

(11/02) Overcoming the Hurdles in Chemical Process Automation

By taking advantage of advanced automation and control technologies, the chemical and petrochemical industries can improve efficiency, reliability and agility

By Nunzio Bonavita and Riccardo Martini
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The chemical and petrochemical industries traditionally have been highly receptive to new control and supervision technologies. These industries have invested more money and time in research and innovation than any other industrial sectors.

Nevertheless, objective benchmarking criteria — using the more innovative manufacturing sectors (automobiles, electronics, etc.) as a basis — show that the efficiency of chemical plants is still far lower than its potential. Improvements could be achieved through the use of advanced computer technology.

Throughout the history of industrial control, automation gradually has progressed toward higher levels of autonomy, the degree to which operations can be handled without human operators. In the process industries, model-based control has led to enormous progress in autonomy during the past 30 years.

Process control began with simple configurations made up of a group of single-loop controllers, with little or no reciprocal coordination. Today, multivariable controllers optimize larger and larger production units. One "package" oversees functions that once could have been implemented only through the use of several different strategies (single-loop control, anti-windup, uncoupling to remove multivariable interactions, constraints management, delay time compensation, feed-forward management, economic optimization). This dramatic function integration, permitted by improvements in both the mathematical algorithms and the processing and memory capability of processors, means that human operators can focus on high-level actions and decisions.

In the past, to control a distillation column using numerous single-loop regulators, operators had to set and monitor each single set-point value for flowrate, pressure and other variables that were only implicitly correlated to the end product's quality. A modern model-based architecture manages these execution details automatically and allows the operator to run the plant by generating commands directly related to the quantity and quality of the end product. One single operator can control a larger portion of the plant. It is possible to measure the level of autonomy of a control strategy by means of a special metric defined by the "number of loops to be supervised per operator." The higher this parameter, the higher the autonomy of the system implemented.

Control systems autonomy has had an enormous impact in economic, environmental and human terms. In 1980, the U.S. refinery industry produced 5.3 billion barrels and employed 93,000 people. By 1998, production in this sector rose by 17 percent, while the number of employees dropped by 35 percent to approximately 60,000.

The first on-line computer-based control system (103 inputs and 14 outputs) was put into service on a catalytic polymerization unit at a Texaco plant in Port Arthur, Texas, in 1959. In the early 1970s, multivariable model-based control was developed in parallel and independently in France and at the Shell research laboratories to optimize petrochemical and refining units.

A census of industrial multivariable control applications by Qin and Badgwell in 1997 shows that 89 percent of these applications occurred in production units within the chemical sector, including refining, petrochemicals, specialty chemicals and pharmaceuticals. A second Qin and Badgwell survey on the introduction of even more innovative techniques in this field placed more than 82 percent of nonlinear control applications in the chemical sector.

In 2000, the chemical industry invested just under \$220 million in process simulation and optimization systems — 65.2 percent of the total investment (\$336 million) by all industries, including power, hydrocarbon extraction and distribution, food and beverage, pulp and paper, steel and iron and more. Yet, only 37 percent of total chemical-industry investments were in industrial automation.

Despite the huge investments it has made in information technology, the chemical industry has been unable so far to achieve the performance of many other manufacturing sectors. Why? Experts have suggested a number of reasons, including:

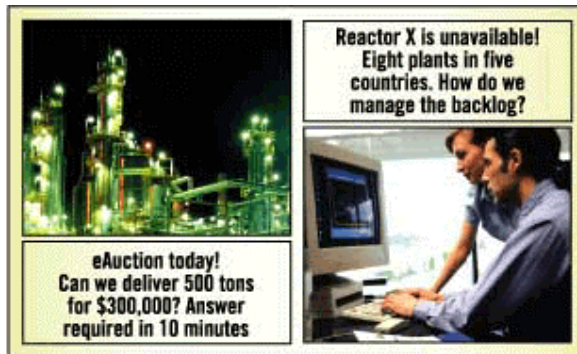
- Knowledge deficit. Contrary to what occurs in discrete event systems, detailed knowledge of the production process often is not available in the chemical industry. The lack of full access to physical-chemical details gives rise to a relatively high degree of unpredictability and, therefore, of unreliability.
- Extreme technological diversification. It is difficult or impossible to standardize or fully duplicate procedures, technologies and operating practices.

