INCOOP

IPCOS
Creators in control

General scope, goals and overview of INCOOP

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Outline of the presentation

- Background to the INCOOP project
- Problem formulation
- Goals set for the INCOOP project
- The INCOOP project structure
- The INCOOP project technology development
- Some highlights of results obtained
- Expected impact of the INCOOP project

Background to the INCOOP project

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The INCOOP project resulted from the need for truly integrated control and optimization technology that enables high performance, dynamic operation of processes in a wide range of industries.

- Technology applicable to improve most of the applied industrial processes
  - Improvement of process economics
  - Coverage of the complete relevant process operating envelope
- Enabling technology to comply with future demands on process operations
  - Process taken as an element of a complete supply chain
  - Adjustment of process operation to changing market demand
- Technology that matches process behaviour with implied operating constraints
  - Imposed constraints on emissions to the environment
  - Minimization of energy consumption
  - Always respect imposed process operating constraints

Background to the INCOOP project

Model Predictive Control technology originally emerged from a need of process industries in the early seventies to improve the performance of their process operations

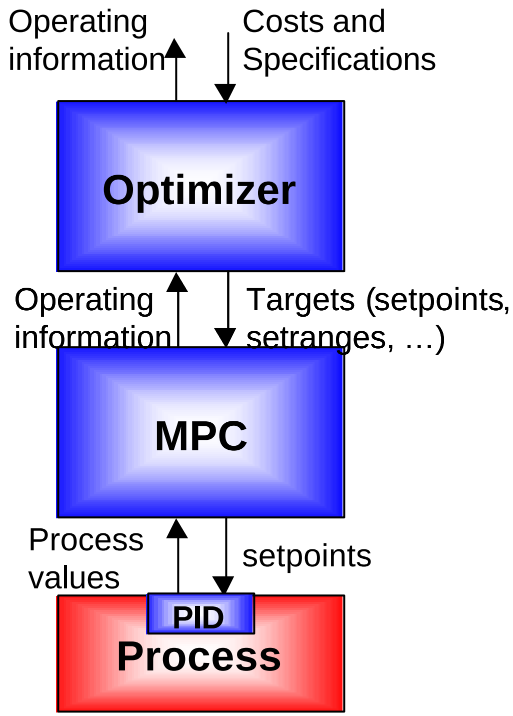
- Enabling predictable and reproducible operation of processing units
- Reduction of impact of process upsets and disturbances by feedforward compensation in stead of feedback control
- Opening the way for closer operation to performance limiting operating constraints to pave the path towards better exploitation of economic potential of production equipment

Background to the INCOOP project

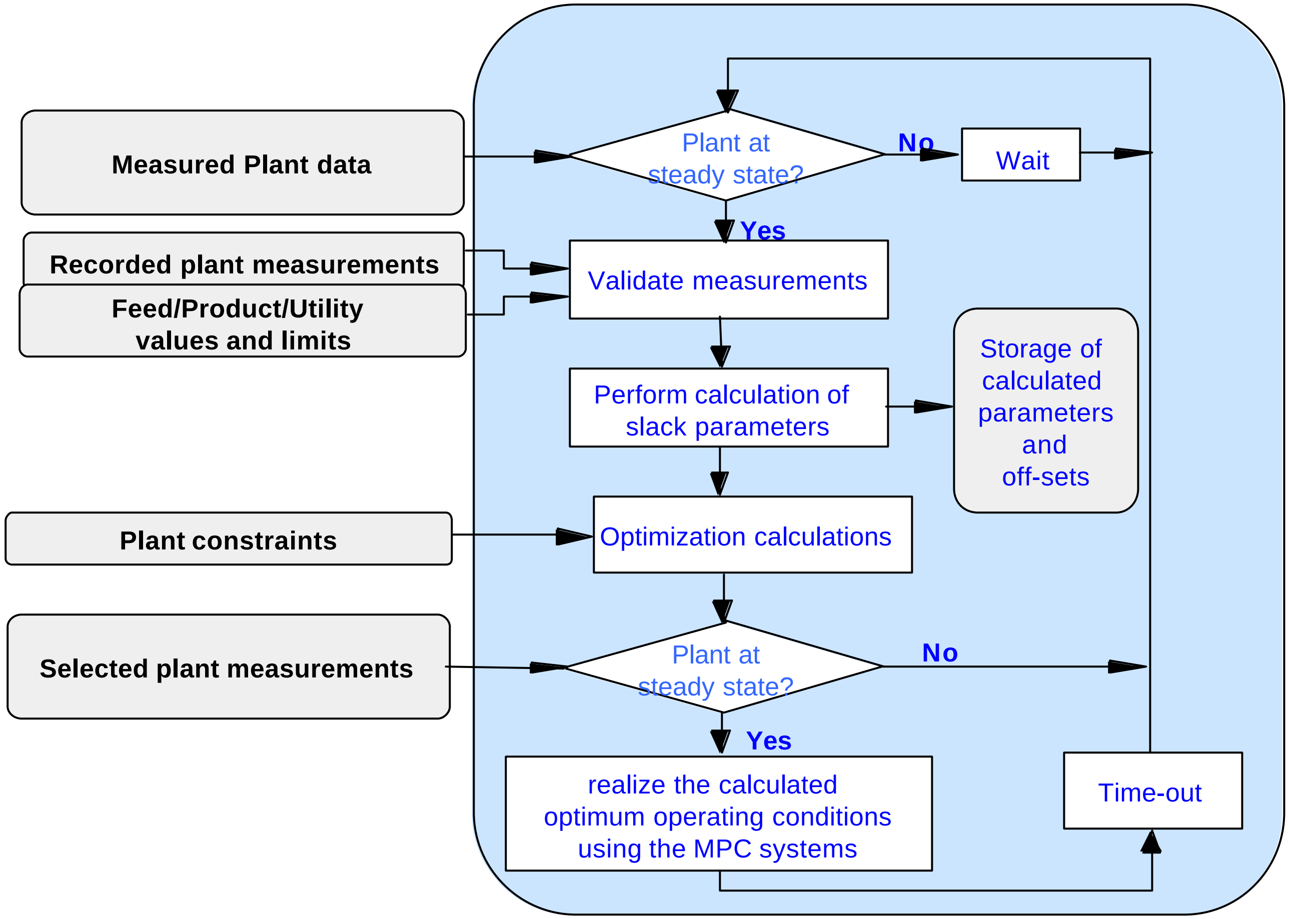
Model predictive control is seen as the supervisory control layer that enables process optimization by minimization of production costs ensuring product specifications and production quantities

