

MODEL^{CAT} - A MODEL CATALOGUE BASED APPROACH TO PROCESS MODELLING

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Abstract: The paper describes a new approach to generate plant models automatically at the end of the plant engineering process using a simulation model catalogue. Such a model can be used to test the functionality of the plant by simulation before it is built and to simulate and optimise the integrated control functions using Computer Aided Control System Design (CACSD) tools. To demonstrate the feasibility of the proposed approach, the prototype software module Model^{cat} (industrial **Model Catalogue**) was realised. Model^{cat} is based on the plant CAE system Comos PT and makes use of the simulation tools Matlab/Simulink and gProms. *Copyright © 2005 IFAC*

Keywords: Process models, chemical industry, computer aided engineering, simulation, computer aided control system design.

1 INTRODUCTION

The ICACSD (industrial **CACSD**) concept as introduced at the 1996 IFAC Congress in San Francisco by Schumann, et al. (1996) was defined to allow the application of advanced CACSD methods by industrial area engineers with a standard, but limited control education who are not necessarily experts in simulation or control. The design of complex nonlinear MIMO control systems based on PID controllers should be made possible for such non-expert users by careful preselection of appropriate CACSD methods and by hiding typical handling problems (like excessive parameterisation) behind a smart user interface. The ICACSD concept was realised with a number of software tools for process modelling and control design, Figure 1.

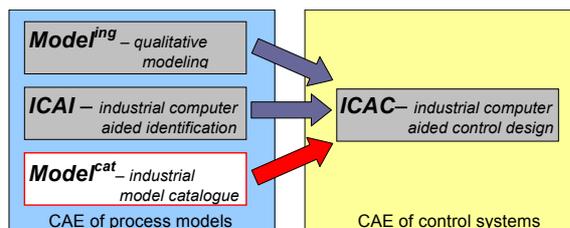


Fig. 1. ICACSD modules

The tools on the left of Figure 1 concentrate on the generation of process models, from which the control system may be designed, whereas the ICAC (Indus-

trial Computer Aided Control design) toolbox on the right provides the means for control system design. The Model^{ing} toolbox was introduced by Strickrodt et al. (1996) to make qualitative modelling possible by transforming process knowledge from area engineers into models without requiring the assistance of a knowledgeable modelling expert or engineer. The ICAI (Industrial Computer Aided Identification) toolbox allows the identification of linear and nonlinear SISO and MIMO process models from process measurements making use of a smart user interface which can adapt to different user levels characterised by different user knowledge and associated degrees of design freedom: the non-expert process personnel level, the area engineer level and the control expert level, see (Körner et al., 1997; Syska et al., 1999). The complementary ICAC toolbox makes use of the same user interface levels and realises the generation of PID based linear and nonlinear SISO and MIMO control systems using state space and numerical optimisation methods, see (Syska, 2002).

In this paper the concept for the third modelling module, Model^{cat} (industrial **Model Catalogue**) will be presented. First, the motivation and background for the design of this module, which is based on the plant engineering process, will be outlined. Then, the general structure of the Model^{cat} prototype will be presented, followed by a typical application example to illustrate how Model^{cat} is able to simplify the generation and simulation of plant models for the plan-

ning engineer and how it is possible by this approach to make use of CACSD toolboxes to simulate and optimise control systems for the plant models generated. Finally, the actual realisation status of Model^{cat} is discussed and future developments and implementation steps are outlined.

2 MOTIVATION AND BACKGROUND

The design of the Model^{cat} module was motivated by specific requirements for the design of control systems during plant engineering where the planning of control functions is in general done separately from and often after completion of chemical process engineering design. The functionality of the control systems is tested only locally during engineering design and often superficially, e.g. with respect to correct wiring. In general, the first realistic function tests of the controlled plant are done during the plant start-up phase after the plant has been built. This means that the majority of design and specification faults becomes evident and must be corrected during the start-up phase causing, in many cases, enormous costs and time delays and putting at risk the financial success of the project. Up to 20% of the overall plant engineering costs are spent in correcting design and specification faults during the start-up phase, see e.g. (Weber, 2002). This could only be avoided if realistic functional testing of the plant including its control system could be done before the plant was built – i.e. by simulation, for which a simulated plant model must be available and connected to the associated simulated control system. To date, such a simulation is only created in a few cases where the enormous additional costs of establishing the simulation models are justifiable. Typically this is the case for hazardous plants, to prove safe operation, or for training simulators, see e.g. (Bayer, 2003) or (Seybold, 2000).