- Riskiness of production. Labor-intensive, high-risk chemical processes with a high impact on the environment encourage a natural — and understandable — conservatism inside plants. This conservatism can result in resistance to change.
- Limited production flexibility. The average plant is large, complex and costly, and any changes to the setup and/or product are very complicated. Quick responses to economic trends or changing market demands are difficult.
- Complex logistics. Production processes often are distributed over vast areas and require movement of large quantities of material both within the production facilities and between sites.

In recent years, most of the return on investments in business-to-business (B2B) has come from marketing and sales (the so-called e-commerce). However, e-commerce has a limited impact on the chemical industry, because so few customers and suppliers are involved in the supply chain. The true impact of B2B in this sector appears to be related to integration of production with logistics services.

If the constant increase in autonomy is key to the evolution of industrial automation, the leading concept for contemporary business is agility. A business is considered agile when it is able to interact advantageously with global markets, adapt to their continual variations and produce high-quality goods/services oriented to the peculiarities of individual customers. If the chemical industry is to benefit fully from the opportunities offered by Internet-related technologies, its production processes must evolve from the "sell-from-stock" mode to the "make-to-order" mode. Fig. 1 shows two typical situations in which an easily reconfigured production setup makes all the difference.

Figure 1. Chemical Industry Production Challenges



Production processes must evolve from the sell-from-stock mode to the make-to-order mode.

Sensor systems

Automation and control are not merely a question of management software or sophisticated mathematical algorithms. Instrumentation that interacts with the physical world — meaning sensors and actuators — plays a fundamental role and will continue to do so in the future.

Many future advances will depend on the ability to accurately and reliably measure the physical-chemical values of the systems to be controlled — acquiring increasingly detailed knowledge of the process. Higher production efficiency, lower emissions and a greater degree of safety require the use of ever more sophisticated and precise sensors.

The very concept of sensors currently is being revised and expanded. Instead of building on a single physical device, some sensors contribute to networks of instruments and/or software programs that are able to exploit analytical redundancies to correct and increase the reliability of existing measurements or to estimate new ones.

Intelligent sensors connected by field buses, inferential sensors, and self-calibrating and/or self-compensating sensors will be key factors in process automation in the coming decade. More precise and cheaper sensors can be placed throughout the plant to produce more complete data for better production optimization. The wide-scale introduction of sensors of various kinds within the automobile industry is a clear precedent: A further lesson that can be learned from this sector is that economies of scale can reduce associated costs drastically.

The increased use of sensors now allows better and more reliable environmental monitoring to rapidly identify sources of pollution. In the same way, preventive and predictive diagnostics will become more effective, especially for tasks that are not currently possible.

Another area that stands to benefit from better sensors is asset management. Networks of dedicated sensors can promptly identify components and/or materials that are not used to their full potential. They can also

replace or repair critical elements as soon as signs of malfunction are detected or before they jeopardize either safety or production continuity. However, all these tasks require not only better sensors, but also better and more careful integration of the sensors within automation systems.

The computer infrastructure

The situations depicted in Fig. 1 require almost instantaneous decisions based on reliable real-time information concerning the plant's status and availability. This scenario is made possible only by the presence of a suitable computer infrastructure connecting the separate worlds of process control and enterprise resource management. Information flows from each single device in the field to the management offices (called device-to-enterprise [d2E]). Numerous applications function in synergy, drawing information from a single data repository.

This dual function is effectively performed by modern process information management systems (PIMS).

