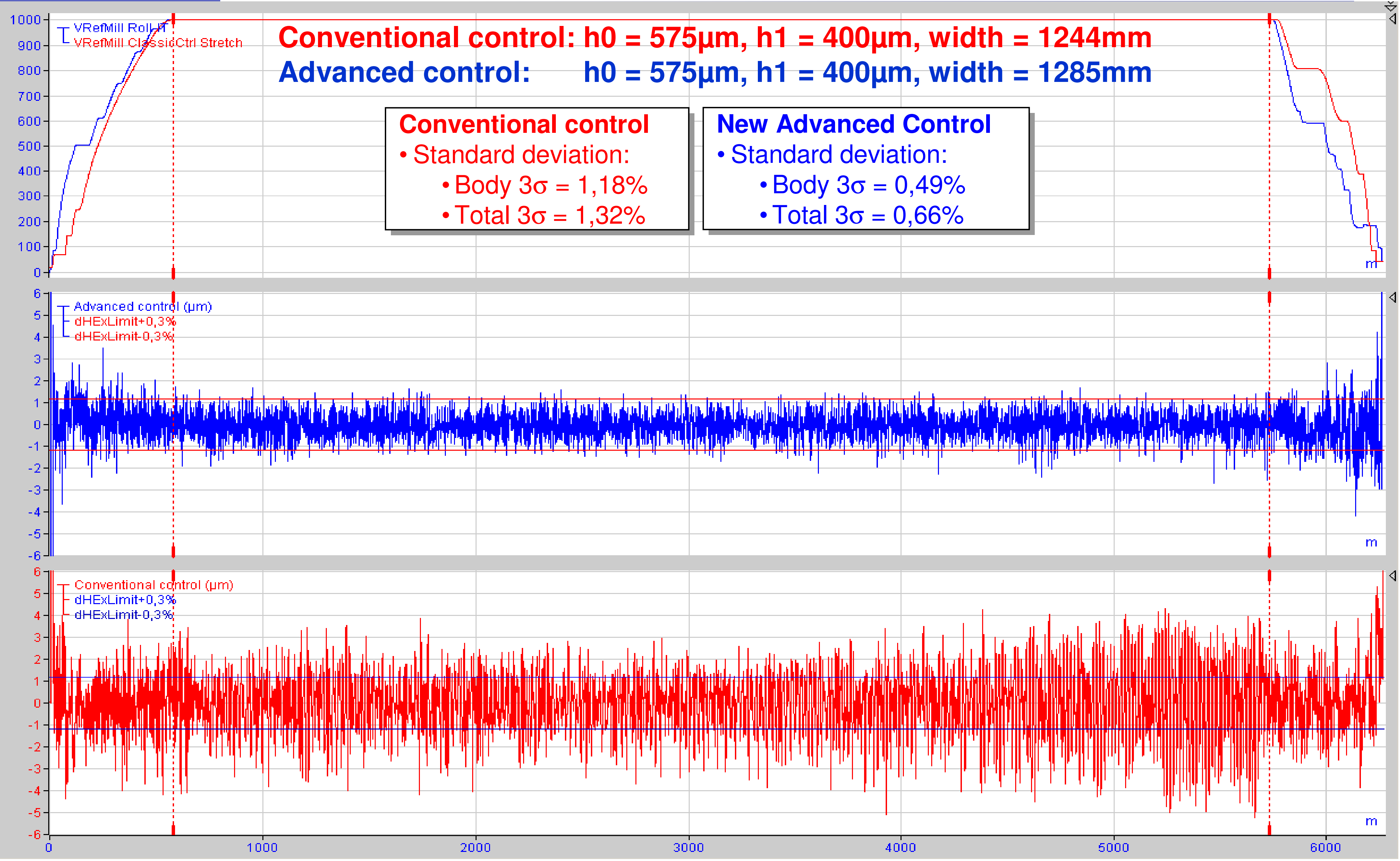
- Online estimation of time varying process parameters
- Online MIMO controller parameter adaptation using an in-built process model
- Dynamic feed-forward strategies support disturbance rejection
- Supervision layer to monitor and track the control quality





