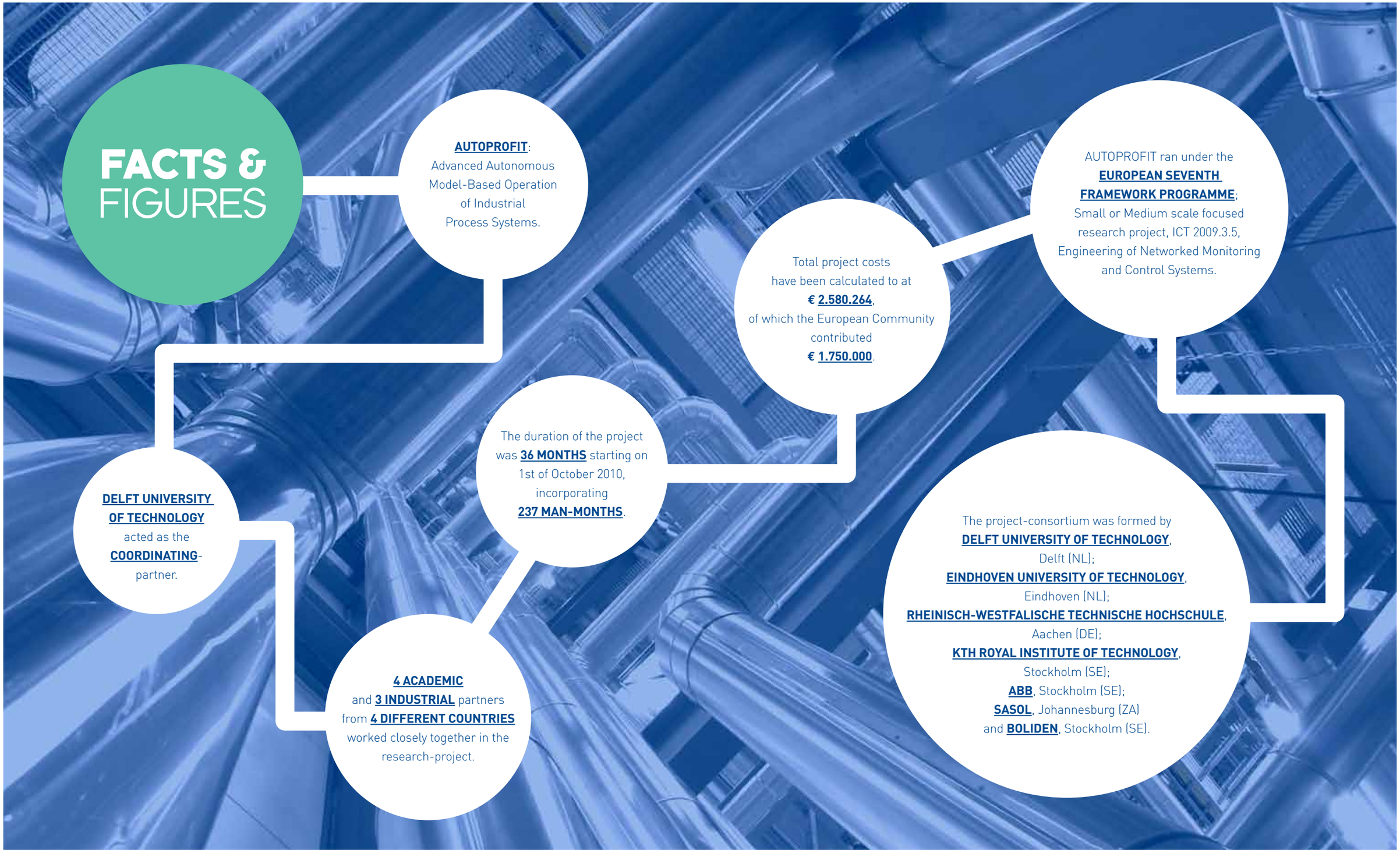
AUTOPROFIT

ADVANCED AUTONOMOUS MODEL-BASED
OPERATION OF INDUSTRIAL PROCESS SYSTEMS


FACTS &
FIGURES
AUTOPROFIT:
Advanced Autonomous
Model-Based Operation
of Industrial
Process Systems.
AUTOPROFIT ran under the
EUROPEAN SEVENTH
FRAMEWORK PROGRAMME;
Small or Medium scale focused
research project, ICT 2009.3.5,
Engineering of Networked Monitoring
and Control Systems.
Total project costs
have been calculated to at
€ 2.580.264,
of which the European Community
contributed
€ 1.750.000.
The duration of the project
was 36 MONTHS starting on
1st of October 2010,
incorporating
237 MAN-MONTHS.
DELFT UNIVERSITY
OF TECHNOLOGY
acted as the
COORDINATING-
partner.
4 ACADEMIC
and 3 INDUSTRIAL partners
from 4 DIFFERENT COUNTRIES
worked closely together in the
research-project.
The project-consortium was formed by
DELFT UNIVERSITY OF TECHNOLOGY,
Delft (NL);
EINDHOVEN UNIVERSITY OF TECHNOLOGY,
Eindhoven (NL);
RHEINISCH-WESTFALISCHE TECHNISCHE HOCHSCHULE,
Aachen (DE);
KTH ROYAL INSTITUTE OF TECHNOLOGY,
Stockholm (SE);
ABB, Stockholm (SE);
SASOL, Johannesburg (ZA)
and BOLIDEN, Stockholm (SE).

MOTIVATION & PHILOSOPHY

THE EUROPEAN PROCESS-INDUSTRY FACES MASSIVE CHALLENGES. JUST-IN-TIME PRODUCTION OF CUSTOMER SPECIFIED PRODUCTS IS A PREREQUISITE TO SURVIVAL IN A GLOBAL DEMAND DRIVEN MARKET. PRODUCT QUALITY, PRICING AND DELIVERY TIME PUT CONTINUOUS PRESSURE ON THE IMPROVEMENT OF PRODUCTION PROCESSES. FURTHERMORE, ENVIRONMENTAL REGULATIONS AND SCARCITY OF RAW MATERIALS ARE FORCING INDUSTRY TO TRANSFORM TO MORE SUSTAINABLE PRODUCTION METHODS. WASTE OF BASIC MATERIAL, ENERGY-LOSS AND CO2 EMISSIONS NEED TO BE MINIMIZED.

