Plant-wide on-line dynamic modeling with state estimation: Application to polymer plant operation and involvement in trajectory control and optimization.

Philippe Hayot
Global Process Engineering
The Dow Chemical Company

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Content

- Dow and its Polystyrene business
- Model based applications as enabler of the business strategy elements
- Advanced Process Information
  - on-line dynamic model with state estimation
  - application examples
  - implementation status
- Trajectory control within IMPACT project
- Trajectory optimization within IMPACT project
- Future Directions

Dow and its Polystyrene business

STYRON
Polystyrene Resins

Dow Polystyrene Plants

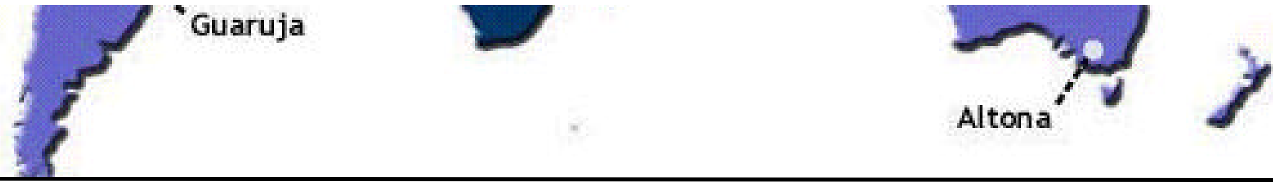
Dow is the global leader in Polystyrene with around 20 plants worldwide

Consequently:

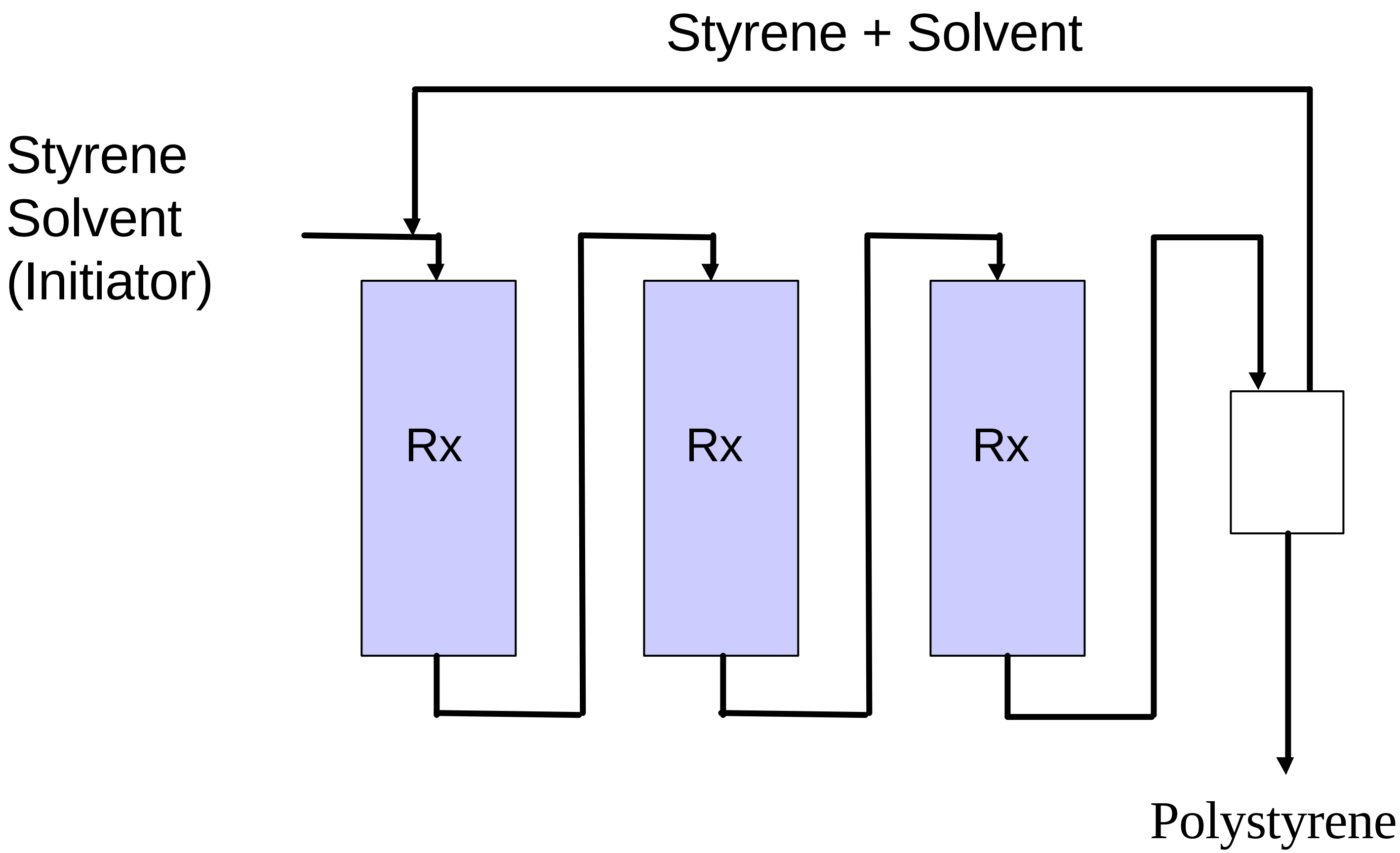
- consistent product quality
- maximizing unit production
- leveraging of standardization and operating discipline

are key business strategy elements

Dynamic modeling with state estimation has proven to be a powerful enabler in achieving these objectives.

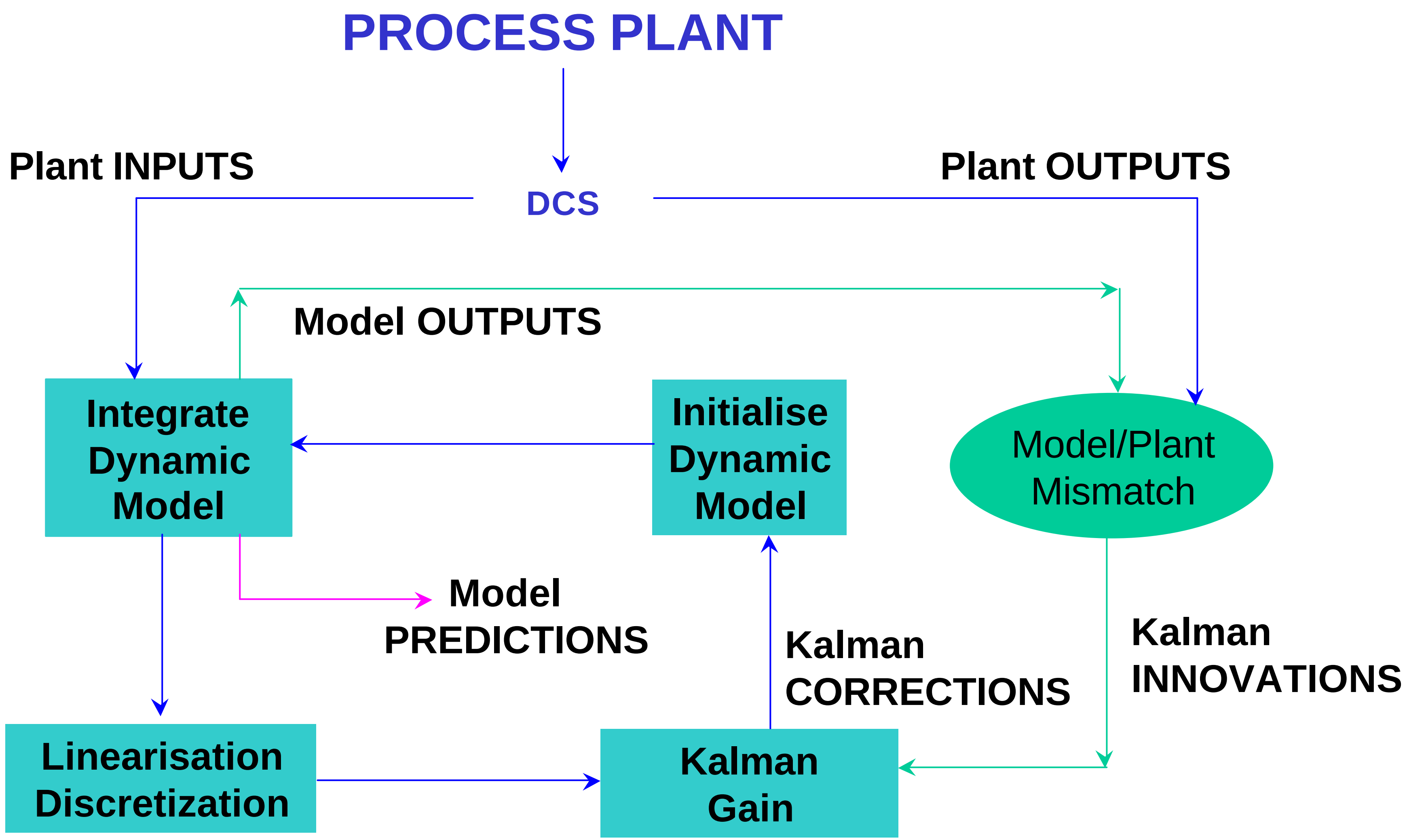


Polystyrene solution process



Implementation using Aspen SEM and Aspen Custom Modeler

- Aspen SEM is a general purpose non-linear dynamic data reconciliation solver using an Extended Kalman Filter linked with ACM for model predictions and time varying linear state space models.
- Main applications :
  - continuous, real-time estimation of relevant process variables that are unmeasureable or infrequently measured
  - Rejection of unknown disturbances and model deficiencies by adjusting parameters via introduction of stochastic states (disturbance model)
  - Look-ahead capability
  - Process monitoring and decision support tool – allow Data Reconciliation to be combined with Multivariate Statistical Process Control techniques for fault detection and diagnosis
  - Model Predictive Control