In this context the question if and how ICACSD toolboxes could help to improve the situation arises. In Figure 2 the possible use of the ICACSD toolboxes is illustrated along with the typical plant engineering phases: Model^{ing} (in combination with ICAC or any other appropriate CACSD toolbox) can already be used in early phases, as models are constructed from the available knowledge of area engineers and process operators; ICAI (together with

ICAC) can only be used if measurements from the real process are available, i.e. at earliest during the start-up phase, but cannot help to correct problems before the plant has been built. This is where the Model^{cat} tool comes in, proposing a new concept to set-up a realistic simulation of the controlled plant at the end of plant engineering design almost automatically - this means with low cost, as no modelling and simulation experts should, in principal, be required. The Model^{cat} concept proposes the integration of a process simulation and a control simulation tool with a plant CAE system as used today for the plant engineering process, and is based on the assumption that simulation models of those process and control system components from which the plant is to be built in reality, are or will become available from the component suppliers. In electrical engineering (e.g. PCB design) this is already standard where simulation models of chips are often available before the silicon is deliverable. Remark: A brief literature review on alternative concepts to computer supported process modelling for the chemical process domain is given in Hoyer et al. (2005a), however, all approaches found so far require modelling and simulation expertise not usually available to planning engineers.

3 STRUCTURE OF THE MODEL^{CAT} MODULE

Currently the plant engineering process is supported by plant CAE systems which provide a component library for all technical data of available plant components (from which the plant may be built). The plant CAE systems also store all planning information regarding selection, connection and specification of plant components in a project database. A typical example for such a plant CAE system is Comos PT with an object oriented engineering database (Innotec, 2004). After completion of plant engineering, i.e. at the end of the detailed engineering phase, see Figure 2, complete technical information required to procure and install all plant components and to build the plant and its control system has been collected in the project database. The general idea behind the Model^{cat} module is to store for every plant component not only general technical data but also a simulation model. Thus, at the end of plant engineering the project database of the plant CAE system would not only hold all the technical information for building the

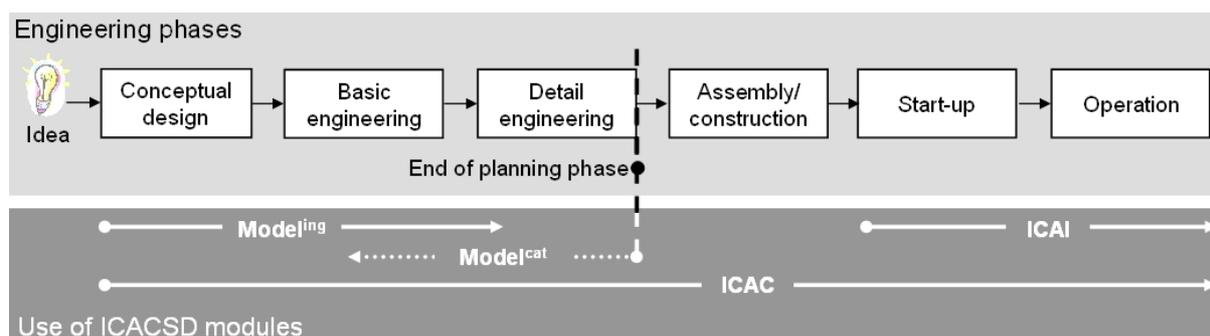


Fig. 2. Use of the ICACSD modules during the plant engineering process

plant, but also simulation models for every component used along with the interconnection information between these models. In principal a simulation model of the plant including its control system could be aggregated from the model information collected. In order to practically realise this idea, the Model^{cat} module was designed, see Figure 3. Model^{cat} is based on the plant CAE system Comos PT with its engineering database to provide and store the component information, and uses Matlab/Simulink for the simulation of control schemes and gProms for the simulation of the chemical process. Comos PT was chosen as it provides an object oriented database which allows easy integration of extra process component information (here: simulation model). The simulation environment was composed from Matlab/Simulink, as de-facto standard for control system simulation and from gProms as specialised tool for the dynamic simulation of chemical processes. These simulation tools can be combined via a standard interface mechanism to make best use of their individual simulation attributes in the control system and process simulation domains, see (PSE, 2003).

For the interaction between Comos PT and the simulation tools a special interface module was designed, the model aggregation module (MAM), which retrieves the component model information from Comos PT for a specified plant area and automatically aggregates the process and control simulation models for the simulators, see Figure 3.