Model-based control and optimization systems such as Model Predictive Control (MPC) and Real-Time Optimization (RTO) are now commonly used in process industry to optimize both the production process and the economic performance. Although these technologies offer substantial benefits on ensuring operational conditions and fulfilling product specifications, costs of deployment and maintenance are also significant.

AUTOPROFIT gains important reductions of these maintenance costs. It brings a high level of autonomy to these operation support technologies, hence minimizing human intervention.

AUTOPROFIT uses a three-step philosophy in its next-generation support strategy:

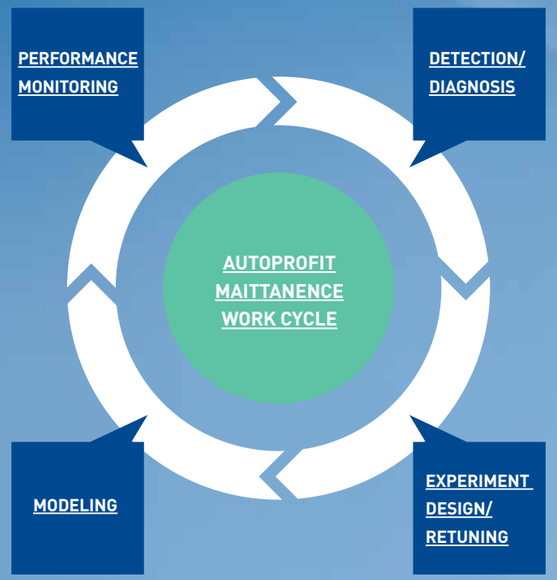
1. Decreasing modeling costs.
2. Automating just-in-time maintenance of the models and the model-based application (MPC, RTO).
3. Using economic criteria for detecting and diagnosing in the automated maintenance.

AUTOPROFIT is a three year European research project. Four academic and three industrial partners, known for their expertise on model based technology, are working together in the development of 'advanced autonomous model-based operation of industrial process systems'. The project is co-funded by the European FP7 program.

APPROACH

THE ULTIMATE GOAL OF THE AUTOPROFIT-PROJECT IS AUTONOMOUS MAINTENANCE OF PRODUCTION PROCESSES. TO ACHIEVE THIS AUTONOMY, MEANING MINIMIZATION OF HUMAN INTERVENTION BY INCREASING THE ACCURACY OF MODEL BASED CONTROLLERS, THE PROJECT FOCUSSES ON TECHNOLOGY DEVELOPMENT IN MAIN ASPECTS OF SYSTEMS AND CONTROL.