PROCESS PLANT
Plant INPUTS
DCS
Plant OUTPUTS
Model OUTPUTS
Integrate Dynamic Model
Initialise Dynamic Model
Model/Plant Mismatch
Model PREDICTIONS
Kalman CORRECTIONS
Kalman INNOVATIONS
Linearisation Discretization
Kalman Gain

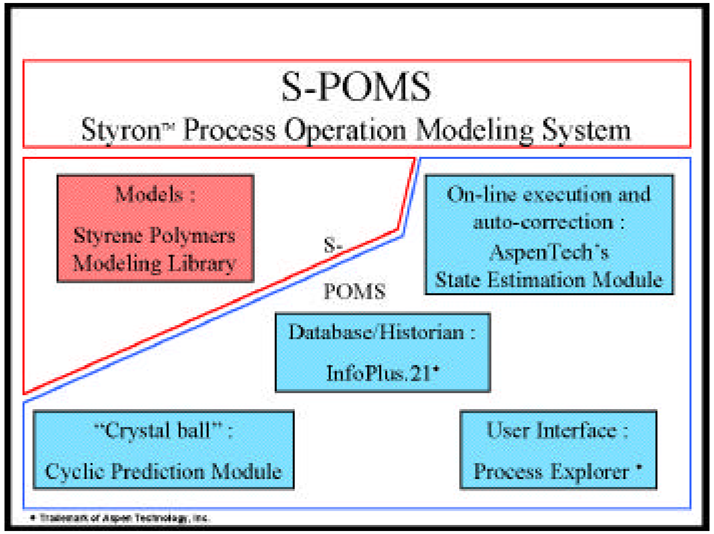
Aspen SEM applications

- Particularly suited for :
  - Multi-Product Processes
  - Frequent and Significant Transitions
  - Frequent Unknown Disturbances
  - Steady-State approximations not valid
  - Batch Processes
- Different operating modes :
  - On-line real time with plant real-time database
  - Off-line faster than real time with historical data (MS Excel as repository)
  - Synchronized with ACM emulation model or with a control application (via dbase)
  - On-line emulation with plant database populated by an ACM virtual plant model
- Key building block for model based Process Information, Monitoring and Control systems

Applications for Polystyrene at Dow

- Increased production rates :
  - better understanding and timely information to plant operation
  - ability to relax some constraints with same reliability
- Reduced transition times and off-spec product :
  - staying longer on Grade A and moving faster to Grade B
  - no waiting for lab results in many cases
  - understanding and removal of limiting steps
- Preventing upsets :
  - look-ahead gives early warning leading to preventive action
  - estimates of unmeasured process variables are used to diagnose and decide how to address operational issues
- Dynamic reconciliation of recycle stream composition

Architecture of implementation at Dow



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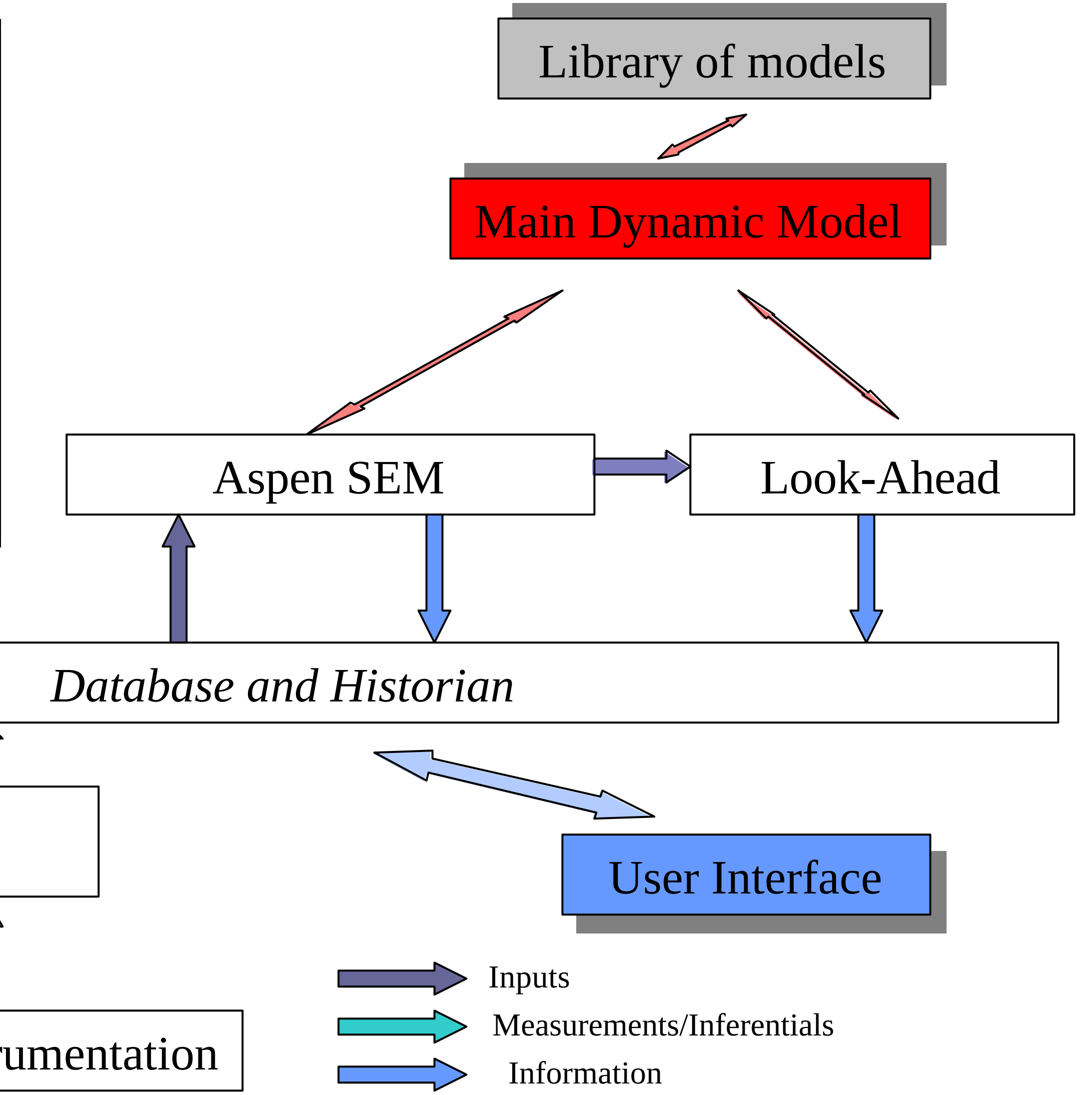
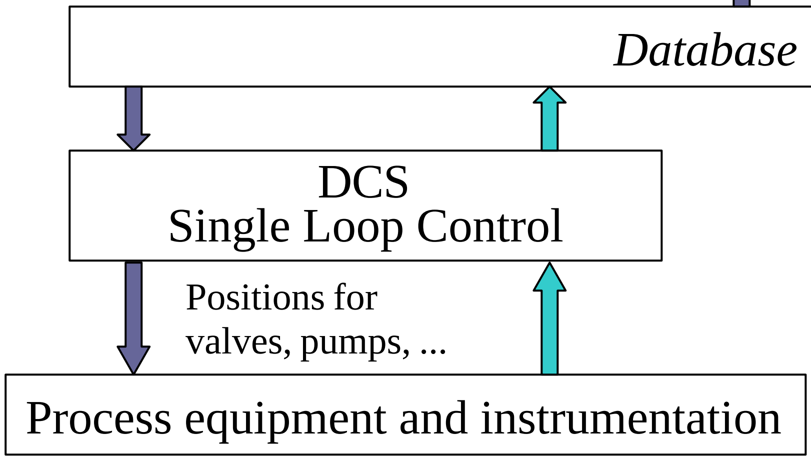
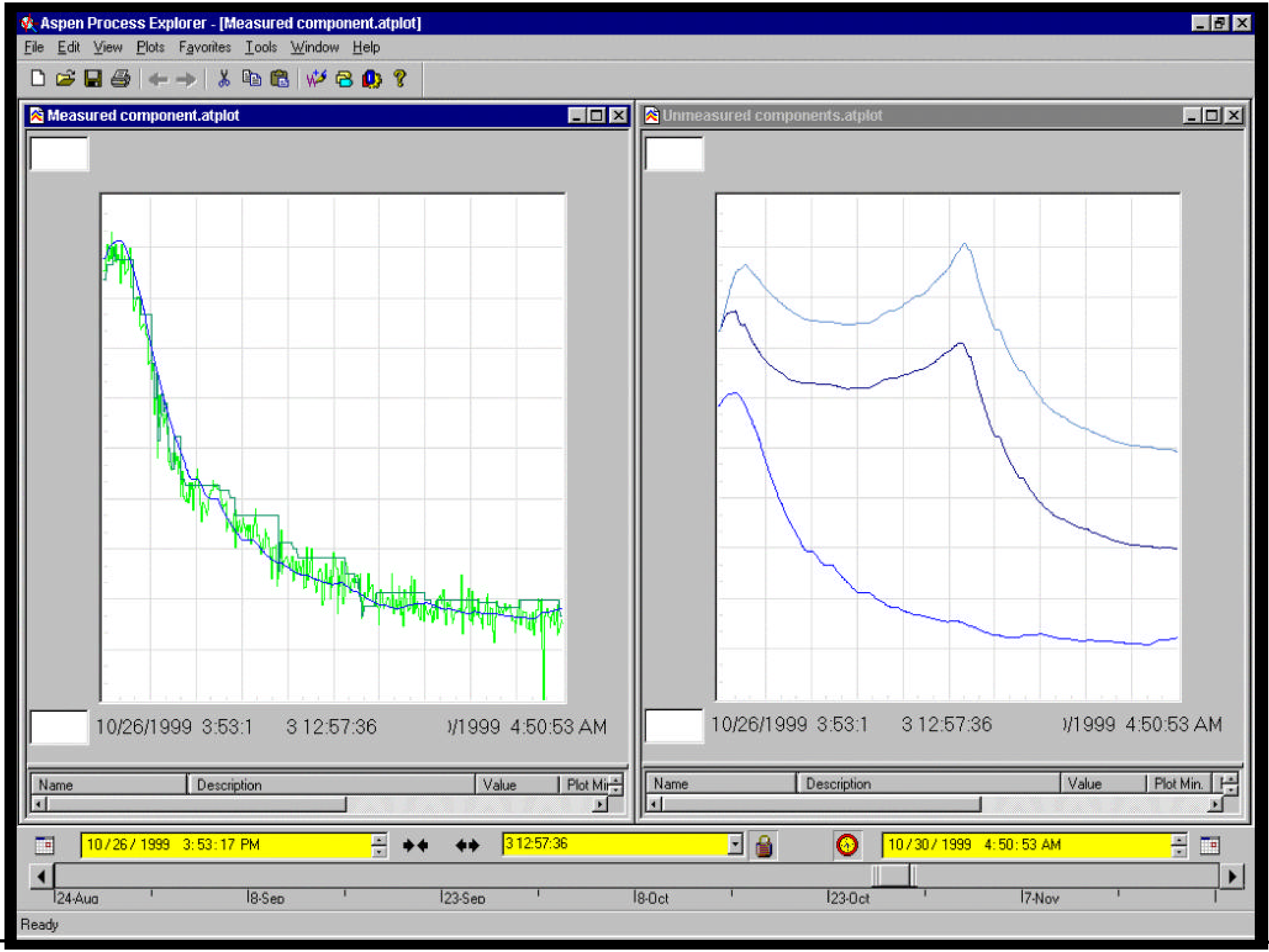