In addition, a smart graphical user interface has been specified to allow non-expert users (like planning or commissioning engineers) to perform simulations of plant models with a minimum of extra specifications and to analyse the behaviour of process and control functions without the support of simulation or modelling experts.

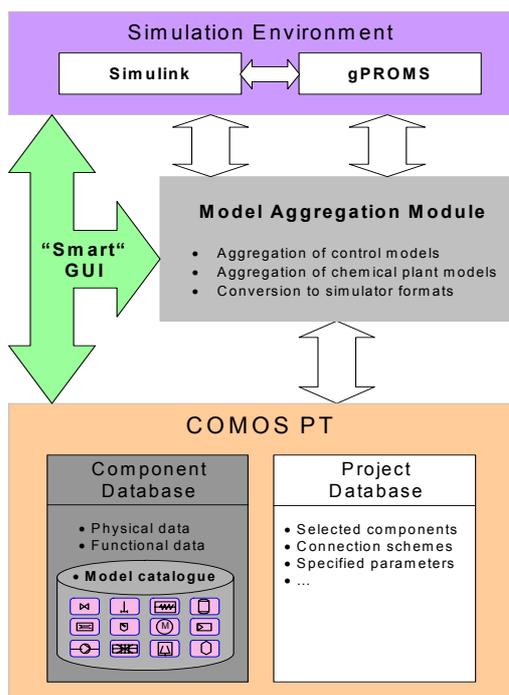


Fig. 3. Structure of Model^{cat}

4 MODEL^{CAT} PROTOTYPE REALISATION

4.1 Simulation model catalogue

For the organisation of the simulation model catalogue it makes sense to clearly separate chemical process components from control system components from the very beginning. This is because control functions are specified by control schemes, simulated by Matlab/Simulink and realised in process control systems, while chemical process elements are specified by means of templates and graphical representations such as P&I diagrams, simulated by gProms and realised in process components and pipework. Sensors and actuators represent the natural interface between the process and control domains, as illustrated in Figure 4, where the physical specifications of such components (valve diameters etc.) are used for their integration into the physically real chemical plant and where their electrical or information interfaces represent sources and sinks in the control system schemes.

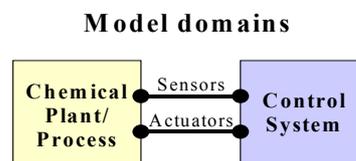


Fig. 4. Model domain separation between (chemical) process and control models

The separation of chemical process and control models is a prerequisite for the separated simulations which use gProms for the chemical process and Matlab/Simulink for the control domain. From the control engineering point of view, gProms emulates the chemical process as basis for the control system design and optimisation, whereas from the process engineering point of view, Matlab/Simulink emulates the control system which acts upon the process model simulation in gProms, thus allowing an inte-

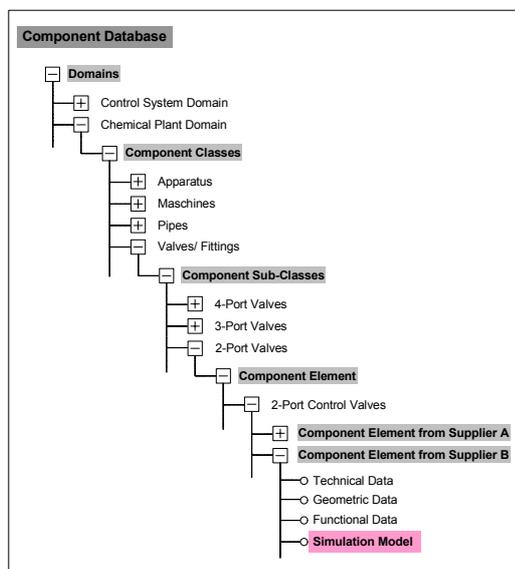


Fig. 5. Component database hierarchy

grated test of both domains. Consequently the storage of process models in Comos PT is done in gProms format and the storage of control system models in Matlab/Simulink format. To allow the generation of simulation models at the end of detailed engineering a prototype version of the component simulation model catalogue with a limited range of process and control components was added to the Comos PT database. The component database hierarchy is shown in Figure 5: The component simulation models are stored in Comos PT as additional attributes of plant components in a simulator specific format.