PIMS:

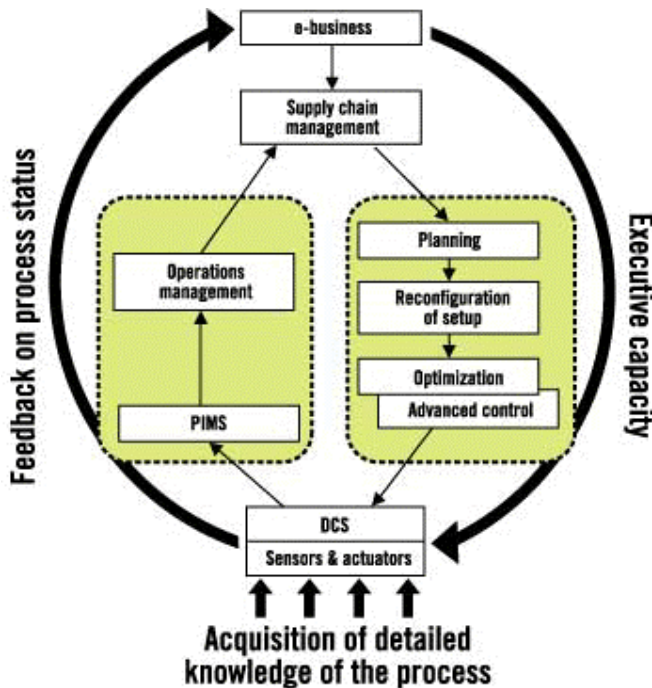
- Interface the various control and basic monitoring systems to gather process data, with sampling times of a second or less.
- Integrate the data gathered into the real-time databases.
- Convert all significant values and store them in large, efficient relational databases that permit sophisticated off-line analyses.
- Validate and reconcile with each other the values most useful in defining the operational status of the plant.
- Deliver the subset of data most relevant to strategic production management at critical times and in specified formats.

At a higher PIMS level, operative process management software made up of a series of applications helps supervise operations, checks the progress of the production plan, manages maintenance and explores any margins for improvement in the production cycle. Last, enterprise resource planning (ERP) systems perform business-cycle management. These systems integrate the information related to plant status, obtained from suitably reconciled data, with data from other production sites, financial data and market opportunity data. It is at this level that the whole supply chain is managed.

The execution capability

The computer infrastructure is the channel through which the transactional level is kept informed about the status of the plant and logistics, thus enabling context-sensitive production plans. Similar attention must be paid to optimization of the channel through which the flow of orders is implemented. See Fig. 2.

Figure 2. The Three Main Contributions to Process Automation



Plants must aim to optimize the channel through which the flow of orders is implemented.

To use an image familiar in the world of automation, the equivalent of a control loop is created: The plant's execution capability corresponds to the actuator's action, and the monitoring performed by the PIMS is the feedback channel (the controller would be the strategic company management). As any control engineer knows, no control loop can work properly if either one of these two channels is not up to the task.

Here too, the greater the involvement of the company in the world of e-commerce, the greater the demands for performance from the order implementation system. Chemical plants have to work in available -to-promise (ATP) and/or capable -to-promise (CTP) modes to seize transitory trade opportunities such as the purchase of raw materials at reverse auctions or an unrepeatable opportunity to satisfy the short -term needs of customers.

The need to increasingly enlarge the execution capability of the process is driving companies to embrace sophisticated process optimization and control techniques. It is now widely held that the most effective control and optimization strategies must incorporate active working knowledge of the process.

Applying advanced automation and control

Part One of this article looked at some of the process control and automation challenges faced by the chemical industry, as well as some prerequisites for meeting these challenges. Part Two (January 2003) will provide some specific plant application examples of how properly planned and implemented solutions improved plants' bottom lines. CP

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(01/03) Overcoming the Challenges in Chemical Process Automation (Part 2 of 2)

Chemical manufacturers benefit from realistic, real-time information about their plants' operating capacities

Nunzio Bonavita and Riccardo Martini
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Part One of this article (November 2002) discussed some of the process automation and control challenges plaguing the chemical industry, and took a look at how the industry might meet those challenges. Part Two provides several application stories that detail how certain chemical and related facilities solved specific process problems through advanced automation/computer technologies.