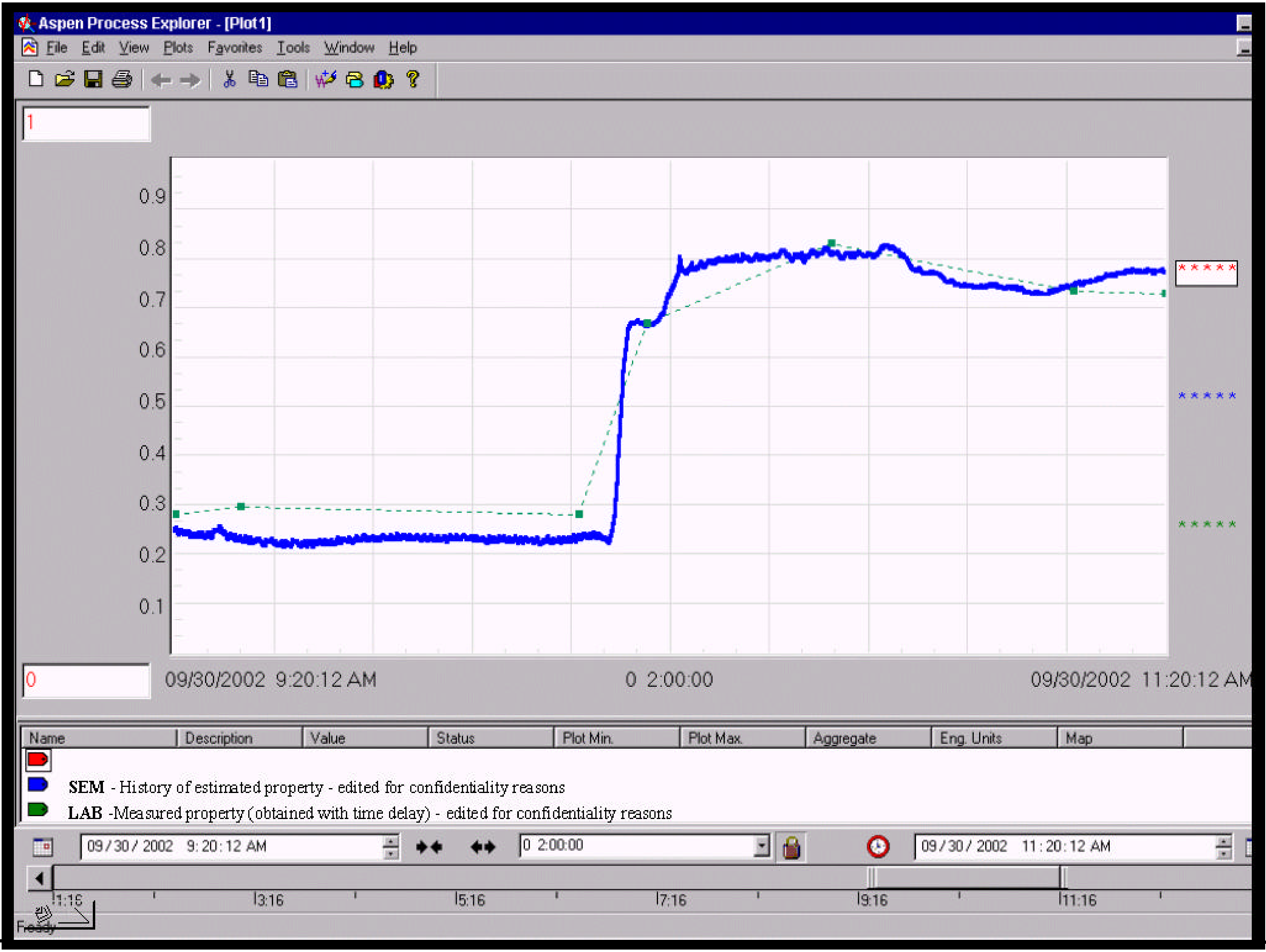
Application example (1) : Process Inferentials

Measured and unmeasured components in a stream



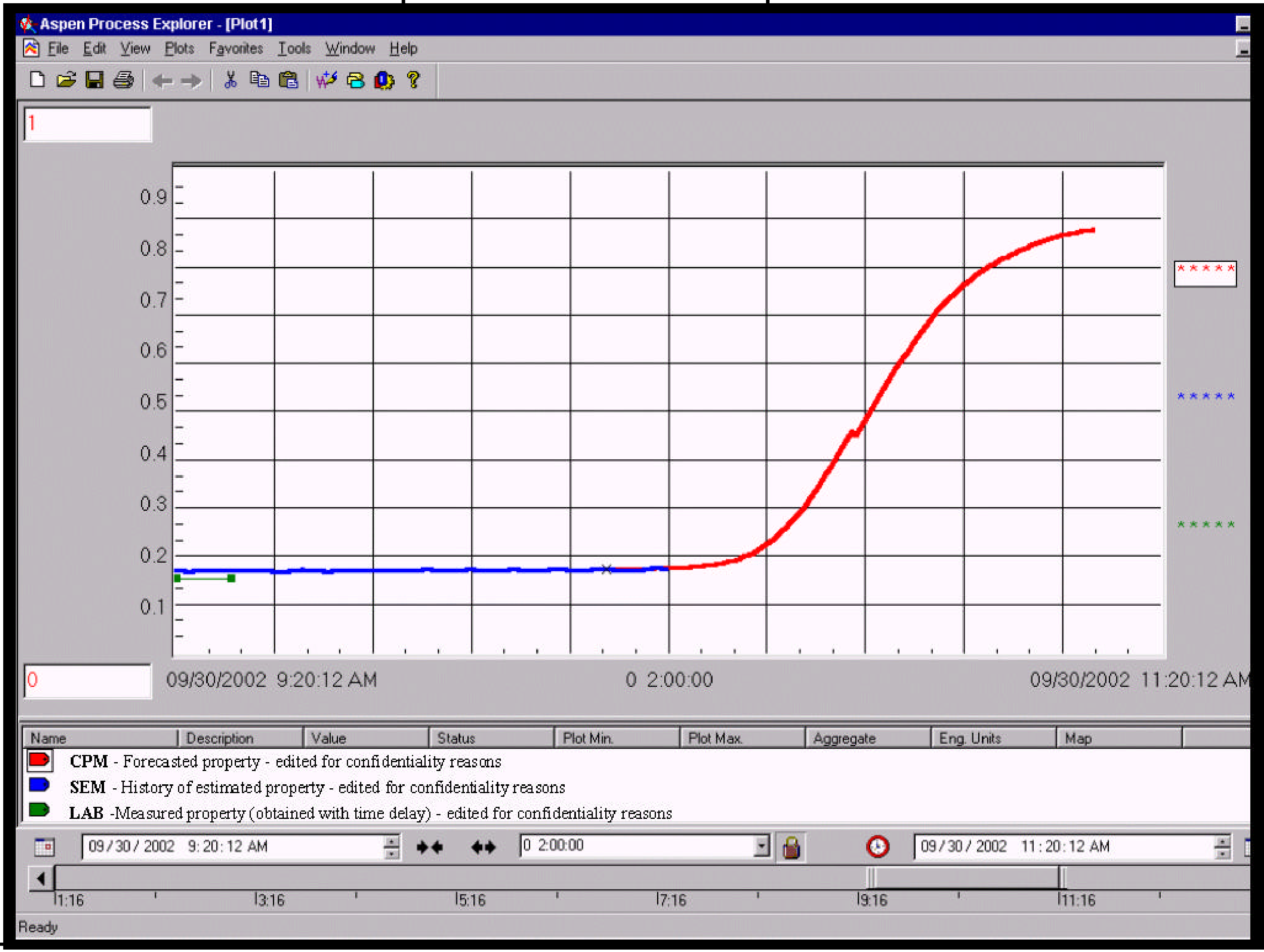
Application example (2) : Product Inferentials