– optimum operating conditions are determined by an optimizer (setpoints, set ranges, priorities and weights, operating constraints)

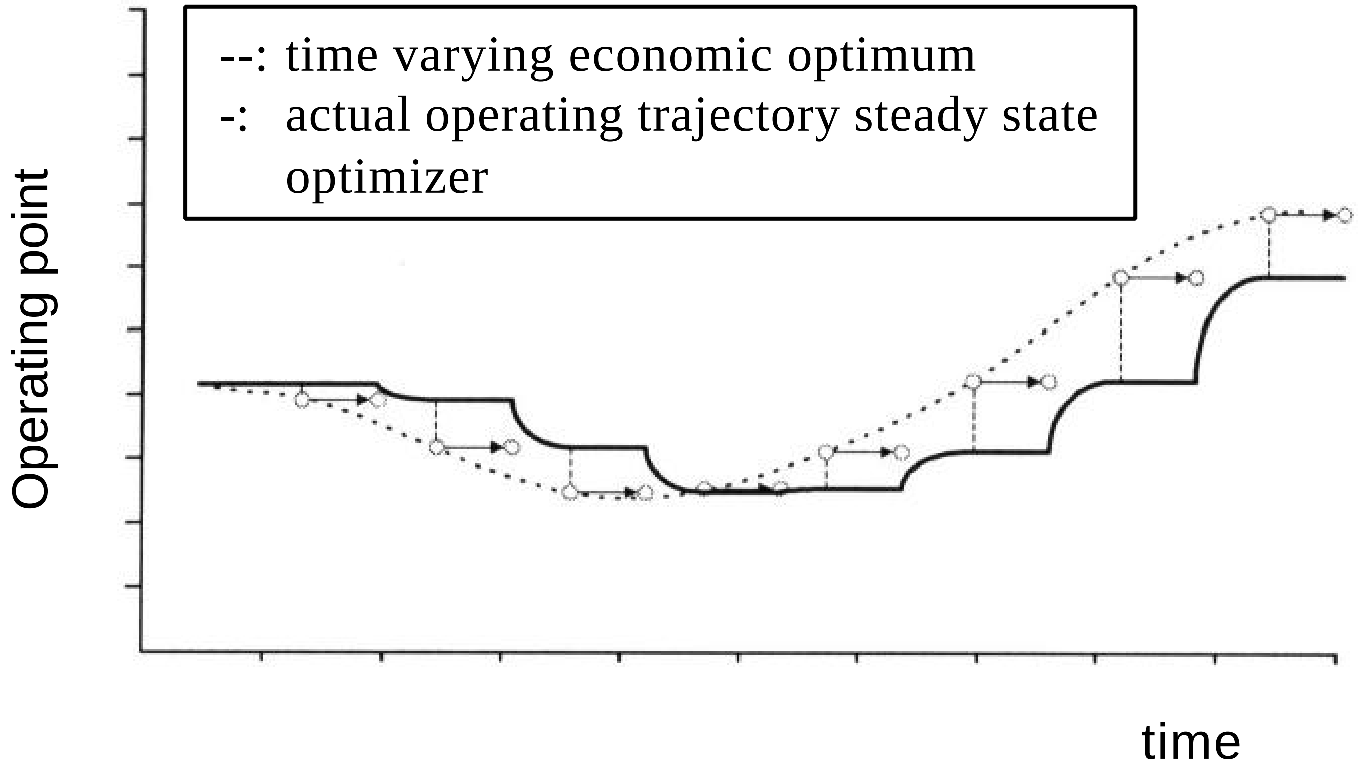
– the model predictive control system realizes targets set by the optimizer



Current state-of-the-art closed loop optimization

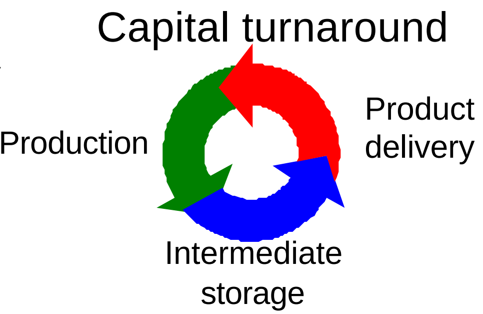


Closed Loop Steady State Optimization



Traditional process operation with a decoupling between actual production and market supply restricts the speed of capital turnaround