Example: Cold Rolling

Comparison: Conventional vs Advanced



Example: Robotics

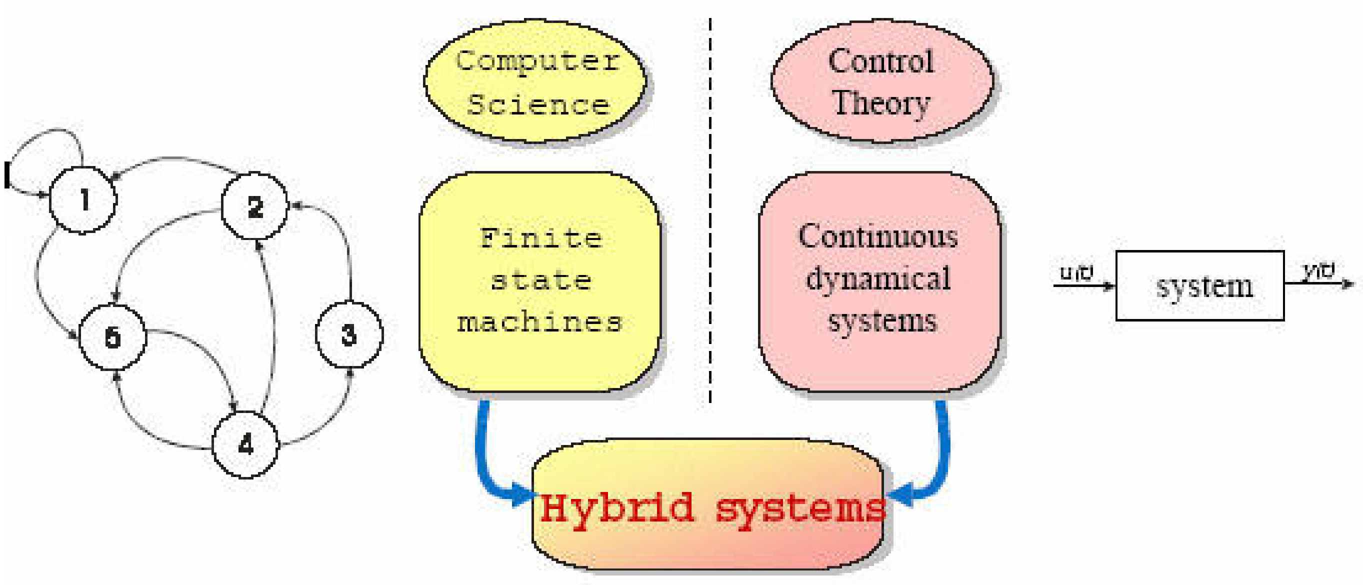
Control: Also at the heart of Robotics

Economic Process Optimization

- Different control systems, office environment, and enterprise systems can all talk to each other in real time
- Live external data feeds also easily integrated, e.g., spot market prices for feedstock, energy, product, weather information …
- Can we use this information together with modeling and a feedback control approach to online optimize whole plants from an economic perspective?