Continuous property estimates with infrequent sampling



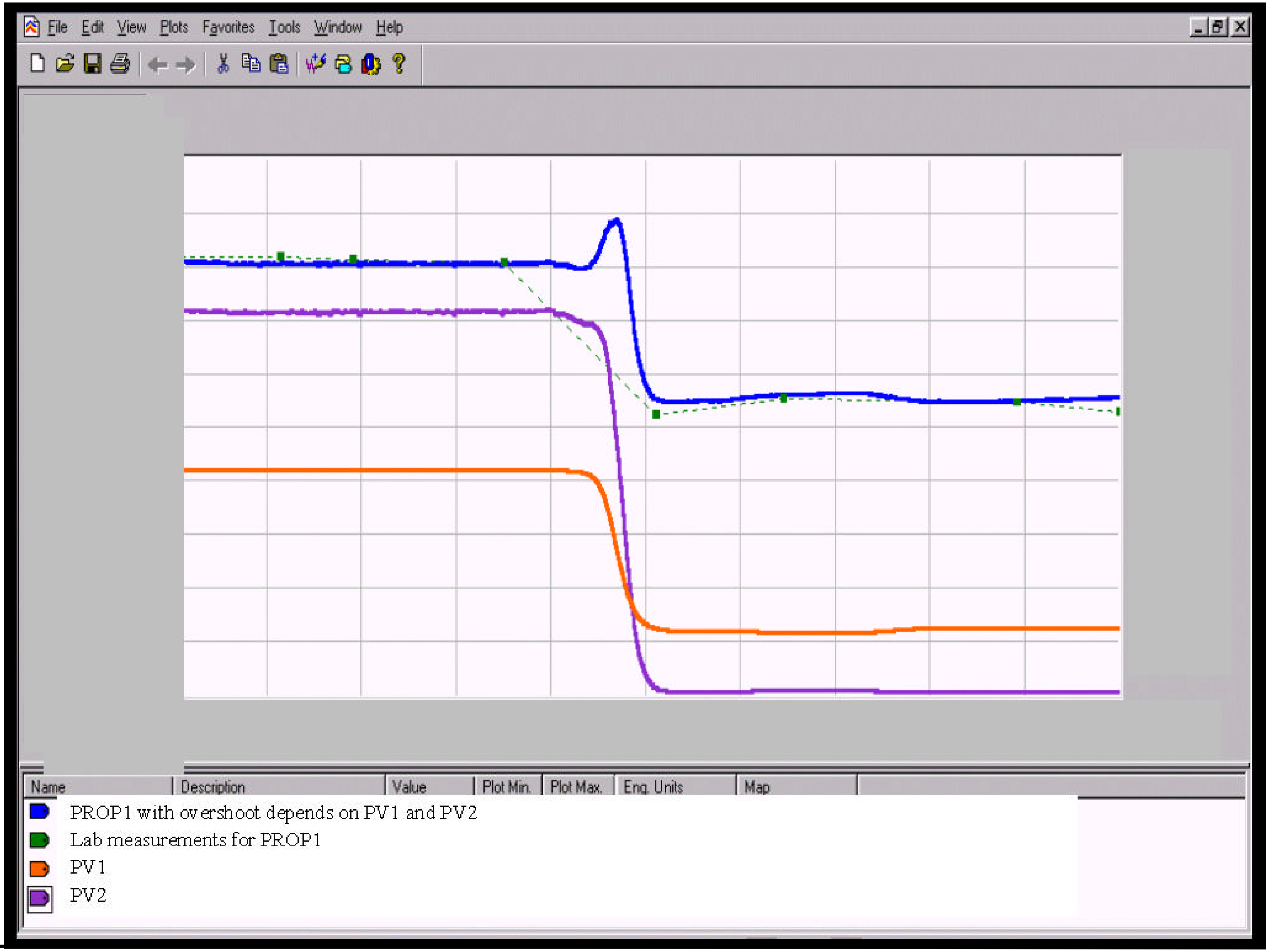
Application example (3) : faster from prime to prime

Look-ahead prediction indicates "prime time"



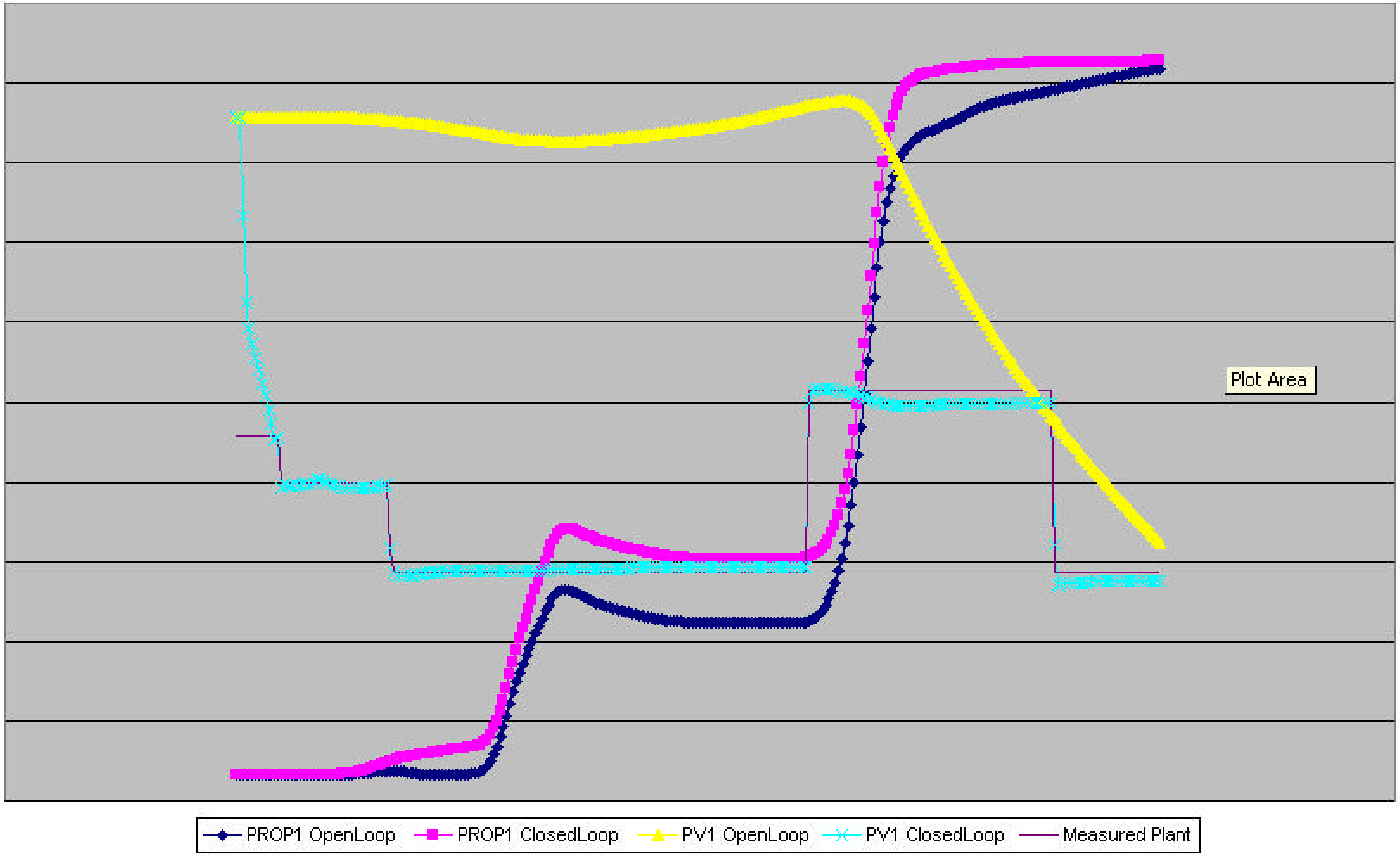
Application example (4) : troubleshooting