- Capital productivity is one to one related to the speed of capital turnaround for given margins
- Market supply from stock reduces the risk of unwanted delays in product deliveries, but slows down capital turnaround
- Production to stock has a significant impact on the flexibility to deliver a requested product in the right volume at the right time with relatively short notice



Problem formulation:

The INCOOP project has to deliver high performance process control and process optimization technologies that enable given production processes to respond fast and reliably to market demand within permitted operating constraints of governed processes

Development of generically applicable technologies for:

- Dynamic optimization of plant operation in order to continuously maximize the added value realized
- High performance, non-linear model predictive control of the processing units to continuously operate as close as possible to maximum added value operating conditions
- Dynamic reconciliation of data obtained from process measurements
- Realizing complete consistency between model predictions applied for control and model predictions applied for optimization

Technical goals of the INCOOP project

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The objective of the INCOOP project is to set the first important steps in realising a *fully integrated, dynamic and non-linear process control and optimisation system* through the following targeted results:

- A new hybrid modelling approach that basically comprises three essential techniques:
  - Guiding principles for the development of hybrid dynamic models consisting of first principle models and empirical model components
  - The reduction of the complexity of such hybrid dynamic models to support Dynamic Real Time Optimisation (DRTO) and High Performance Non-Linear Model Predictive Control (HP-NL MPC)
  - Techniques for updating the aforementioned DRTO and HP-NL MPC models.

Technical goals of the INCOOP project

- New High Performance, Non-Linear MPC and Dynamic RTO methods and technologies, which include:
  - a (dynamic) process optimisation algorithm capable of handling large scale systems robustly and sufficiently fast,
  - an algorithm for parameter updating within the RTO model,
  - a (non-linear) multivariable predictive control system (MPC) that supports large bandwidth, high performance quality control, accurate transition trajectory tracking control, dynamic constraint handling and economic performance based constraint pushing over a large operating envelope,
  - a data processing filter for dynamic data reconciliation (before input to the control system) and a new numerical method for large scale non-linear constraint dynamic optimisation calculations.

Technical goals of the INCOOP project

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- Development of prototype software tools that perform the tasks under 1 and 2 and provide a simulation basis to show the correctness and to demonstrate performance of the developed methodology
- The new technologies have to support smooth migration from currently applied (linear, quasi steady state) model predictive control technology and (steady state) optimization technology to the new, integrated (high performance, non-linear) model predictive control and (dynamic) optimization technologies