The basic principle lies in the continuous monitoring of key-indicators for economic performance. This economic performance can fluctuate under influence of changes in material costs or quality, energy prices or losses due to the violation of constraints.
The functioning of model-based control and operation systems declines over time. In case a significant performance drop is detected, an instant action from the operation system is desired.
Least costly experiment design is used to diagnose the actual cause of the economic malperformance with minimal impact on resources. The algorithm examines process variables without production-loss.
Subsequently, the most economically effective way to recover the system performance is determined. Hence, identification of a new model in closed loop or retuning of the controller is inevitable.
At this moment linear, time-invariant models are the standard in model based control systems. AUTOPROFIT aims at the development of new linear models in closed loop. A future goal is the development of a model structure that can have both static as dynamic behavior, enabling smooth transitions between linear and nonlinear dynamics.
AUTOPROFIT uses a selection of weighting matrices for controller auto-tuning, focusing on a good balance between system robustness and performance.



THE AUTOPROFIT EXPERIENCE: **INSIDE PERSPECTIVES**

"AN EXCITING THEORETICAL AND EXPERIMENTAL ADVENTURE."
Max Potters, MSc., Delft University of Technology

"REACHING NEW FRONTIERS THROUGH APC AUTOMATION."
Hernan Guidi, Sasol Synfuels

"MANY FRUITFUL DISCUSSIONS WITH PARTNERS."
Dr. Pelle Moden, ABB

"AUTOPROFIT IS A GOOD EXAMPLE OF PERFECT ACADEMIA-INDUSTRY COLLABORATION."
Dr. Leyla Ozkan, Eindhoven University of Technology

"CHALLENGES ARE THE MILESTONES ON THE ROAD LEADING TO THE BREAKTHROUGH"
Dr. Roland Toth, Eindhoven University of technology

"AUTOPROFIT HAS BROUGHT OUR LEAST COSTLY FRAMEWORK A STEP FORWARD TO MATURITY'.'
Dr. Xavier Bombois, Delft University of Technology

"WE'VE NEVER WORKED SO CLOSELY TOGETHER WITH INDUSTRY."
Prof. Dr. Hakån Hjalmarsson,
Sweden Royal Institute of Technology

"A PRICELESS EXPERIENCE AND A WONDERFUL TIME WORKING WITH THE ACADEMIC AND INDUSTRIAL PARTNERS AROUND THE WORLD."
Quang Tran, Eindhoven University of Technology

"AUTOPROFIT INCREASES THE CONFIDENCE TO IMPLEMENT ADVANCE CONTROL STRATEGIES IN REAL APPLICATIONS."
Dieogo Munoz, RWTH Aachen University

"AUTOPROFIT PROVIDES EVIDENCE THAT REAL INDUSTRIAL PROBLEMS CAN TRIGGER REWARDING FUNDAMENTAL METHODOLOGICAL RESEARCH".
Prof. Dr-Ing. Wolfgang Marquardt, RWTH Aachen University

"A CHALLENGING AND REWARDING PROJECT, MAKING ME CONSIDER THE BROADER PICTURE AND THE CONSTRAINTS OF A REAL WORLD SITUATION."
Mariette Annergren,
Sweden Royal Institute of Technology

"A UNIQUE OPPORTUNITY TO DEVELOP INDUSTRIALLY HIGHLY RELEVANT TOOLS AT THE FOREFRONT OF RESEARCH IN COLLABORATION WITH ACADEMIC AND INDUSTRIAL PARTNERS."
Christian Larsson, MSc.,
Sweden Royal Institute of Technology

"A VALUABLE EXPERIENCE; A CLOSER BOND TO THE ONGOING ACADEMIC RESEARCH. AND ADDITIONAL INSIGHT INTO HOW MPC MAINTENANCE CAN BE SIMPLIFIED USING NOVEL ALGORITHMS."
Johan Boström, Boliden Mines

"EXCITING, TO ADVANCE THE STATE OF THE ART IN PROCESS OPERATIONS WITH A CLEAR ECONOMIC GOAL IN MIND, WITH AN INTERNATIONAL TEAM OF ENTHUSIASTIC YOUNG PEOPLE"
Prof. Dr. Ir. Paul Van den Hof,
Eindhoven University of technology

"RESEARCHING INDUSTRIALLY RELEVANT PROBLEMS WITH INTERDISCIPLINARY VISION AND COMMUNICATION SKILLS, IN COLLABORATION WITH EXPERTS ACROSS VARIOUS FIELDS."
Dr. Ir. Ali Mesbah, Delft University of Technology