Relative behavior of PV estimates explains overshoot

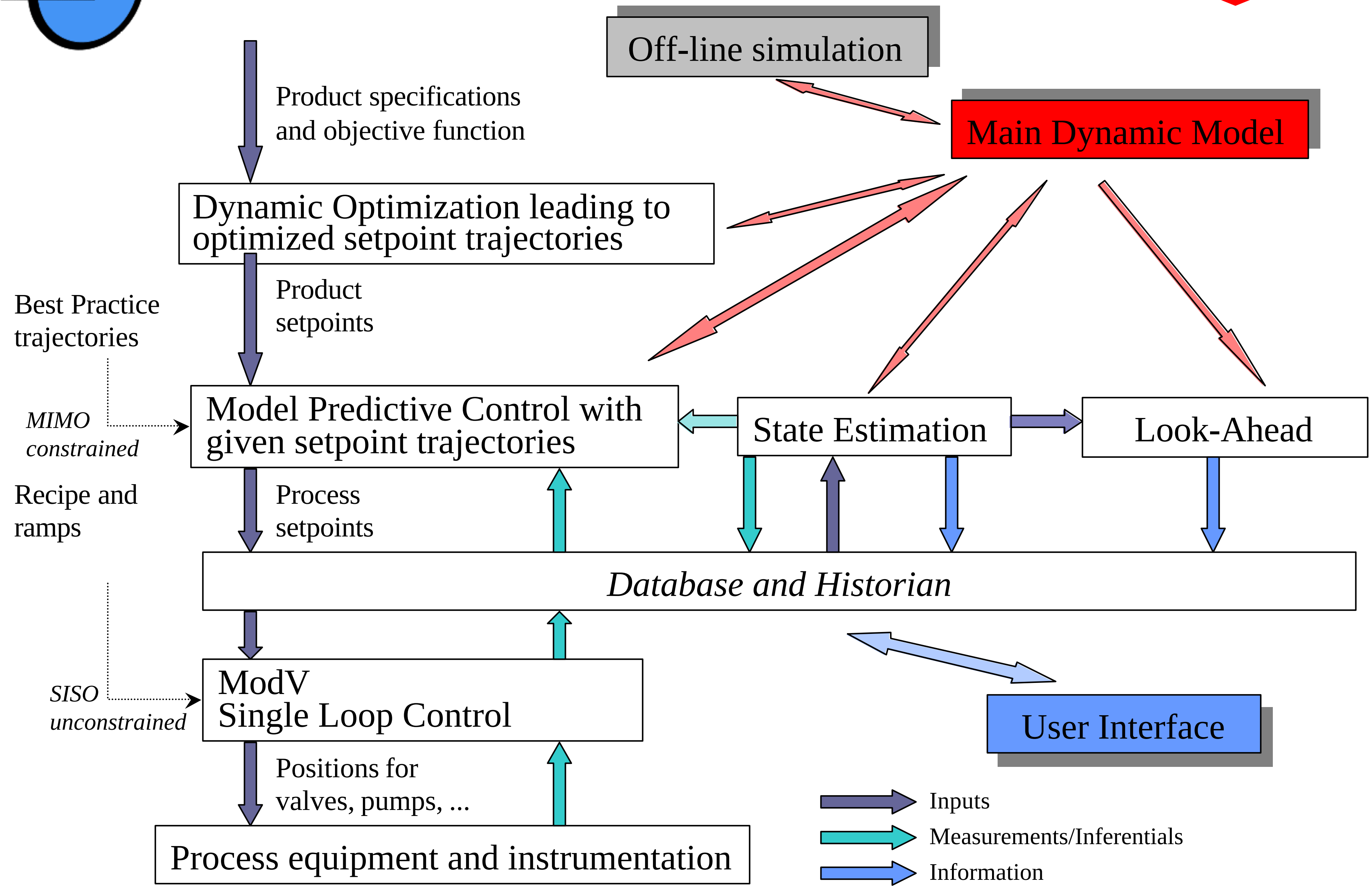


Application example (5) : off-line FTRT

Off-line study on the effect of KF updates on final product property



Advanced Control and Optimization



Project IMPACT

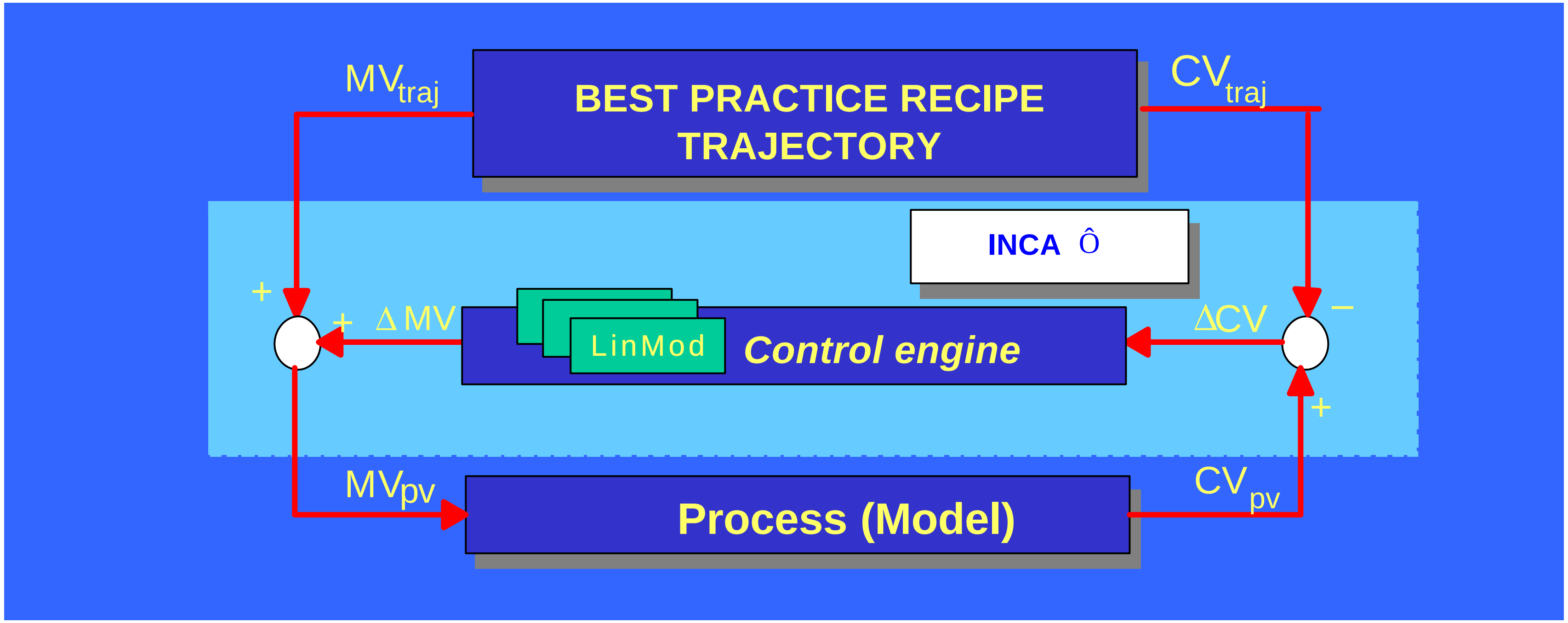
- IMproved Polymer Advanced Control Technologies
- European Research Project (Eureka)
  - Belgium : ISMC, KU Leuven, Dow Belgium
  - The Netherlands : IPCOS, TU Delft, Dow Benelux

- Dow Scope : Feasibility of MPC and Trajectory Optimization applied to the Polystyrene process
  - Application on dynamic model of a Polystyrene plant
  - Design and simulate the application of a constrained multivariable controller for trajectory control
  - Design and execute trajectory optimization based on existing process model
  - Economic evaluation