The INCOOP project structure

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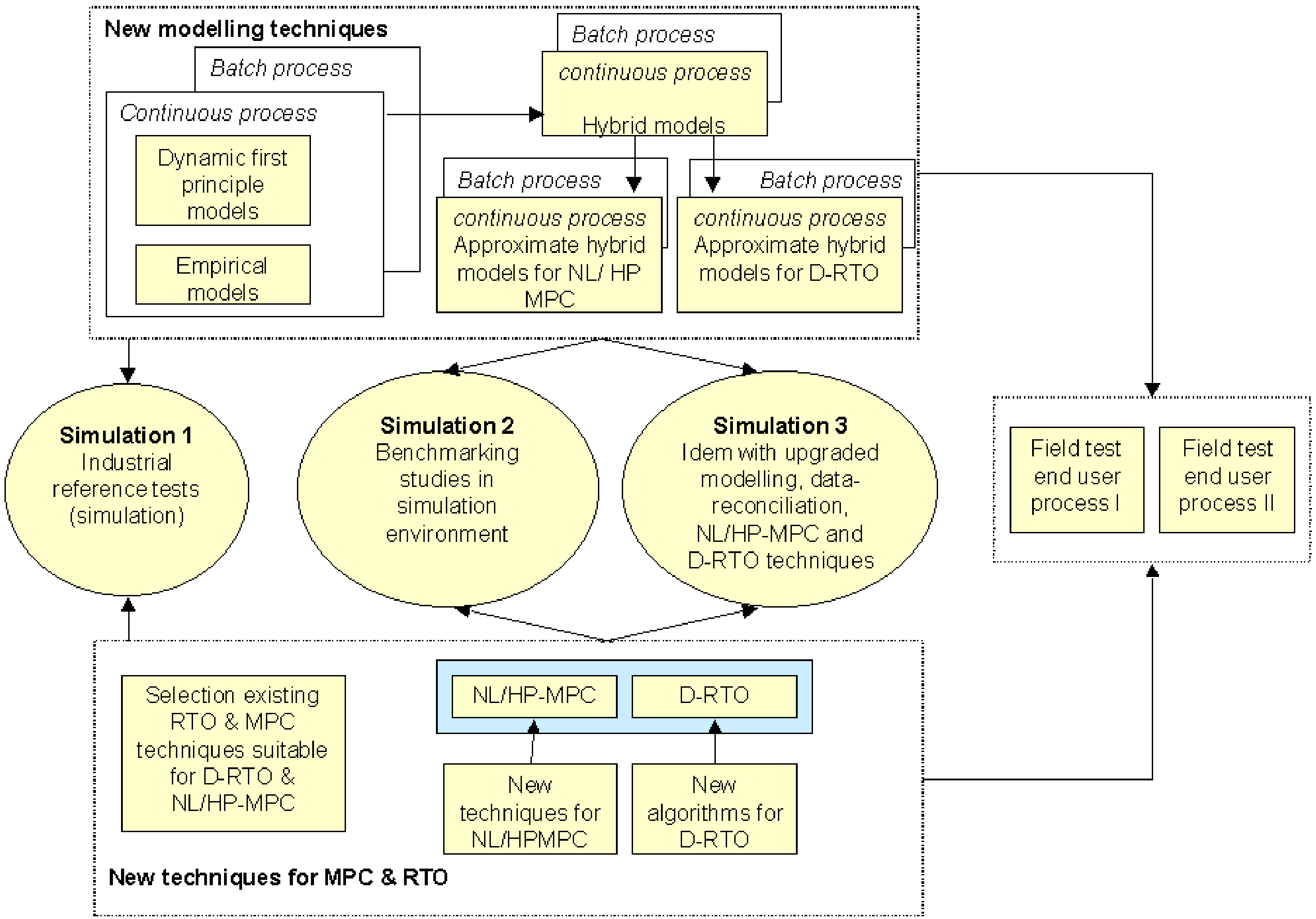
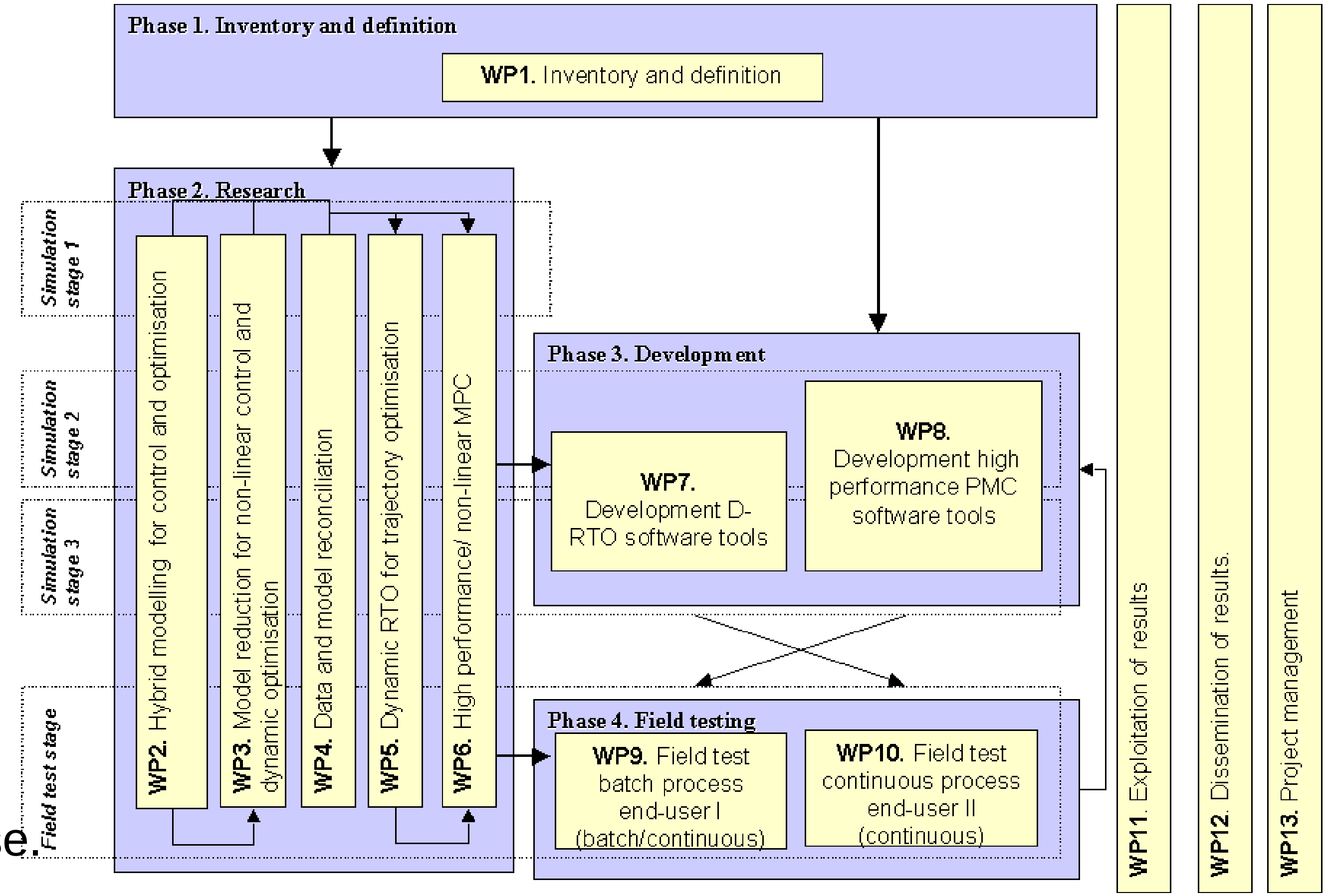


The INCOOP project structure

Overview Work Packages

Project phases:

- The inventory and definition phase;
- The research phase;
- The development phase;
- The field testing phase.