Hybrid: Mixed Logic Dynamic Systems

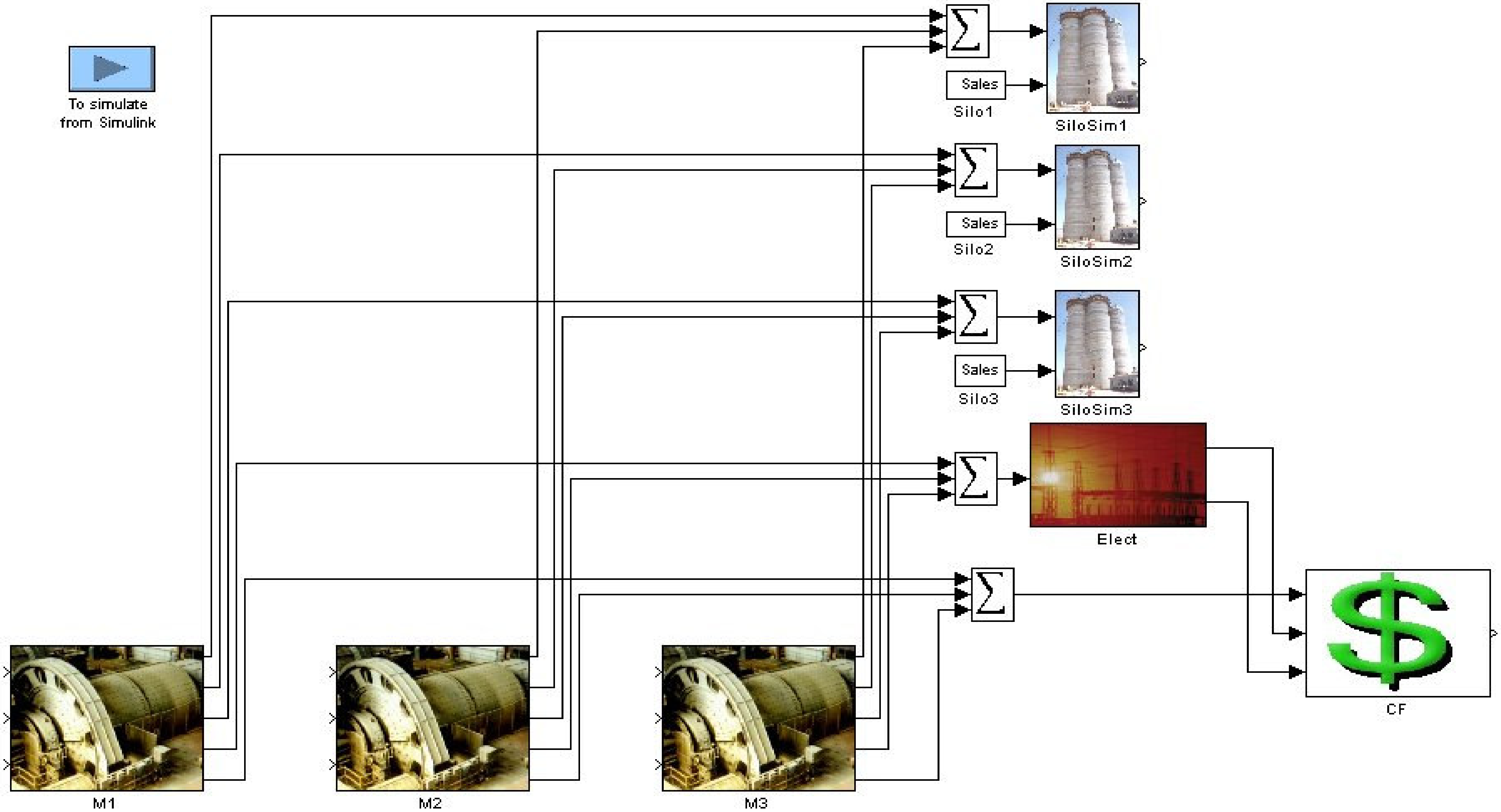
- Framework for handling continuous and discrete dynamics
- Describes both plant constraints and objective function
- Collaboration with ETH Zürich