"AUTOPROFIT HAS SHOWN HOW THE INDUSTRIAL RESEARCH CAN BENEFIT FROM THE ACADEMIC RESEARCH, AND HOW THE ACADEMIC RESEARCH CAN BE STIMULATED BY THE INDUSTRIAL RESEARCH."
Dr. Dario Piga, Eindhoven University of technology

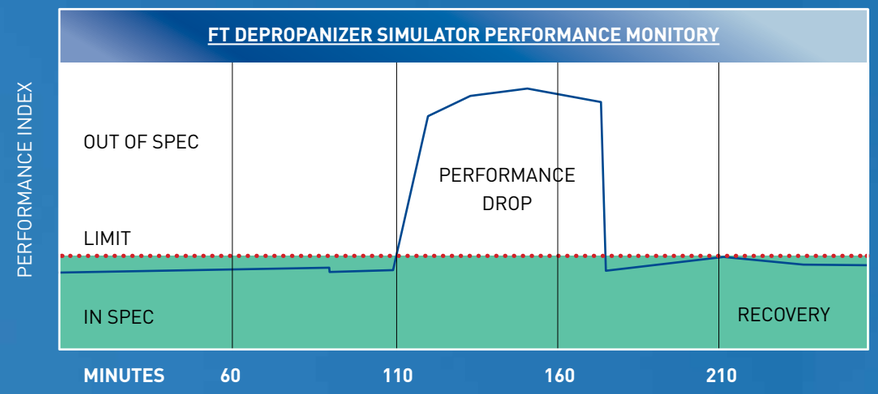
"LIMITATIONS OF STATE OF THE ART TECHNOLOGY ENCOUNTERED IN INDUSTRIAL PRACTICE CAN RESULT IN CHALLENGING ACADEMIC RESEARCH WITH A HIGH INDUSTRIAL RELEVANCE."
Dr. Jobert Ludlage,
Delft University of Technology

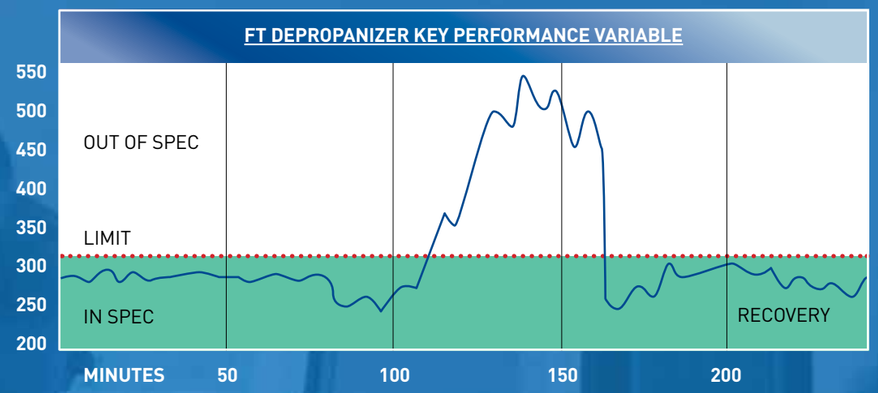
RESULTS

THE AUTOPROFIT PROJECT HAS ALREADY LEAD TO PROMISING RESULTS IN THE PRE-FIELD DEVELOPMENT PHASE. CLOSE-COOPERATED RESEARCH BETWEEN THE ACADEMIC AND INDUSTRIAL PARTNERS HAS RESULTED IN THE FOLLOWING OUTCOMES:

OVERALL

- The technology is done; the fundamentals are ready for testing in real, commercial situations.
- The economic performance criteria are identified and are ready to be used in test signal design, performance-monitoring and diagnosis.
- Novel model calibration and adaptation techniques are developed.
- The basic principles for nonlinear modeling (LPV) are ready for implementation.
- Least costly test signal design in closed loop has been developed. This fundamental technique balances the test duration and impact on process operation against the accuracy of the new model.
- The model based control application has evolved for automated (re)tuning.
- A practical tool which integrates all of the technological developments into a single software package has been developed with an intuitive graphical user interface. GUI allows the tool to be used by the wider process control community.





IMPLEMENTATION CASES

TO ASSURE A SUCCESSFUL TRANSFER FROM STUDY TO OPERATION, AUTOPROFIT HAS IMPLEMENTED ITS RESEARCH RESULTS ON A REPRESENTATIVE CHEMICAL PROCESS.