Overview Workpackages and prime responsible partners:

1. Inventory and definition
   Bayer (H. De Meijer/M. Friedrich)
2. Hybrid modelling for control and optimisation
   Delft University (J. Grievink)
3. Model reduction for non-linear control and dynamic optimisation
   Delft University (O. Bosgra)
4. Data and model reconciliation
   Delft University (O. Bosgra)
5. Dynamic RTO for trajectory optimisation
   RWTH Aachen (W. Marquardt)

Overview Workpackages and prime responsible partners:

6. High Performance Non-linear MPC
   Eindhoven University (P. van den Bosch/T. Backx)
7. Development D-RTO tools
   MDC (C. Hawkins)
8. Development high performance non-linear MPC software tools
   IPCOS Technology (T. Backx)
9. Field test process 1
   Bayer (H. De Meijer/M. Friedrich)
10. Field test process 2
    Shell (P.-J. Brouwer)

Overview Workpackages and prime responsible partners:

11. Exploitation

    MDC (C. Hawkins/T. Backx)

12. Dissemination

    RWTH Aachen (W. Marquardt/O. Bosgra)

13. Project management

    Overall project coordination: Bayer (H. De Meijer/M. Friedrich)

    Technical project coordination: IPCOS Technology (T. Backx)

The INCOOP project structure

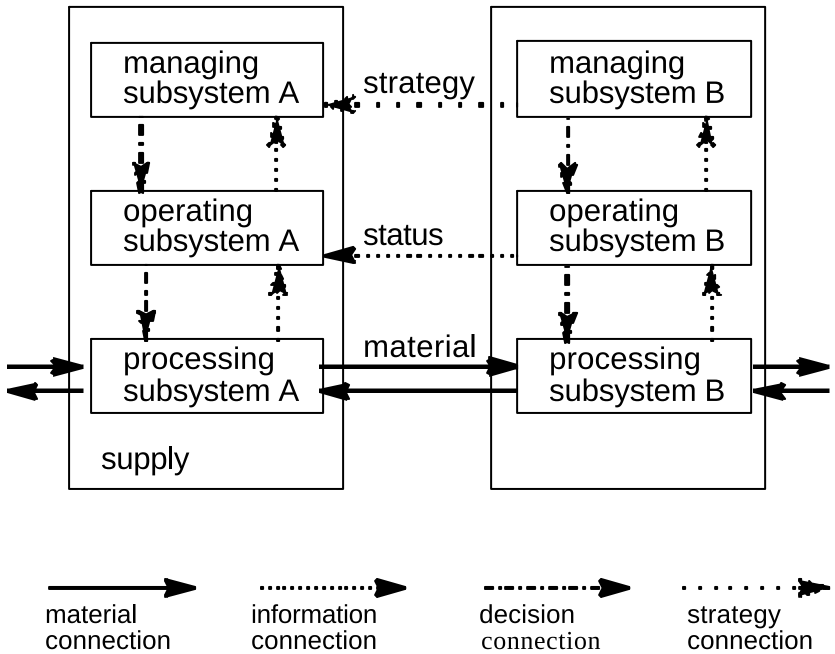
An ambitious project like the INCOOP project puts extreme demands on cooperation between the partners. Communication between partners and appropriate exchange of relevant information between partners are key elements for success:

- BSCW Intranet site for the project
  - Public area
  - Protected technical area accessible for read access by each project team member (All project related information)
  - Protected areas accessible for read/write access by authorized team members only (Dedicated work package related detailed information)

New *Manufacturing Execution Systems* (MES) have to support optimum operation of plants as elements of a flexible supply chain*)

Flexible and predictable production on the basis of received orders:

- production scheduling
- dynamic optimization of plant operating conditions
- high performance model predictive control



*) Towards intentional dynamics in supply chain conscious process operations, FOCAPO 1998, W. Marquardt, T. Backx and O. Bosgra