4.2 Model aggregation module (MAM)

After completion of plant engineering, the planning engineer may specify the plant area to be simulated in the P&I diagram. The task of the model aggregation module (MAM) is to analyse the P&I diagram (and its associated function charts) with respect to the selected components and their interactions and to retrieve all component model information from the Comos PT project database, which is shown in Figure 6. From this information, the model aggregation module aggregates the process domain simulation model into gProms format and the control domain simulation model into a Matlab/Simulink format and generates the MATLAB simulation script. This contains both, the control scheme with standard blocks and an integrated special gProms block with the gProms process simulation script, such that gProms serves as simulation engine for the process model part through a standard interface.

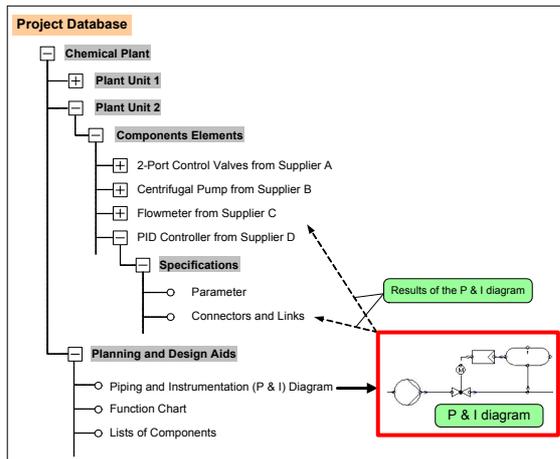


Fig. 6. Project database hierarchy

After specification of the required simulation parameters, Matlab/Simulink is started and provided with the previously generated simulation script. The simulation results are generated and presented to the user in the context of the P&I diagram. The prototype model aggregation module was realised in MS Visual Basic as an add-on module to Comos PT. For more details see Hoyer et al. (2005a).

4.3 Smart graphical user interface

The smart GUI was defined to simplify the use of the complex simulation environment such that typical planning or commissioning engineers familiar with the plant CAE system would be able to select the plant area to be simulated. They would also specify the necessary simulation parameters, start the simulation and read the simulation results from an intuitive presentation. Ideally, the complex simulation environment should be hidden behind the P&I diagram from which the simulation is started. All simulation results should be presented directly in the context of this P&I diagram allowing easy interpretation of results. A general procedure for the simulation of a part of the chemical plant is the definition of boundary conditions and simulation parameters which must be specified to allow the required simulation – and these specifications may cause problems for a non-expert user if they are not supported sufficiently. At the present stage of prototype development only an essentialised version of the user interface is provided, which allows the selection of the plant area to be simulated in the P&I diagram, the specification of simulation parameters, (in general by simple dialogue windows but not with the required non-expert support) and the automatic start-up of Matlab/Simulink with no special additional user interface. This means that the basic feasibility of the Model^{cat} approach can be demonstrated and tested with the actual prototype realisation of the GUI, but not yet the full support for non-expert users.

5 ILLUSTRATIVE EXAMPLE

The functionality of the realised Model^{cat} prototype outlined above is illustrated using an example from a fresh cheese production line, (Hoyer et al., 2005b). The P&I diagram in Figure 7 is the result of the plant planning procedure in Comos PT. The (red) dashed boundary marks the selected components of the production line. The process part contains (besides some pipework) the separator with input stream “curd”, output streams “sour whey” and “fresh cheese”, control valve and the physical elements of the sensors for curd flow and dry matter content. The control system part includes the flow control loop FC 005 for the curd flow to the separator and the cascaded dry matter control loop QC 001. During detailed engineering of the fresh cheese production line using Comos PT, the component objects were arranged and specified in the P & I diagram and the corresponding object tree also shown in Figure 7. In the project database all necessary component information is available including the component models from the simulation model catalogue. After graphical selection of the plant parts to be simulated (dashed lines) the simulation parameters have to be specified in a dialogue window (here boundary conditions for input and output streams, set points for flow control loop, etc.). Then the separation and aggregation of the required simulation models for