© ABB Group - 33 -

Example: Minerals

Grinding Plant Scheduling

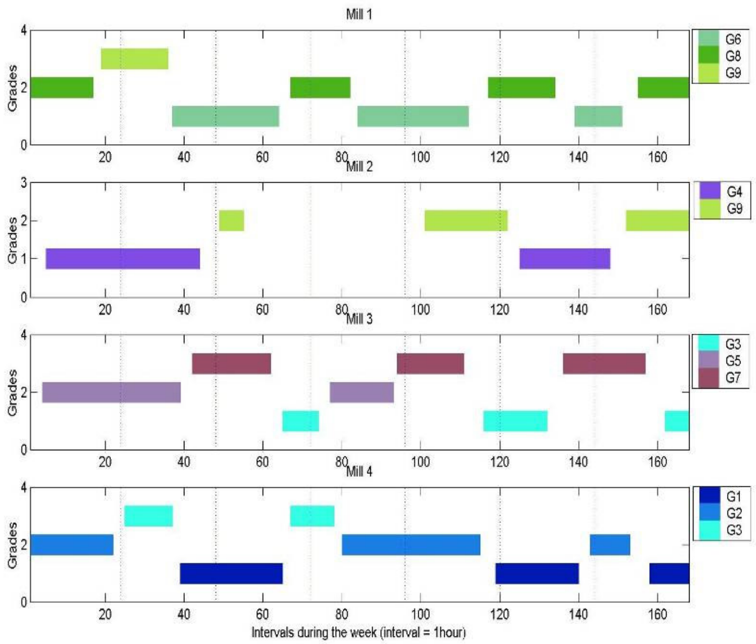


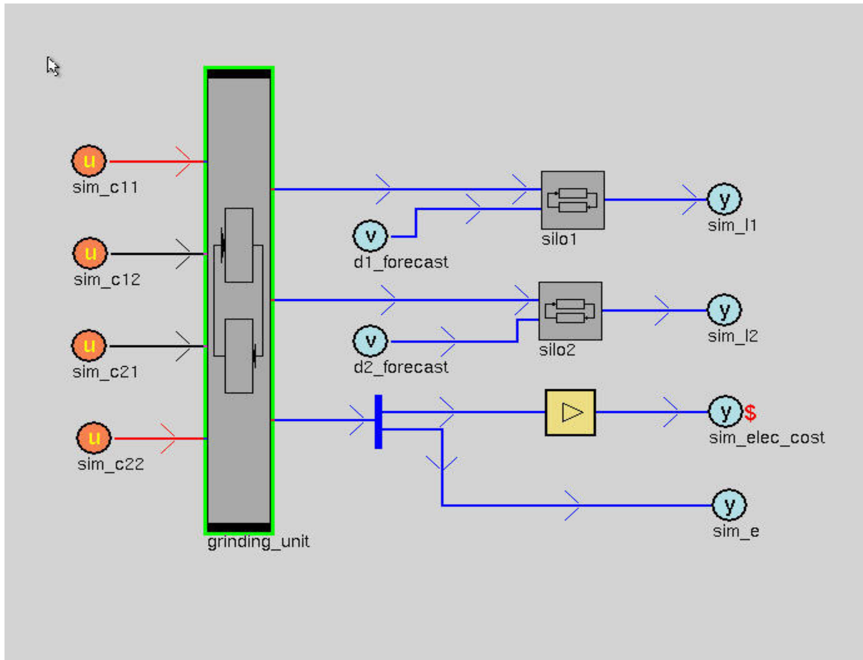
© ABB Group

Example:
Minerals