The INCOOP project technology development

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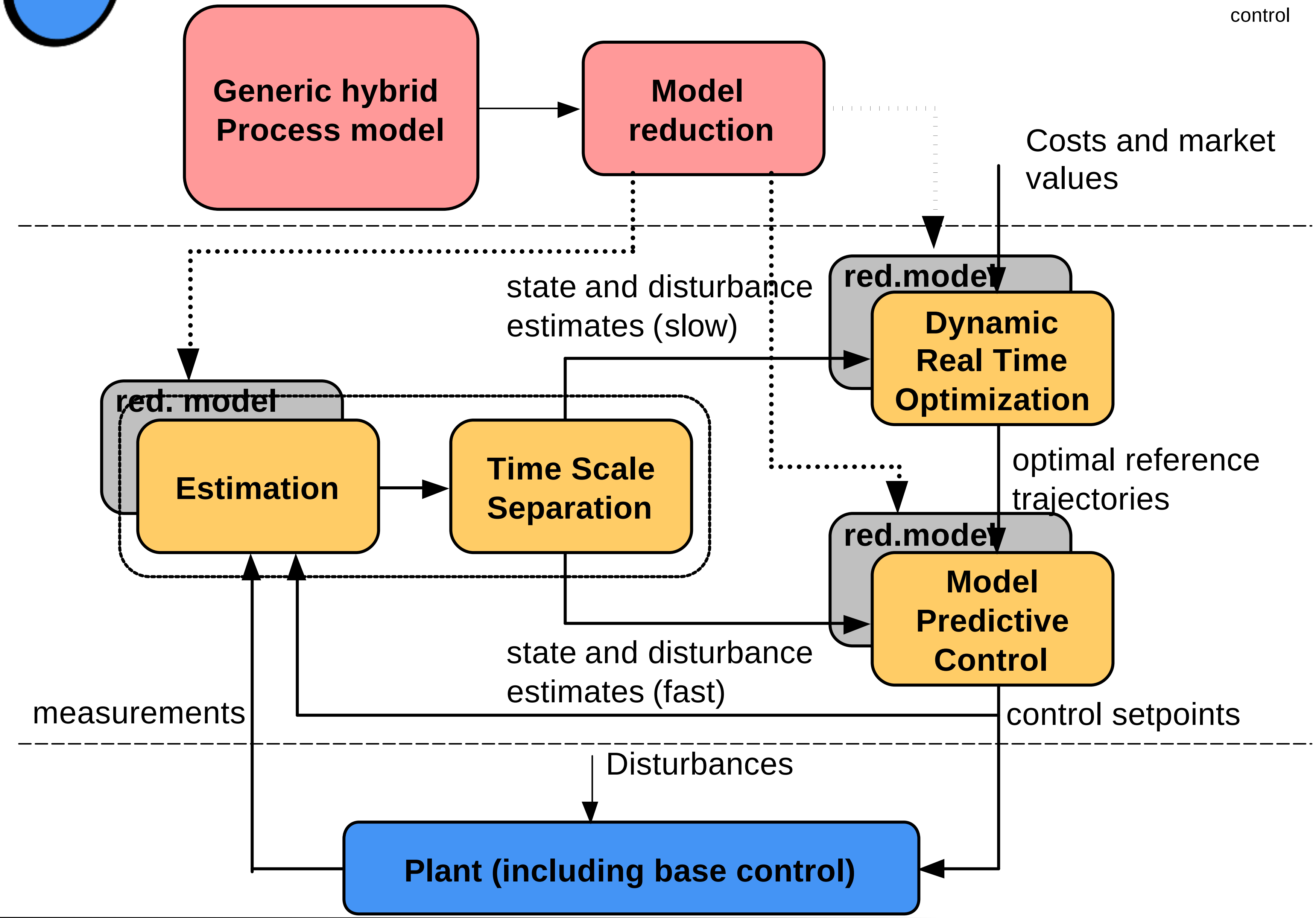
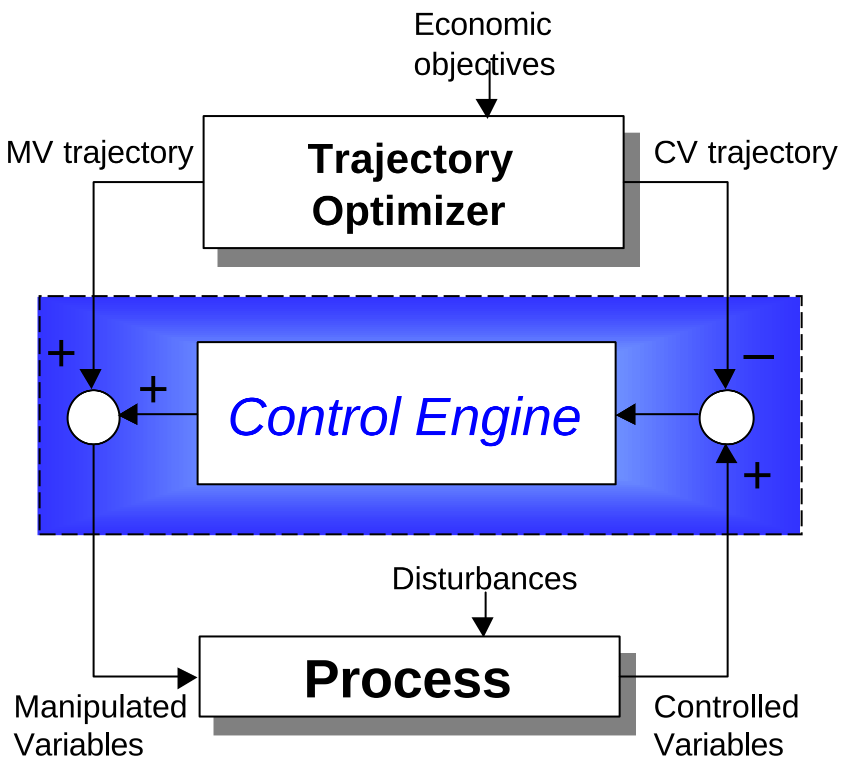
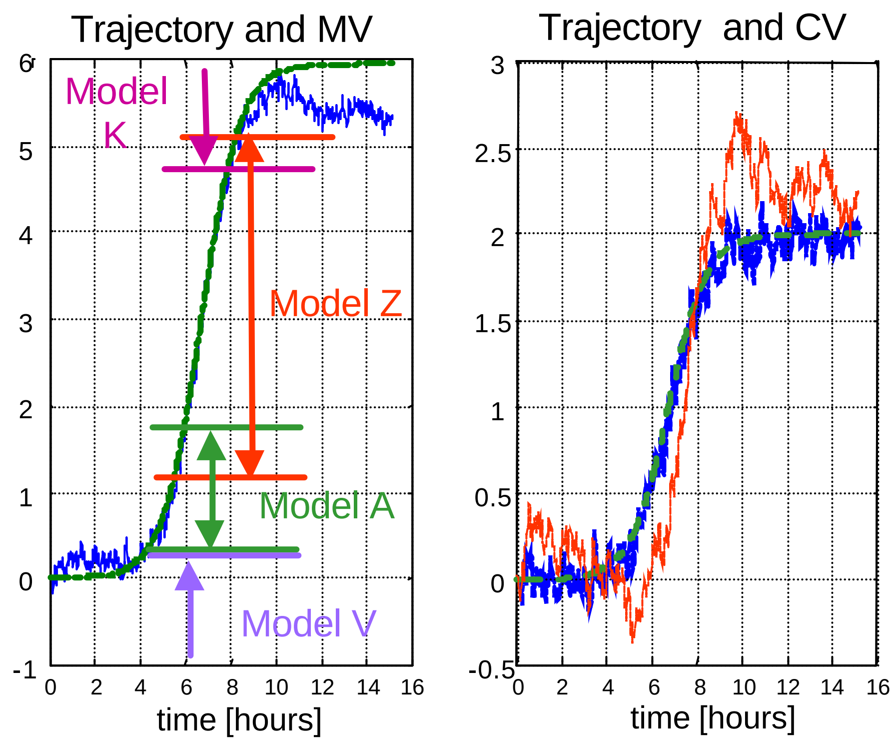