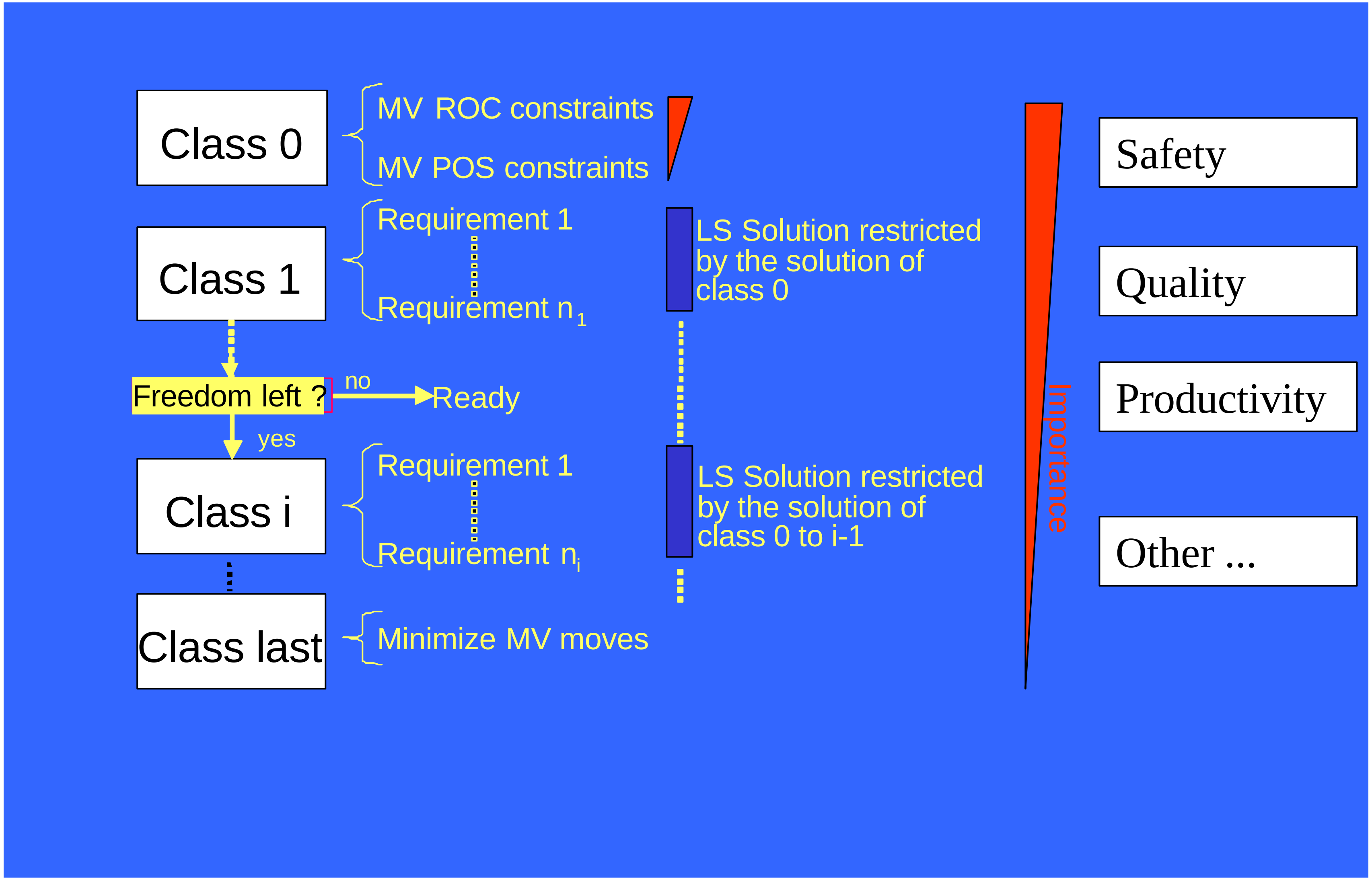
Project IMPACT : advanced control (1)

Trajectory control

- Moving from one operating point to another following a best practice path
- Dealing with non-linearities through :
  - Delta mode configuration
  - Multiple linear models

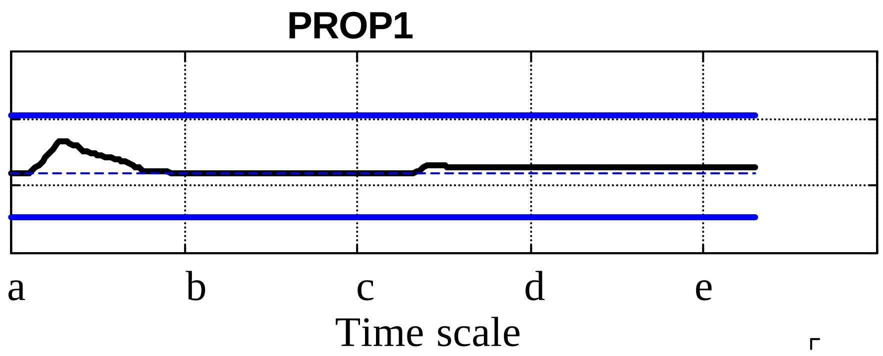


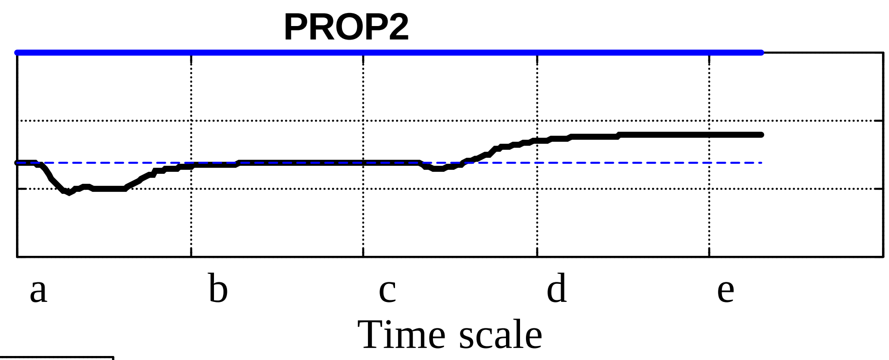
Prioritized control

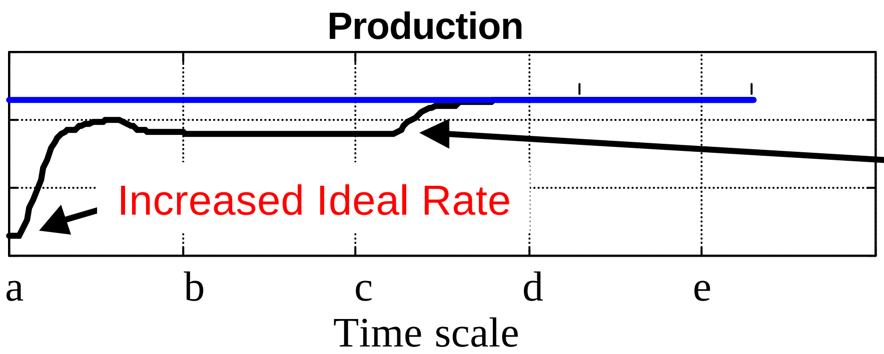


Project IMPACT : advanced control (3)

Related application with model based multivariable control using INCA :
Production rate increase for “on-aim” or “within specification” mode







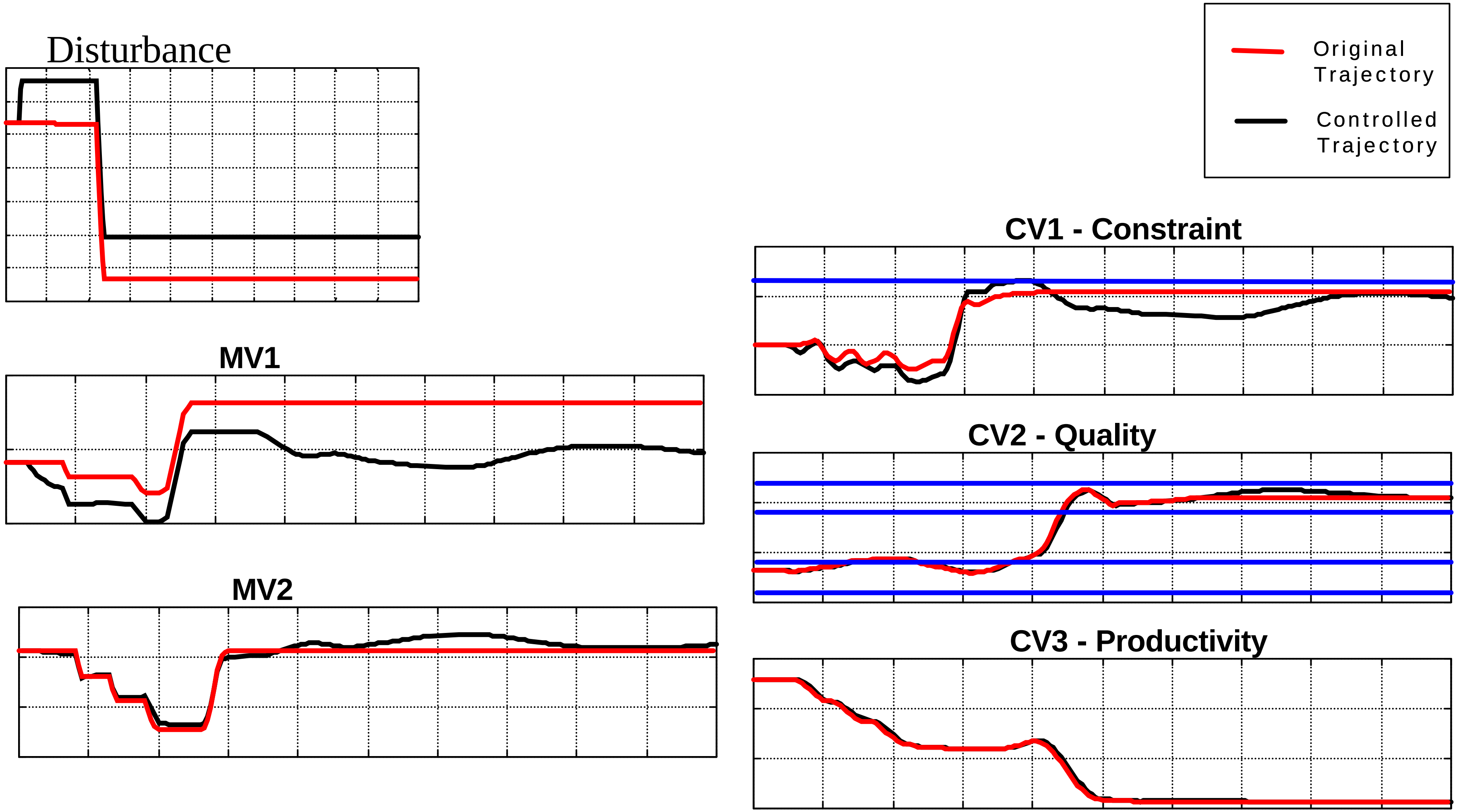
Priority : PROP1/PROP2
< Production

Controller with around 10 MV/20 CV applied to simulation based plant emulation

Project IMPACT : advanced control (4)

