

## **104b An Integrated Environment for Support of Process Operations**

*Pablo A. Rolandi and Jose A. Romagnoli*

Throughout the 1990s, the computer-aided process engineering (CAPE) community made considerable progress in two strategic areas: the technical development and commercialisation of general-purpose modelling environments, and the standardisation and validation of open interface specifications for component-based modelling and simulation. Not only did these advances motivate the widespread use of rigorous process models to solve conventional process-engineering problems of interest to both the academy and industry, but they also inspired a genuine interest in model-centric technologies.

The potential of model-centric technologies as support systems of industrial manufacturing operations has long been recognised within the CAPE community. However, in order to succeed in their insertion in the industrial environment, model-based software tools must overcome a series of challenges limiting their ability to meet the needs of the Process Industries. First, a series of software components aiming at assisting the definition of hybrid data-driven/model-based problems must be created so that realistic process-engineering problems can be defined and solved. Second, these software components must be integrated seamlessly into a single environment so that points-of-synergy between complementarity model-based technologies can be unravelled and exploited.

In this work we present a software environment for integrated simulation, estimation/reconciliation and optimisation of large-scale/plant-wide industrial process systems based on mechanistic process models. This environment is inspired on a framework that eases the definition of rigorous model-based activities and promotes the transfer of knowledge between complementary model-based software tools.

The framework proposed in this work redefines the architecture for software development and identifies the scope of a novel software tool, the Problem Definition Component (PDC). The PDC manages the definition of advanced hybrid data-driven/model-based problems by a series of mechanisms which entail the manipulation of the so-called Data Model Templates (DMTs) and Data Model Definitions (DMDs). The introduction of these data models redefines the way model-based problems are defined by users of model-centric technologies and it creates a paradigm that brings model-based software tools closer to users in the industrial workplace.

DMTs are language-neutral data models which determine what information of the model's structure is available to the user and how this information can be used at higher levels of the hierarchy to define hybrid data-driven/model-based problems. DMTs corresponding to simulation, optimisation and estimation/reconciliation activities and plant data have already been derived (Rolandi, 2004). DMDs are also language-neutral data structures representing plant data sets and simulation, optimisation and estimation activities. However, on the contrary to DMTs, DMDs represent valid (although not necessarily feasible) model-based activities and associated experimental process data.

DMDs are generated by the user as a series of refinements of the original DMTs according to particularities of the conceptual definition of a given process-engineering problem. This process is regulated by the PDC. Within the proposed software architecture, the modelling and solution engine (MSE) (e.g. gPROMS, EMSO) fulfils the role of model-builder and problem-solver; the PDC, on the other hand, is a problem-builder (a software tool for supporting the definition of model-based problems). Overall, the DMT/DMD mechanism creates an innovative means to capture both in-house knowledge on the process system and expertise on the use of model-centric tools and combine these with experimental process data with the aim to support process operations. DMTs/DMDs also provide increased opportunities for language-neutral documentation and re-use of case-studies that further promote the continuity of corporate memory.

In this work, the environment is tailored to support the operation of the continuous pulping system of a state-of-the-art industrial pulp and paper mill. The results of the several case-studies provide excellent feedback to both the Pulp and Paper and Process Industries.

In the first case-study, the data management and estimation environments of the integrated support system (ISS) are used to define a joint parameter estimation and data reconciliation problem using industrial plant data. The process model is validated as a suitable representation of the process system according to the statistical analysis of results. Concurrently, this case-study demonstrates that parameter estimation of large-scale industrial process systems (such as the continuous cooking digester) is feasible in conditions where the magnitude of certain parametric variables of the mechanistic process model are not known a priori but can be derived from the wealth of information springing continuously from process instrumentation. The economic incentive for accurate inventory analysis and production accounting is also highlighted in this case-study, which illustrates the importance of gross-error detection and estimation and minimises the relevance of the conventional reconciliation of random errors in plant-wide industrial process systems.

In the second case-study, historical operating conditions of the continuous pulping system are explored in a hybrid dynamic simulation activity for extended inferential monitoring and troubleshooting. The data management and simulation environments of the ISS are used to define the corresponding simulation case-study. The results of this mixed data-driven/model-based activity allow the quantification of the extent of pulping reactions within the vessel and subsequent identification of those zones where undesired solubilisation of cellulosic components occurs.

Then, the optimisation environment of the ISS is used to define a case-study for improvement of the nominal operating conditions of the continuous pulping system at a given production level. The improved process conditions results in a better synergy between temperature and cooking profiles, which gives rise to a redistribution of reaction zones. A less intensive use of cooking chemicals and a more effective distribution of the available liquor and filtrate leads to millionaire profit increases.

In the last case-study, the optimisation environment of the ISS is used to determine a transient operating procedure which reduces the variability of quality control indicators of the continuous cooking digester during scheduled transitions. Superior process performance is attained by applying a sequence of non-trivial control moves to a small number of manipulations of the continuous pulping system. These results provide further insight into the optimal transition management of production rate changes which are a regular operating practice in modern pulp and paper mills.

Overall, the environment for integrated model-centric support offers an unparalleled chance to assimilate recent advances in MSEs, open-software architectures (OSAs) and IT within the industrial environment. This software tool facilitates the execution of a series of model-based process-engineering activities in a progression that reshapes raw plant data into useful process knowledge, which provides a genuine competitive advantage for continuous optimisation of process operations.