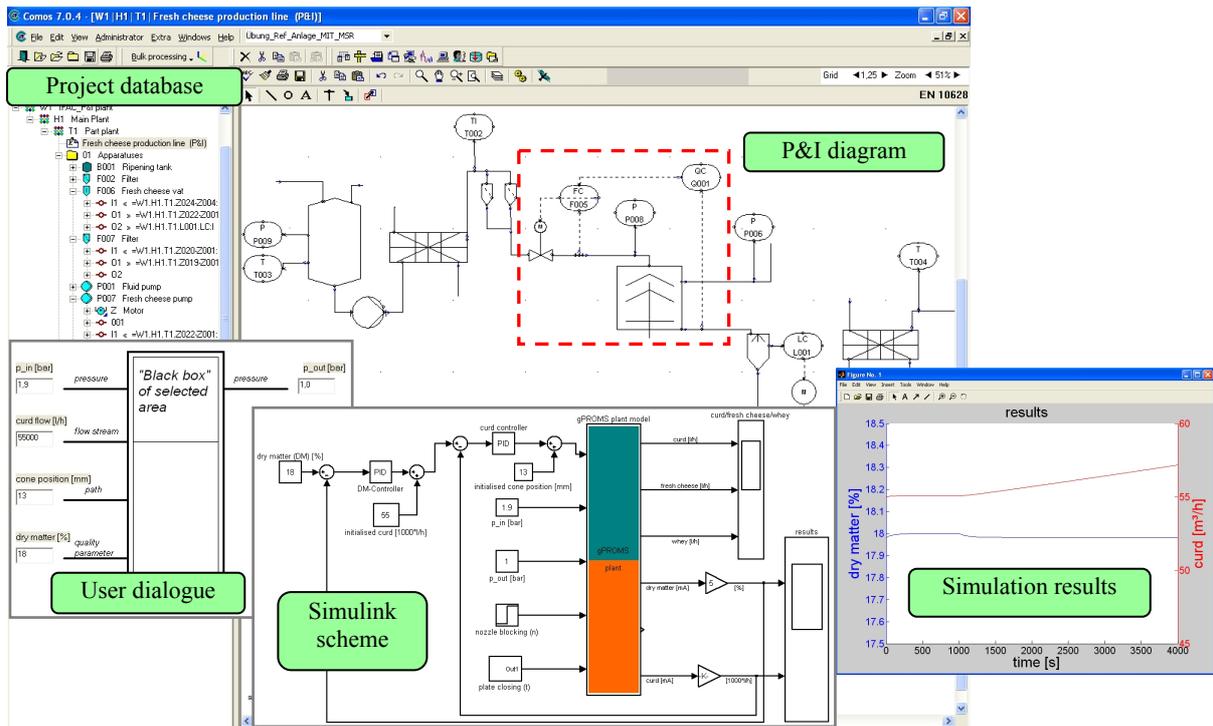


Fig. 7. Example: Flow control system in Comos PT (project database, P&I-diagram, user dialogue) and Simulink with gProms block

gProms (process part) and Simulink (control part) is automatically started by the model aggregation module: The separation is done along the sensor and actor components (here the flow sensor and the control valve). The generated Simulink scheme (control part) contains the controllers in the cascaded control system for dry matter and curd flow and the gProms process model block. The gProms block includes the dynamic properties of the sensors and the control valve (with its internal positioning controller), the separator and the pipe works. The simulation script as generated by the MAM is automatically fed to Matlab/Simulink and the simulation must then be started by the user. The simulation results are presented to the user in Simulink format, see Figure 7, showing here typical sample signals from the cascaded control system for dry matter and curd flow. The example shows that having specified disc fouling in the separator at time > 1000s, the dry matter controller keeps the dry matter value at about 18% by increasing the curd flow.

6 INTEGRATION OF MODEL^{CAT} INTO THE CACSD ENVIRONMENTS

The Model^{cat} module was conceived to almost automatically provide simulation models for process and control system components at the end of plant engineering. These models are simulated in the Matlab/Simulink environment including the process model realised as gProms block. This set-up allows direct use of all Matlab based CACSD tools to analyse the simulated plant behaviour and to tune and optimise the control system. In the ICACSD frame-

work, the ICAI toolbox may be used to identify linear and nonlinear SISO and MIMO plant models for the gProms process simulation block, the control system design may be correspondingly supported by the ICAC toolbox. One of the advantages of the Model^{cat} approach is the direct availability of a process simulation model in gProms format where the simulated behaviour reflects the behaviour of the real world process components, (provided the components are realistically modelled). Thus the Model^{cat} approach could open the way towards a broad application of CACSD modules for the realistic optimisation of real industrial plants in addition to the general ability to detect planning errors by simulation.

7 FUTURE TASKS

The actual prototype realisation of the Model^{cat} module has demonstrated the feasibility of the concept. However, several tasks (see below) need to be accomplished in future to make this approach generally applicable.