Trajectory control example :

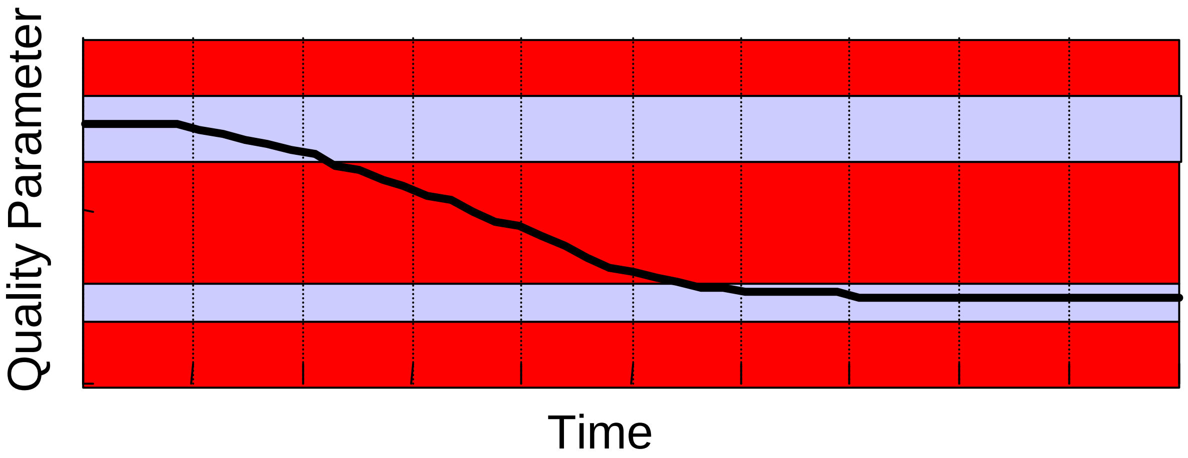
Following a best practice trajectory = history data for MV’s & CV’s



Economically Optimal Grade Transitions

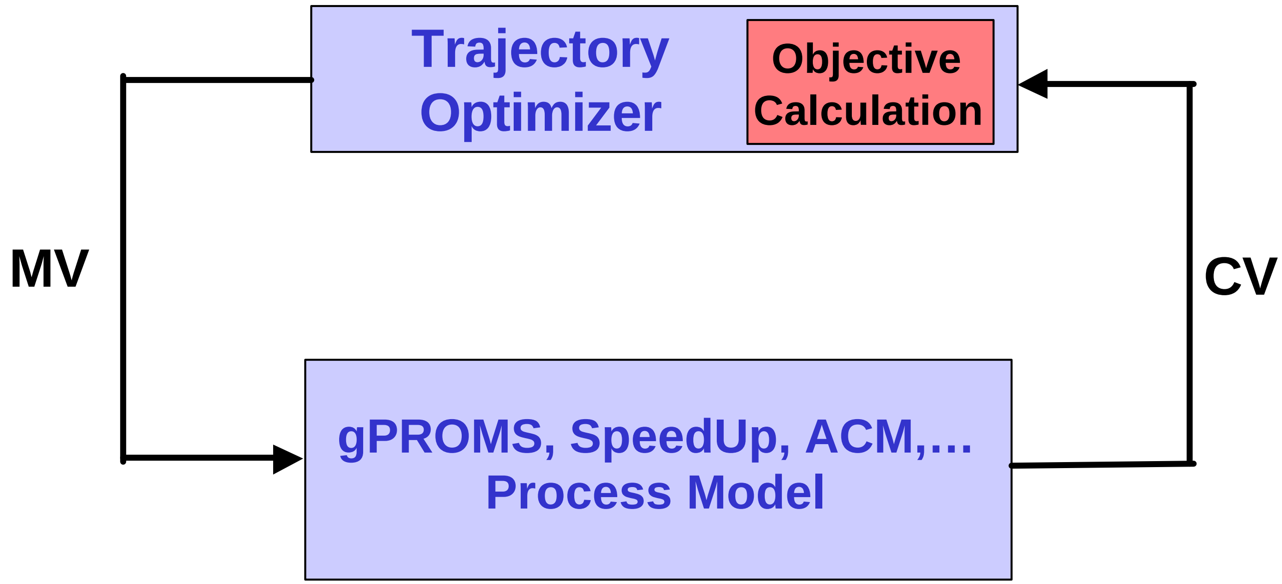
Objective = Maximize Added Value during a transition

$$AV(T) = \underbrace{\int_0^T \sum_j price_j(t) throughput_j(t) dt}_{\text{REVENUES}} - \underbrace{\int_0^T \sum_i cost_i(t)\, feed_i(t) dt}_{\text{COSTS}}$$



PathFinder, a tool for calculation of Economically Optimal Dynamic Grade Transitions

'Find dynamic MV's such that objective is optimized <u>subject to process operation constraints</u> (Off-line)'



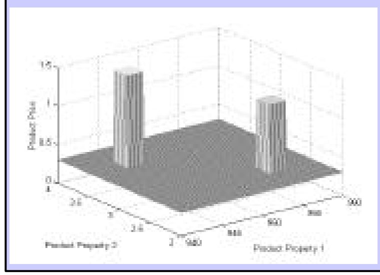
Project IMPACT : Trajectory optimization (3)

Economically Optimal Dynamic Grade Transitions

Fast (Off-Line) Trajectory Optimization

Prices Specifications

MV's → **gPROMS, ACM, SpeedUp,…** → Mass flow, Quality, Constraints → Objective



Process Model

- **Smoothly Non Linear**
- **Long Calculation Time**

Economic Objective

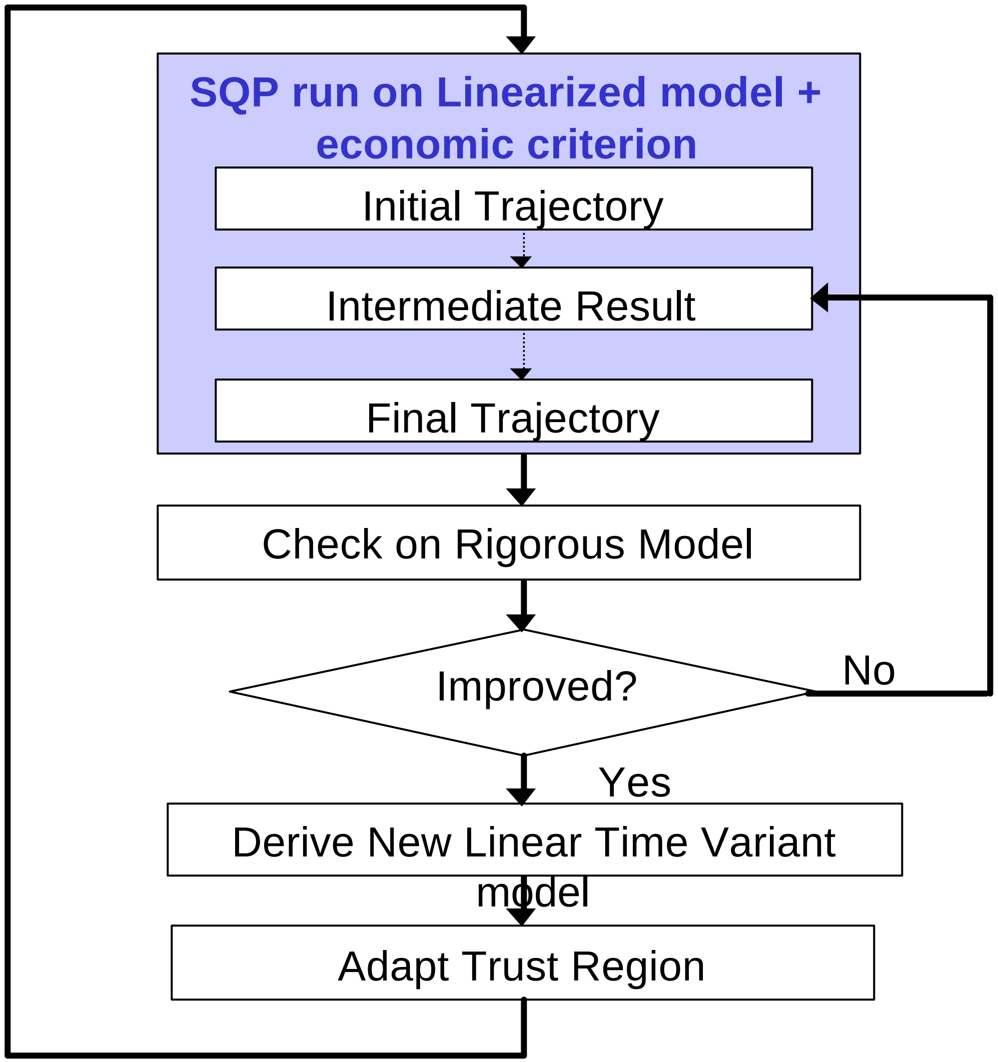
- **Highly Non Linear**
- **Short Calculation Time**