The plots above represent the implementation of the **AUTOPROFIT** maintenance work cycle on a depropanizer operator training simulator.
The first plot shows the calculated performance index. At time t≈100 min, an increase is diagnosed in the performance index. This is a clear indication of performance degradation; the key performance variable (KPV) starts exceeding the upper quality limit.
The performance diagnosis resulted in the identification of a new model in closed loop. Once the new model was identified and used in the model based control, the performance is recovered and the KPV returned to an acceptable value.

FUTURE PERSPECTIVES

IN THE IDEAL SITUATION, THE EUROPEAN PROCESS-INDUSTRY OPERATES IN FULL AUTONOMOUS CONTROL. HUMAN INTERACTION HAS BEEN ELIMINATED. THE PROCESS CONTROL IS REALIZED BY THE SO CALLED 'SMART INTELLIGENT MODEL-BASED CONTROLLERS'.

To arrive to this ideal situation, in the context of the **AUTOPROFIT** research project, the technology needs to be extended to non-linear model based control. Fundamental research in this direction is elementary.
It would, besides, be interesting to adapt and implement the **AUTOPROFIT**-technology to different types of industrial processes.

AUTOPROFIT PARTNERS

DELFT UNIVERSITY OF TECHNOLOGY, CENTER FOR SYSTEMS AND CONTROL
Delft Center for Systems and Control (DCSC) coordinates the education and research activities in systems and control at the Delft University of Technology. DCSC has been established in 2003 by merging the systems and control groups of Electrical Engineering (EWI), Mechanical Engineering (3mE), and Applied Physics (TNW).

EINDHOVEN UNIVERSITY OF TECHNOLOGY, DEPARTMENT OF ELECTRICAL ENGINEERING, CONTROL SYSTEMS
The control systems group aims to carry out fundamental and application oriented research that enables novel technological developments in a wide variety of application domains including electrical engineering. Our vision is to apply and develop techniques for the automated control and optimization of dynamical systems so as to influence their behavior towards desired specifications of performance, safety, efficiency, product quality and environmental conditions.

RHEINISCH-WESTFALISCHE TECHNISCHE HOCHSCHULE AACHEN, AVT, (AACHEN CHEMICAL ENGINEERING DEPARTMENT), PROCESS SYSTEM ENGINEERING GROUP
The research group has been founded in November 1992 as a result of a joint initiative of RWTH Aachen and Bayer AG, Leverkusen and is being directed by Prof. Dr.-Ing. Wolfgang Marquardt. The research covers different topics of process systems engineering which link chemical engineering with computational engineering science. It is focused on the development of basic principles of mathematical modelling, the combination of experiments and modelling, conceptual process design, process operations and control as well as the development of numerical algorithms and software-tools.

KTH ROYAL INSTITUTE OF TECHNOLOGY, THE SCHOOL OF ELECTRICAL ENGINEERING, AUTOMATIC CONTROL LAB. STOCKHOLM
The School of Electrical Engineering at KTH carry out research and education in fundamental areas of information and communication technology, including automatic control, signal processing and wireless communication. The Automatic Control Lab consists of about thirty researchers, including PhD students, and five professors. Major research areas include networked control, control and optimisation of communication systems, hybrid control systems, autonomous control and system identification. The Lab has long tradition in collaborating with internationally leading industry (e.g., ABB, Bombardier, Ericsson, Scania) and academia (e.g.,UC Berkeley, Caltech, Stanford, ETH Zurich, SICS, INRIA).

ABB PROCESS AUTOMATION, STOCKHOLM
The main focus of the ABB-Process Automation division is to provide customers with products and solutions for instrumentation, automation and optimization of industrial processes. The industries served include oil and gas, power, chemicals and pharmaceuticals, pulp and paper, metals and minerals, marine and turbocharging. Key customer benefits include improved asset productivity and energy savings.

SASOL
Sasol is an integrated energy and chemical company based in Johanneburg, South Africa. The company was formed in 1950 in Sasolburg, South Africa. Sasol develops and commercializes technologies, including synthetic fuels technologies, and produces different liquid fuels, chemicals and electricity.

BOLIDEN
Boliden is a metals company with focus on sustainable development. The roots are Nordic, but the business is global. The company's core competence is within the fields of exploration, mining, smelting and metals recycling. Zinc-, copper-, lead-, gold- and silver-bearing ores are mined in Boliden's four mining areas. The ore is processed to produce metal concentrate, the majority of which is delivered to smelters within the Group. Boliden's five smelters refine metal concentrates and other raw materials.

Autoprofit

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