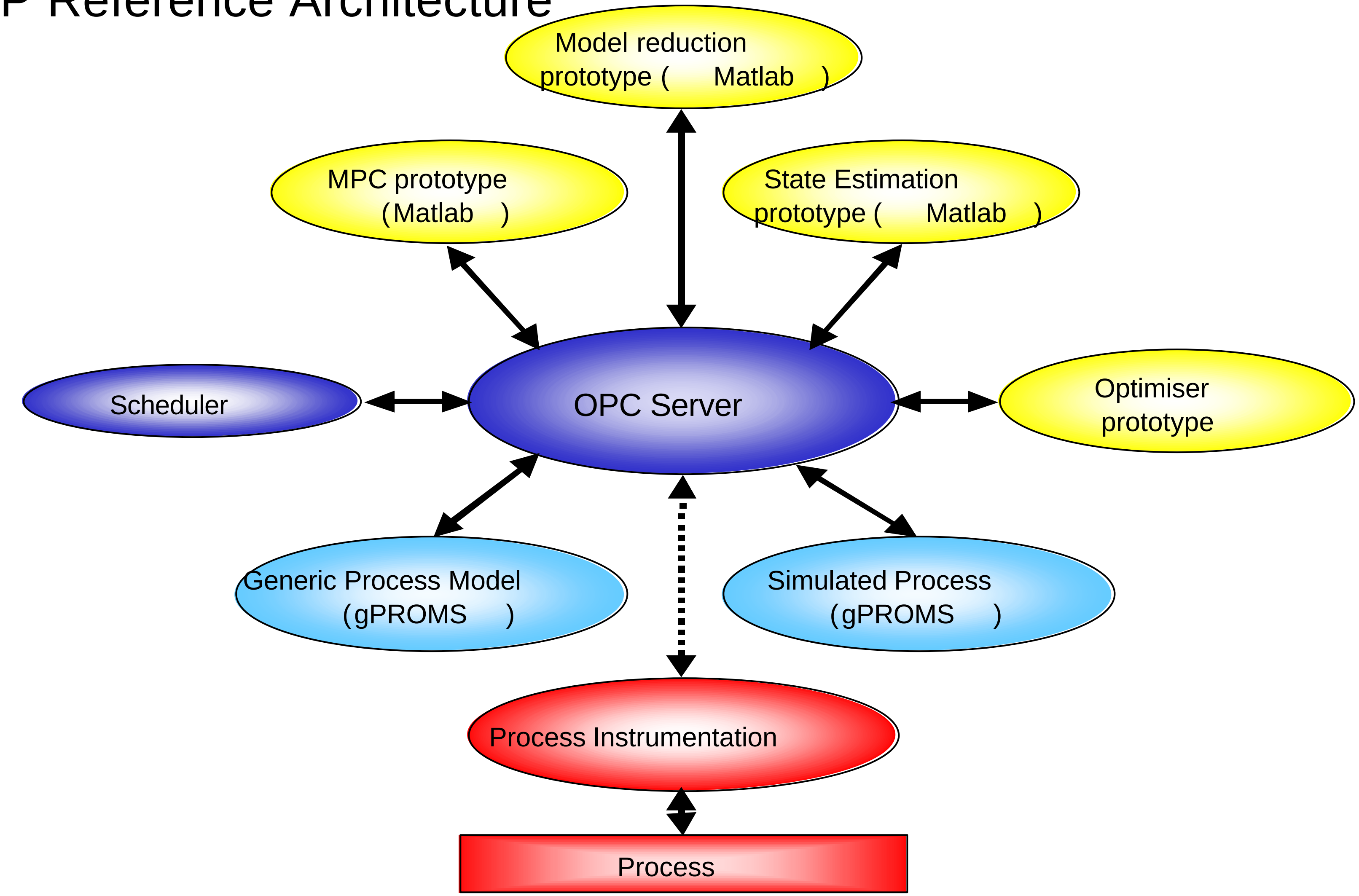
Combining rigorous model based optimizers and model predictive control:



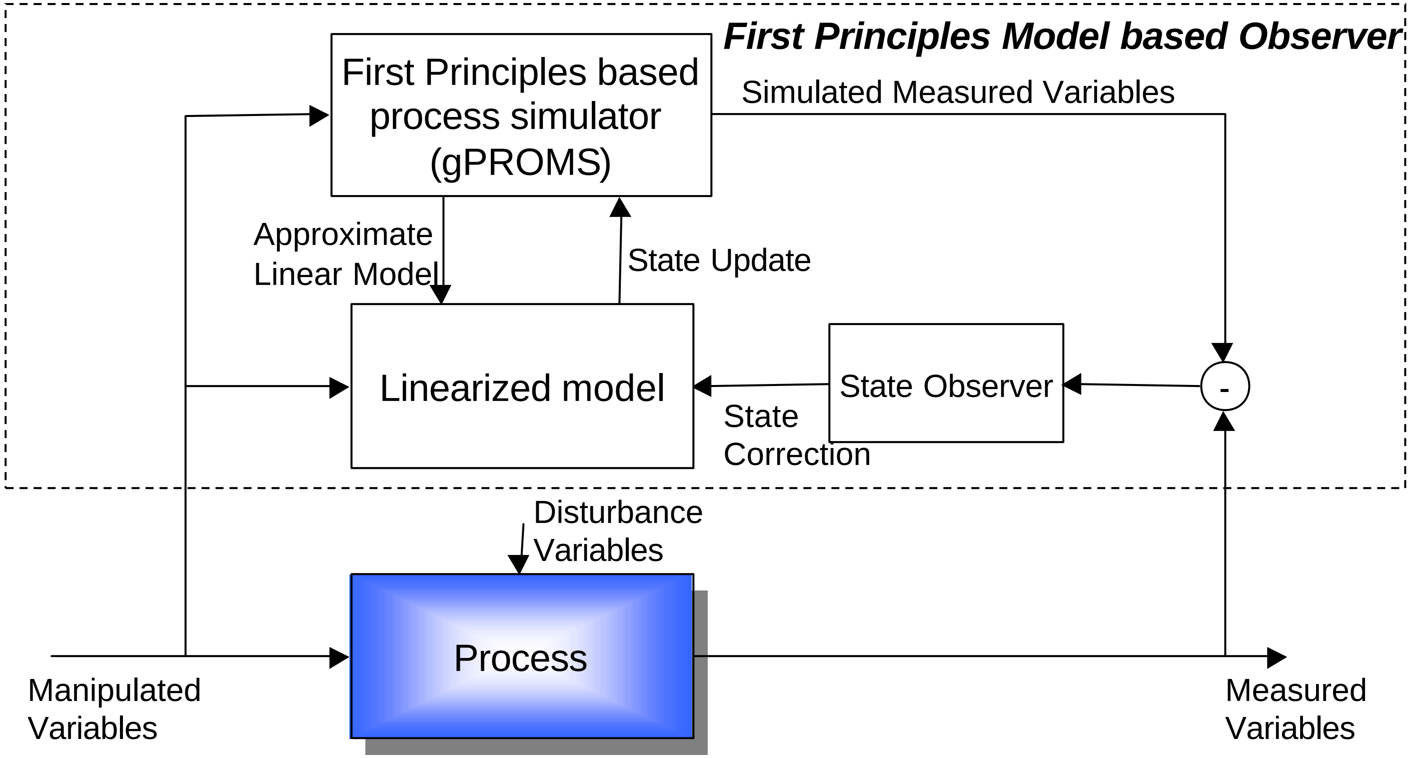


Trajectory following in delta mode

INCOOP Reference Architecture



Use of state-estimation techniques to closely align process simulator and process to enable its use for soft sensoring and MPC



Some highlights of results obtained

Overview of specific project achievements in each of the workpackages

- INCOOP architecture
  - Early in the project an INCOOP reference architecture has been designed
    - Easy exchange of (intermediate) results between groups
    - Smooth integration of new developed technologies over the whole range
    - Quick prototyping and easy connection to existing instrumentation in production environment
    - Extensive use of commercial toolsets to minimize dedicated software developments (gPROMS, INCA, Matlab, DCS systems, …)
- Modelling and model reduction
  - Detailed insight has been obtained in the requirements for modelling for control and optimization
  - Mathematical model reduction techniques enable significant reduction in model complexity
  - Realized reduction in computing time is (too) limited

Some highlights of results obtained

Overview of specific project achievements in each of the workpackages

- Dynamic data reconciliation/state observer achievements
  - Solid technology has been developed for state estimation of the first principles simulation model
  - Accurate tracking of actual process behavior by the model
  - Technology enables use of the simulation model as soft sensor for observable, but not directly measured process states
- Dynamic optimization techniques highlights
  - Plant wide optimization of dynamic behavior of the plant resulting in optimum trajectories for critical process variables (MV's, CV's)
  - Enables high performance non-linear model predictive control of poorly conditioned processes (stiff systems)

Some highlights of results obtained

Overview of specific project achievements in each of the workpackages

- Non-linear high performance MPC results
  - Wide bandwidth control by enabling large prediction/control horizon
    - Control of processes with large range of process dynamics
  - Close tracking of optimum trajectories (e.g. transitions, recovery of process upsets)

- Prototype software developments
  - Software developments that enable detailed testing of newly developed techniques
  - Implementation in INCOOP reference architecture enabling integration of all developed technologies
  - Due to reference architecture application also suited for industrial field testing

Some highlights of results obtained

Overview of specific project achievements in each of the workpackages

- Environment setup that enabled easy exchange of results amongst partners
  - Smooth interconnection of different software tools (gPROMS, Matlab, INCA, …)
  - Software prototypes can be applied for industrial field tests
- First Field Test results
  - Confirmation of the results obtained from simulations

Expected impact of the INCOOP project

Overview of intended technology developments towards commercially available products and supporting services

- Intended follow-up developments by suppliers
  - The INCOOP project has resulted in solid technologies for
    - Model reduction
    - State estimation, dynamic data reconciliation
    - High performance non-linear MPC
    - Dynamic optimization
  - These technologies will be further developed and integrated into available commercial software toolsets
- Intended applications at end-users
  - Industrial application of the newly developed technologies is discussed between industrial partners and suppliers