REPLACE WITH FAST LINEARIZED MODEL (SSQP)

Typically: 10 Process model evaluations/Linearizations needed

Project IMPACT : Trajectory optimization (4)

SSQP

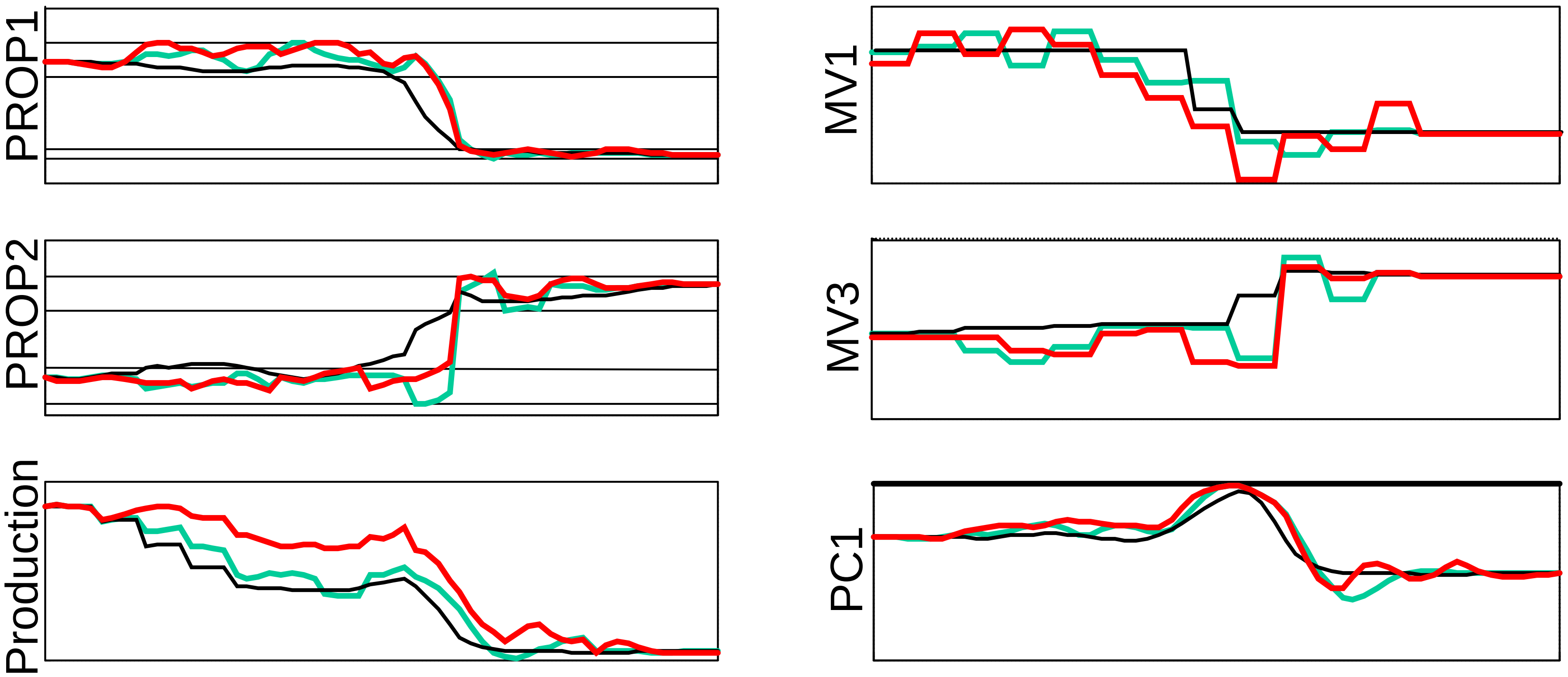


PathFinder applied to a validated rigorous model of a Dow polystyrene production facility at Tessenderlo, Belgium

- 14 Manipulated Variables with 13 move times = 182 Degrees of freedom
- Absolute Boundaries on all MV's
- Rate of Change Constraints on 10 MV's
- Path Constraints on 8 Process Variables

Project IMPACT : Trajectory optimization (6)

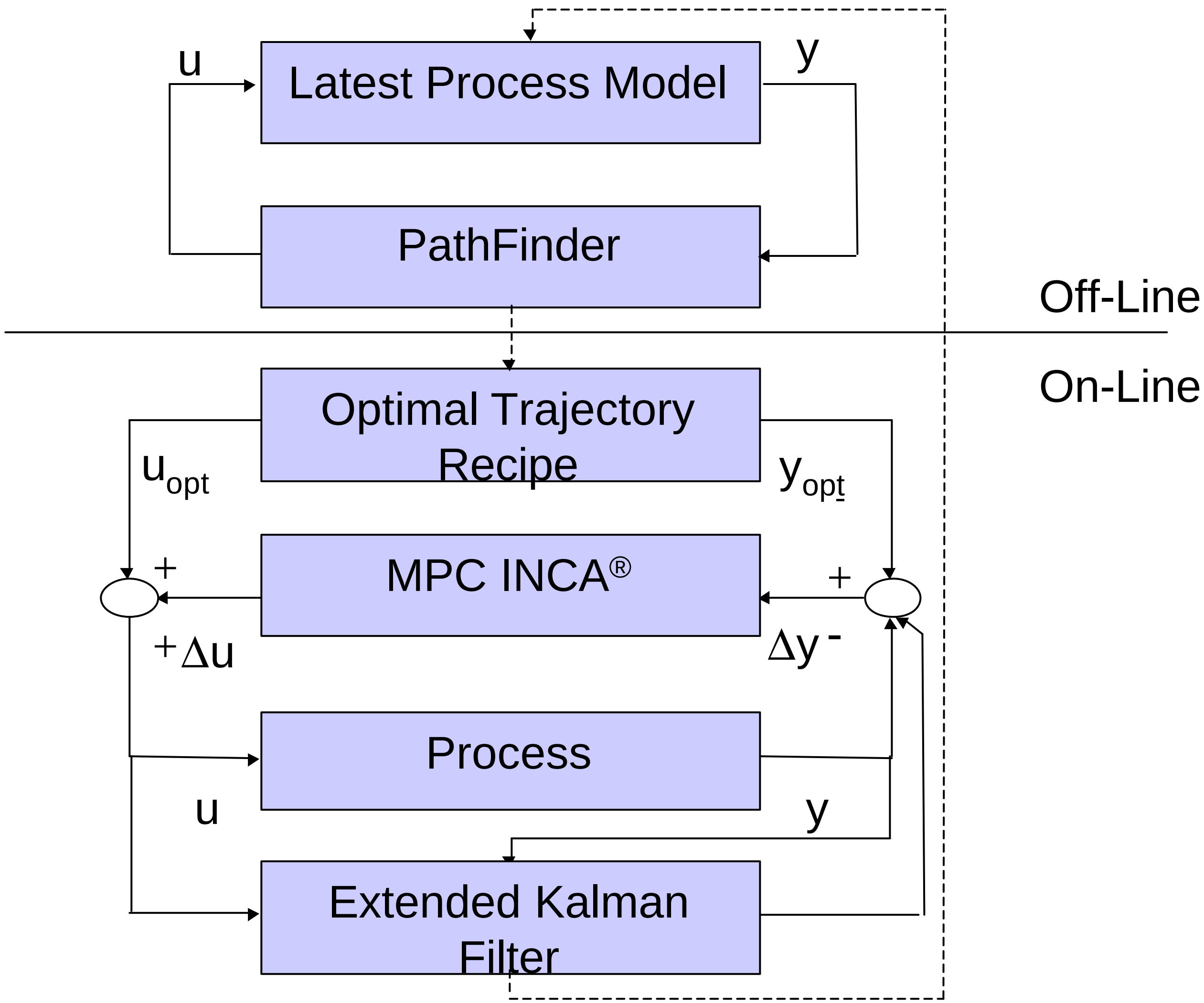
Example of result : Trajectory Optimization based on market situation



	Original	Case 1	Case 2
Price Onspec-Offspec	Not Applicable	High	Low
Price Offspec-Styrene	Not Applicable	Negative	Positive
Legend :			

Simulation based results

Integrated Trajectory Control and Optimization



Future directions

- More model based advanced process information implementations and applications
- Real life application of transition control in a polymer plant
- Combined application of transition optimization and control
- Other area of particular interest :
  - Robust dynamic modeling for optimization and control applications
  - Real-time integrated dynamic optimization and control
  - Robust non-linear model predictive controllers
  - Non-linear model reduction
  - Operator training

- **Related papers :**

  - W. Van Brempt, P. Van Overschee , T. Backx, J. Ludlage, P. Hayot, L. Oostvogels, S. Rahman, “Economically Optimal Grade Change Trajectories: Application on a Dow Polystyrene Process Model”, ESCAPE-12, The Hague, The Netherlands, 2002.
  - W. Van Brempt, P. Van Overschee , T. Backx, J. Ludlage, P. Hayot, L. Oostvogels, S. Rahman, **“**Grade Change Control using INCA Model Predictive Controller: Application on a DOW Polystyrene Process Model”, invited paper at the American Control Conference 2003, Denver, Colorado, USA, June 2003.
  - P.Hayot, S.Papastratos, “Going on-line with dynamic models using Aspen Custom Modeler and Aspen SEM”, AspenWorld 2002, Washington D.C., USA, October 2002.