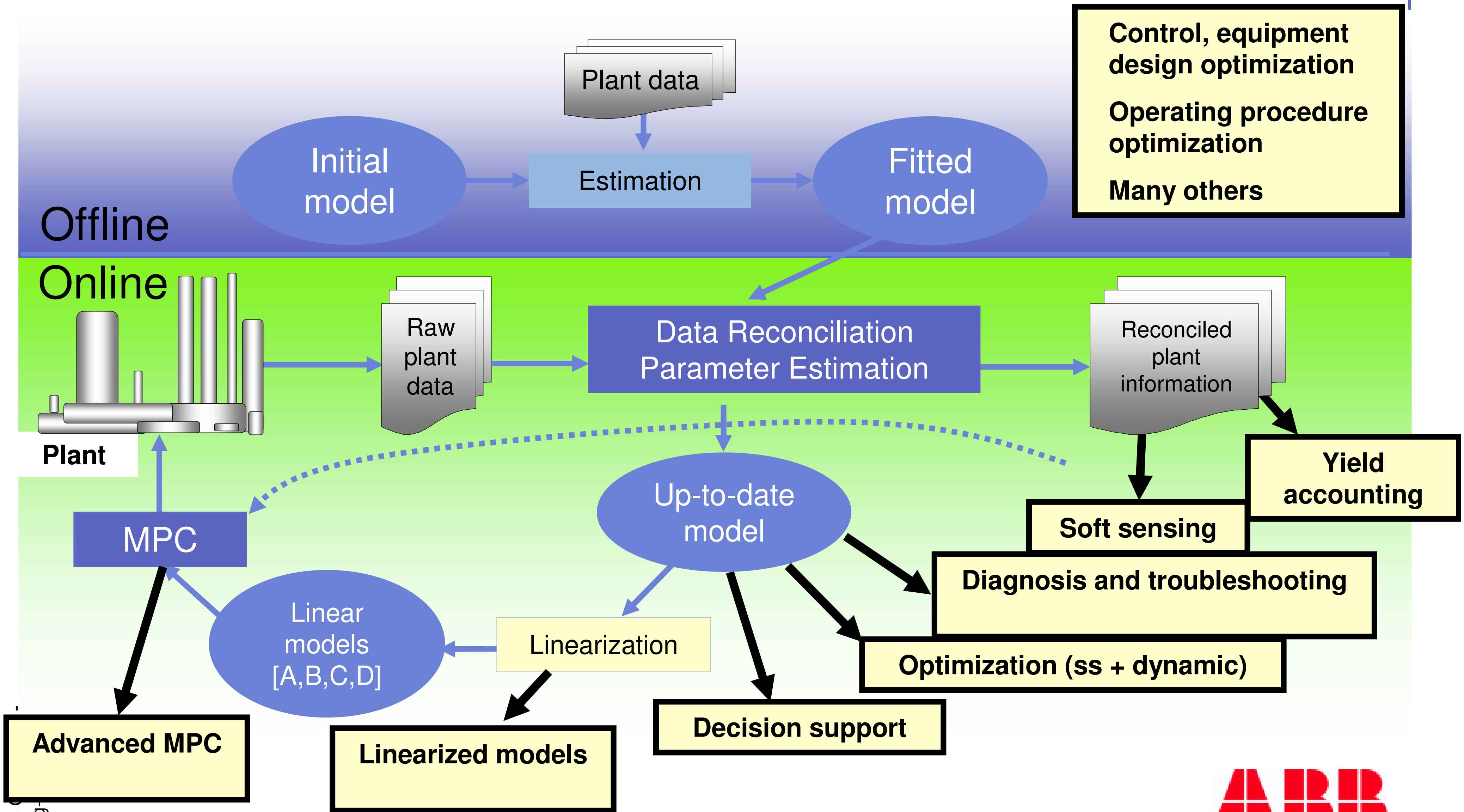
Electrical Energy Management: Benefits

- Power cost down by 2-3%
- Automatic rescheduling in case of unexpected events
- Strict contractual and equipment constraint satisfaction