Rethinking refinery sensors

An Italian refinery was frustrated with the traditional sensor system installed for its crude oil units.

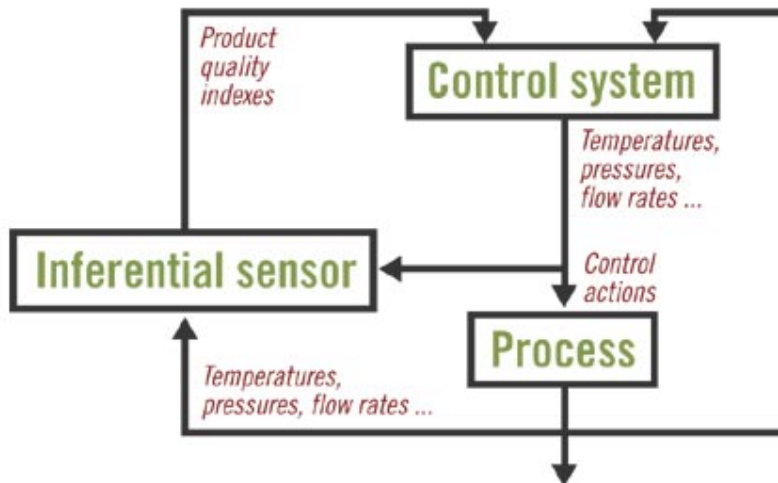
The plant was equipped with hundreds of physical sensors, often redundant, to measure fundamental parameters such as product quality or pollutant content of emissions. However, these measurements were not on-line, so the information was never available when needed. Specific analyses had to be performed off-line at company laboratories because suitable devices were not available or not economical.

The procedure began with the collection of product or effluent samples, which then were sent to the laboratory and analyzed — in some cases, requiring several hours. Finally, the control room was notified of the results.

If a disturbance occurred and production went off-spec at noon, for example, the operators were not notified by the laboratory until 4 p.m. It is easy to understand the detrimental effects the combination of delay and intermittent measurement had on overall production efficiency. To limit these effects, operators used process variables heuristically related to quality parameters to control the plant, although this method led to less-than-optimal operations.

The plant worked with the authors to install inferential sensors, which sharply increased the quality of plant operations.* The sensors make indirect measurements based on a mathematical model that estimates a specific process value in real time, on the basis of available related process measurements. See Fig. 1.

Figure 1. Working Principle of Inferential Sensors



Inferential sensors estimate a specific process value in real time.

In the last few years, several inferential sensor applications based on neural technology models have been developed. A neural network is a processing mechanism made up of elementary units, known as neurons (or nodes), that are tightly interconnected. Each neuron performs a specific nonlinear transformation on the weighted sum of the signals sent to it as inputs. The value calculated is sent as an input to the other neurons.

On the basis of a series of examples presented to the network during training, algorithms calculate the optimum weight given to each neuron and each input, "setting" the model directly in the network morphology.

From a mathematical point of view, training a neural network corresponds to minimizing the distance (averaged on a wide set of examples) between the results inferred by the network and the actual measurements.

Neural networks have many characteristics that make them attractive for a wide variety of applications in the field of industrial process automation. For example:

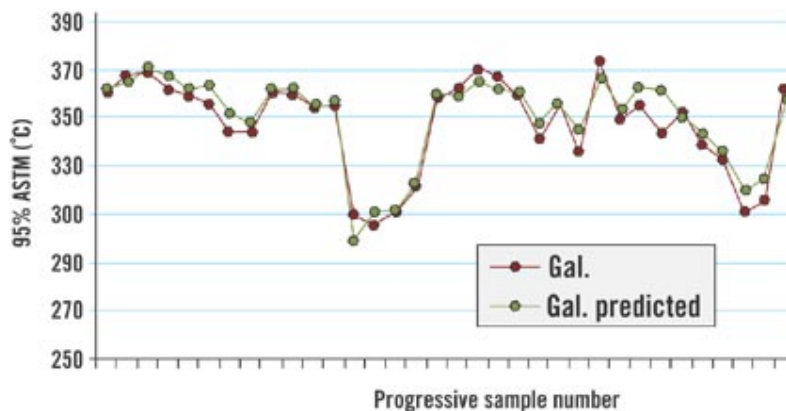
- They do not require any prior detailed knowledge of process behavior, although knowledge at a phenomenological level could be very useful.
- They do not need to be programmed.
- They can be "trained" simply by the presentation of examples.
- They are extremely efficient from a computational viewpoint.