7.1 Extension of simulation model catalogue

In its current state the simulation model catalogue comprises only some exemplary component models. It is not realistic to expect that a few institutions could, on their own, be able to provide models of most of the available plant components in the process industry. The electronics industry has shown an alternative approach which may also work in the chemical process domain: simulation models of de-

liverable plant components could be made available by the component suppliers along with the standard technical data. Although these models may be rather simple in the first instance, continuous refinement would improve the quality (and complexity) of models through the years as has been the case in the electronics industry. To trigger the collection of component models from their suppliers, a systematic collection process could be organised by creating software tools for the collection of simulation models, providing generic models for component classes (which only have to be parameterised by the component supplier to reflect the behaviour of the real component) and proposing/introducing general model description formats. Furthermore, the advantages of simulation support for the plant engineering process should be communicated widely to build up support from component users by asking for component models from their suppliers. It is believed that the commercial pressures will stimulate rapid adoption if consensus on model structures and a critical mass of component models can be achieved.

7.2 Refinement of Model^{cat}

The Model^{cat} prototype will have to be completed to overcome several restrictions evident in its current realisation. The completion of a smart graphical user interface is aimed to allow plant simulation for planning engineers as non-expert users by minimising the required user inputs and further automating the model aggregation and simulation process. The number of component models which can be aggregated and simulated simultaneously will be increased. The aggregation of the simulation models from possibly a high number of component models may lead to an analytically problematic set-up with respect to the numerical reliability and accuracy of the simulation results. This may be overcome in some cases (depending upon the simulation models and tools used) by complementing model aggregation with an optimising compiler rearranging the simulation code with respect to numerical stability and accuracy.

8 CONCLUSION

The Model^{cat} module as proposed in this paper shows a new path towards the automatic generation of plant simulation models at the end of the plant engineering process (when detailed design would normally be considered to have been completed). Such models can not only be used to test and gain confidence in the planned plant functions by simulation before the system is built thus reducing the cost for physical corrections during the plant commissioning phase but also to test and optimise the designed control systems, (here by using CACSD tools). In order to achieve this, a simulation model catalogue, which may be built up by a systematic collection of simulation models from the component suppliers, is re-

quired. The future will show if the proposed approach can help to improve planning quality and control functionality in the process industry.

ACKNOWLEDGEMENT

This work was supported in part by the Volkswagen foundation, AUBIOS (project ZN-1195) and the British Council and DAAD (Deutscher Akademischer Austauschdienst) through the Anglo-German Academic Research Collaboration Programme ARC, project No. D/03/20266-1216.

REFERENCES

- Bayer (2003). Operator training simulation. <http://www.bayer-technology.com/index2.htm>.
- Hoyer M., R. Schumann and G.C. Premier (2005a). An approach for integrating process and control simulation into the plant engineering process. *ESCAPE conference, Barcelona, 2005*, to be published.
- Hoyer M., R. Schumann, E. Wüst and G.C. Premier (2005b). Feedback control system design for a fresh cheese separator. *16. IFAC World Congress, Prague 2005*, to be published.
- Innotec (2004). Comos PT. <http://www.innotec.de/en/index.php>.
- Körner, S., R. Schumann and K.J. Baker (1997). ICAI - A MATLAB toolbox for industrial computer aided identification. *SYSID '97, Fukuoka*.
- PSE (2003). gO:Simulink: User's guide for gPROMS version 2.2, Vers. 1.1. Process System Enterprise Limited, London. <http://www.psenderprise.com>.
- Schumann, R., S. Körner, K.J. Baker and M. Strickrodt (1996). Shaping CACSD for practical use in the process industry. *13. IFAC World Congress, San Francisco, USA*.
- Seybold, H. J. (2000). Simulation senkt Kosten. *IT & Production, 1*, pp. 14-17.
- Strickrodt, M., Baker, K.J. und R. Schumann (1996). An integrated knowledge engineering approach to process modelling for CACSD. *13. IFAC World Congress, San Francisco, USA*.
- Syska, B., S. Körner and R. Schumann (1999). User-friendly CACSD for complex industrial processes. *14th IFAC World Congress, Beijing*.
- Syska, B. (2002). ICAC – A Matlab toolbox for industrial computer aided control. *15th IFAC World Congress, Barcelona*.
- Weber, K.H. (2002). *Inbetriebnahme verfahrenstechnischer Anlagen – Praxishandbuch mit Checklisten und Beispielen*. Springer-Verlag, Heidelberg.