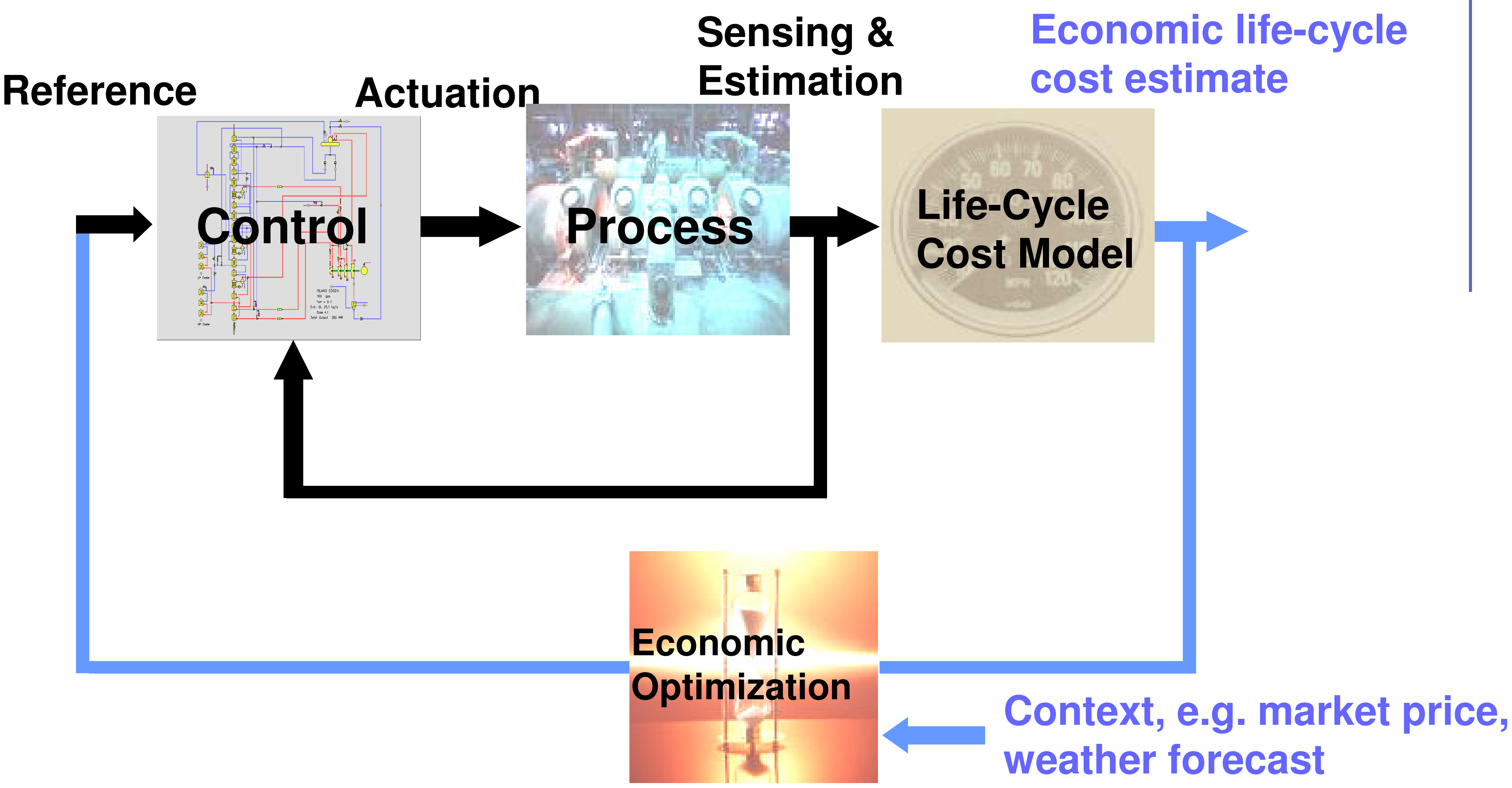


Modeling and model re-use



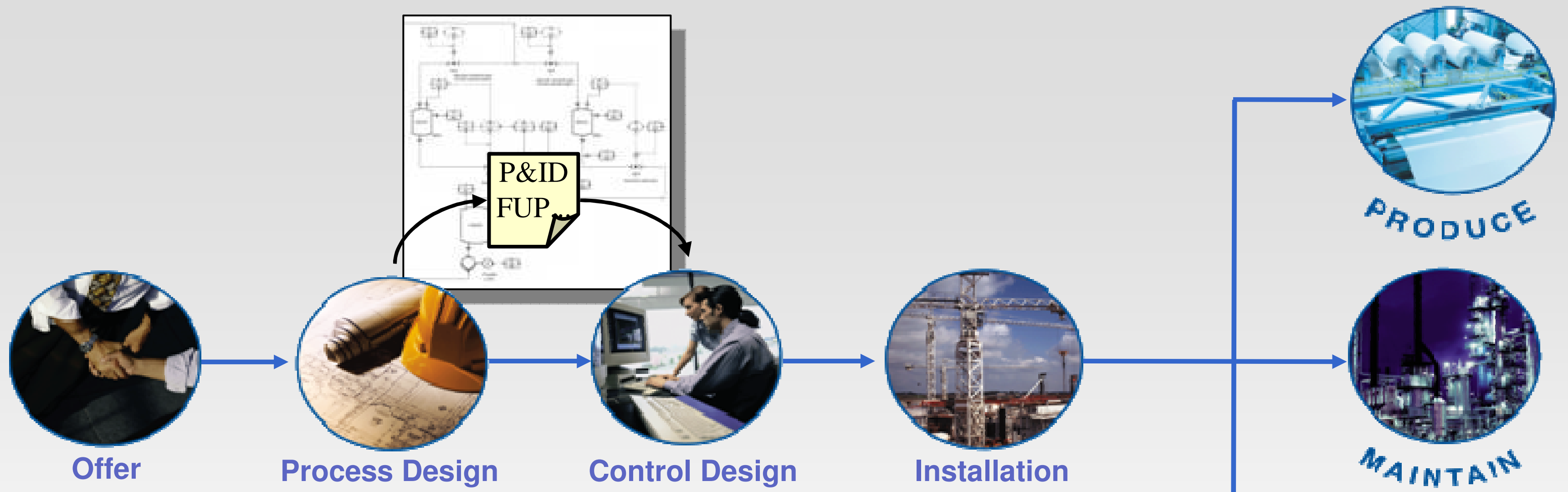
© ABB
26-Aug-

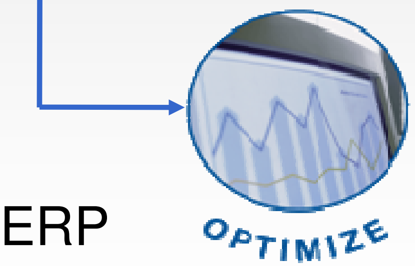
Life-cycle optimization: The Next Loop?



Outlook

Automating automation: The engineering data chain





Engineering

- Ideally, feed in only process model and objective
- Plant topology from P&ID, economic context from ERP
- Hardware and software components from vendor
- Hardware realization/configuration automatic

➔ Still a long journey, but economic importance high

Other open frontiers

- Methods
  - Bring mathematical assumptions and physical reality closer together
    ➔ extend hybrid optimizers to larger problem sizes
    ➔ guaranteed properties for real-world closed-loop systems?
  - Robustness of solvers towards unsupervised closed-loop operation
  - Dealing with significantly different time horizons
    (asset dynamics tend to be much slower than process dynamics, e.g., wear, corrosion, crack propagation)
- Problem solving
  - Deal with abnormal, unexpected, situations
    (e.g., interruption of communication, or alarm bursts etc)
  - Deal more readily with changing constraints and changing configurations
  - Exploit distributed problem-solving capabilities
    ➔ distributed problem solving, e.g., agent approaches?
    ➔ gain flexibility, but loose predictability? system properties?

Summary and Acknowledgments

Summary

- Control system capability ceases to be the active constraint regarding computing power, memory, flexibility, and ease of interfacing
- Is the theory-practice gap narrowing?

Acknowledgments

- To customers, colleagues and university partners for sharing their insights
- R. Franke, A. Vollmer, A. Isaksson, E. Gallestey for providing examples

IFAC

50