In the case of the crude units in question, no measurements were available for product quality, which was checked by the laboratory once a day. Therefore, the sensor supplier implemented four separate inferential sensors to generate an on-line estimate of the quality (final distillation point) of the light petrol, heavy naphtha, kerosene and light diesel fuel products.

Each sensor is made up of a multi-input-single-output (MISO) neural network, the result of which is compensated automatically by a corrective factor determined by a statistic procedure that is activated each time the results of the most recent laboratory results are received from the laboratory. This on-line recalibration reduces the incidence of systematic errors or instrument deterioration.¹ The whole strategy is integrated into the plant automation system so control room personnel can access the virtual measurements in the same way they access the normal field measurements.

The application has produced excellent results. See Fig. 2, for example, for the estimate-measurement comparison in the case of light diesel fuel. During the 12 months or so the application has been in effect, operating personnel have increased process operating capacity, reduced the incidence of off-spec production and brought the process closer to optimum economical conditions.²

Figure 2. Light Diesel Fuel Estimate -Measurement Comparison



The figure shows a comparison between the estimated value and the measured value for the 95 percent ASTM point of light diesel fuel.

Creating a common data repository

The process information management systems (PIMS) market has expanded considerably during the past 10 years.

A major producer of nonferrous metals in the Mediterranean basin wanted to seamlessly integrate several different legacy systems to create a common data repository from which various categories of personnel (production management, process technology, top level management, etc.) could obtain data and information according to their needs. At the same time, the facility wanted to equip the plant with a kind of "information backbone" that would provide the basic layer for approaching e-commerce and supply chain management applications and for implementing advanced control and/or monitoring functions.

Essential requirements were:

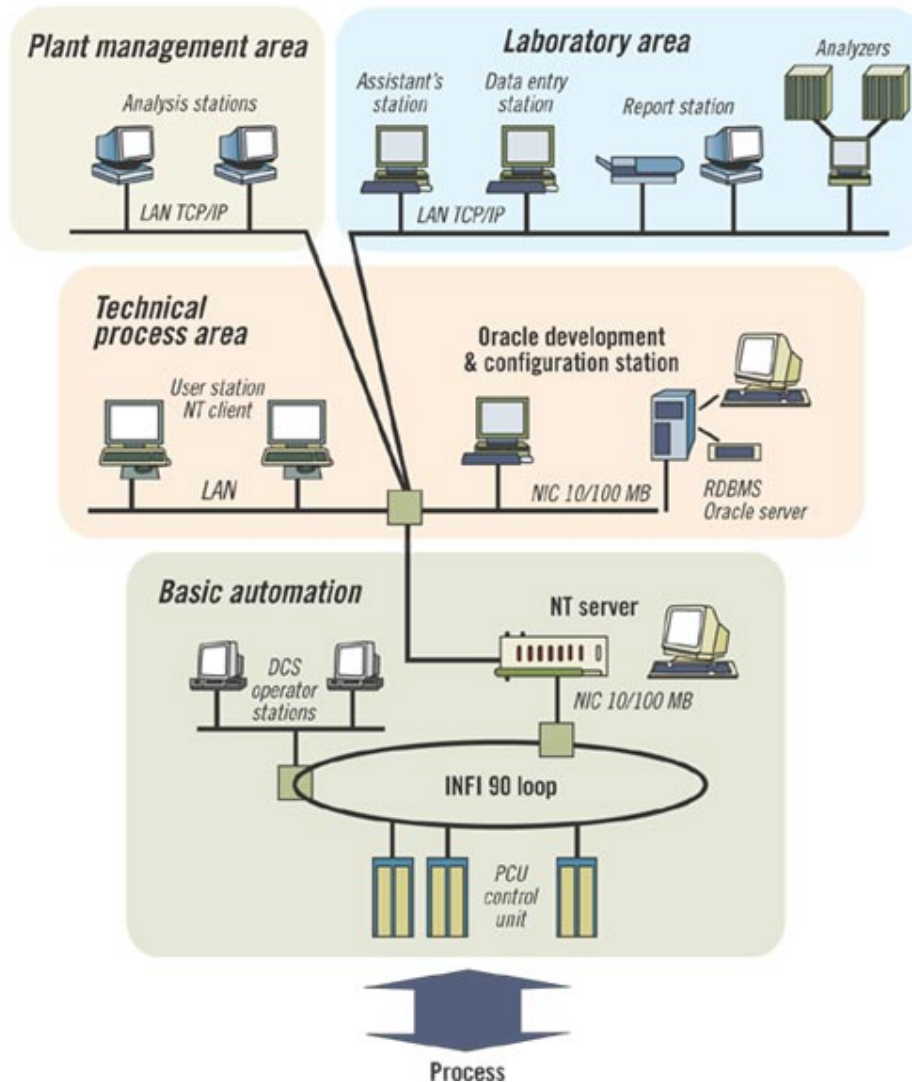
- The availability of distributed process information through an efficient client/server architecture.
- The use of familiar and widely used hardware and software platforms, ensuring easy data import and export.
- Full integration with existing process control systems.
- A Web-enabled interface to share information and data on the intranet and Internet.
- Maximum security for data access and management.

The solution implemented by the facility consisted of a PIMS solution,** Tenore NT server^{3,4} and a relational

database based on the Oracle software package.

The system architecture is divided into four separate areas. See Fig. 3. The server system is placed immediately above the distributed control system (DCS) and interfaces with it to collect process data. Above that is the second area, a plant-wide local area network (LAN) with seven server clients that allow the technical manager and technologists to perform functional evaluations and set-up checks.

Figure 3. Metal Plant Application Architecture



The system architecture is divided into four separate areas.

At this level, the system is configured to handle as many as 500 real-time trends. The Oracle server, the actual centralized data warehouse and the related development and configuration station are installed on the same LAN. System maintenance is made easier by means of Visual Basic interfaces.

The laboratory is the third area in the system architecture, consisting of three stations for manual data entry, procedure validation and product-certification report creation. The laboratory system connects directly to several analyzers, which make their measurements available immediately on-line.

Last, plant management is able to access the real-time production data through the Web. It should be stressed that each single station, if enabled, can access all the information in the centralized database. With this system, the DCS operator stations also receive all the relevant information from the laboratory to ensure control room personnel receive suitable feedback on production parameters.

While modernizing and homogenizing the information backbone, the PIMS solution also made it possible to streamline internal company procedures for a faster and more efficient decision chain. Furthermore, the

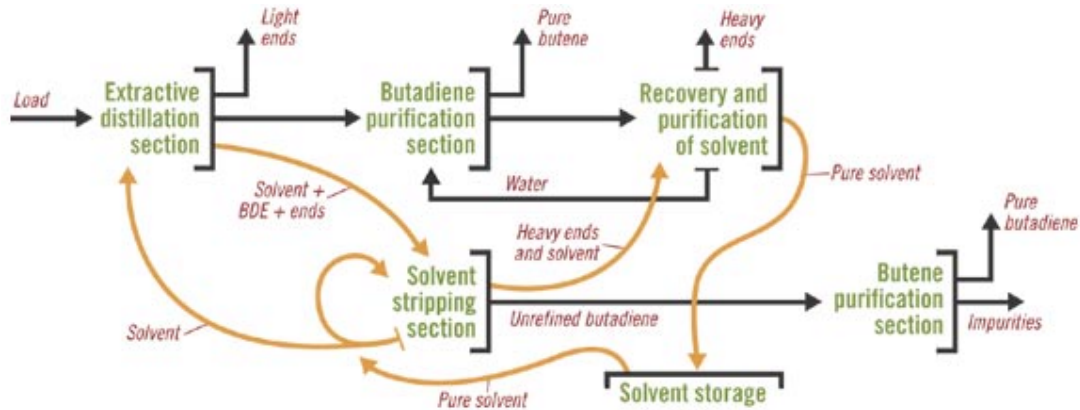
availability of Web access allows the plant to align with suppliers and customers.

Agility through model-based control

A butadiene extraction plant owned by one of Europe's major petrochemical companies needed an advanced control solution that would allow it to respond in an agile manner to market opportunities. The plant separates the feed — a mix of butadiene, butene, light ends and heavy ends — into its basic components, extracted with extremely pure characteristics. Because the boiling ranges of the various components are so close, normal binary distillation techniques are not efficient enough.

Separation is eased by the introduction of a third element, which acts as a solvent and modifies the relative volatility between the two main components. Addition of the solvent, however, leads to a considerable increase in plant complexity because units must be devoted to solvent recovery and recycling. See Fig. 4.

Figure 4. Layout of Butadiene Extraction Plant



Solvent use increases the complexity of plant operations.

The plant is made up of many distillation columns, resulting in many interactions between process variables and long delays that make traditional control inefficient and complex. Basic control strategies, while reliable with regard to the quantity and quality of the product, require so much energy that energy becomes one of the most significant operating costs. A further challenge to plant operations comes from the following logistical problems:

- The butadiene produced is actually an intermediate for other company productions, carried out at another site.
- Both raw materials and products are transported by ship (with consequent delays in arrivals or with demurrage when delays in production occur).
- Plant production is influenced by that of similar plants.

Because of these factors, production levels are varied. The plant must not only follow normal fluctuations in market demand, but also adjust to unexpected opportunities and/or needs within the company such as an unforeseen shutdown at a site or excess stock to be cleared.

These problems justified the use of multivariable control to increase the flexibility of the process and optimize production. Therefore, the authors introduced a series of multivariable control strategies, coordinated with one another at the overall plant level, for significant improvements in the quality of process operations so plant operators are brought closer to optimum economic conditions. The models used are linear and time-invariant.

To maintain the intrinsically nonlinear behavior of some variables, the supplier used strategies for real-time adaptation of model gains. Moreover, inferential sensors, seamlessly integrated with the multivariable control, were used to improve system performance and to monitor and control values that could not be measured or that suffered significant measurement delays.

The introduction of multivariable control strategies led to a significant increase in process control performance, reducing the solvent-feed ratio while maintaining production specifications, with considerable financial savings.⁵ One major source of savings was quantified as an 8 percent to 10 percent reduction in total steam consumption; further savings resulted from a reduction in solvent consumption and other utilities (electric power, water, etc.), a drop in off-spec production and a reduction in operator workload. Just as significant was the increase in process flexibility.

Conclusion

The benefits derived from the application of e-commerce processes can be achieved only if production processes are made more reliable, agile and efficient.

Therefore, manufacturers need realistic and real-time information on their plants' operating capacities. They

also must have confidence in their ability to follow plans established on the basis of economic opportunities, while maintaining the highest standards of safety and reliability, minimizing environmental impact and optimizing the use of company assets.

The use of mathematical models — in different forms and in different contexts — has proved fundamental in raising the level of autonomy of process control systems, and also promises to satisfy many of the operational needs of global enterprises.⁶ New mathematical paradigms such as models based on distributed agents and mixed logical dynamical (MLD) models for the treatment of hybrid systems are being defined to extend the possibilities of the model-based approach to the management of complex systems.^{7,8}

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