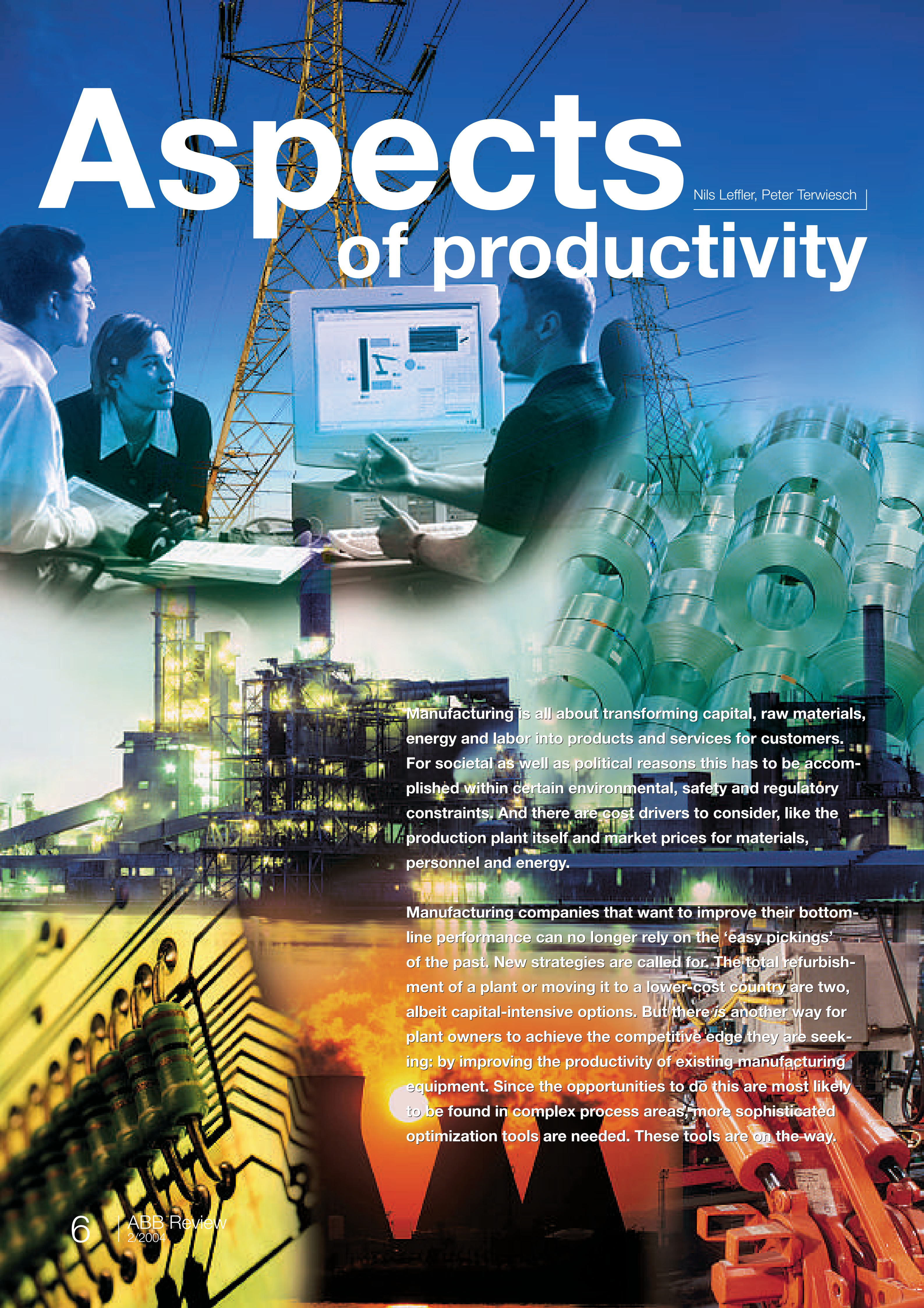

Aspects of productivity

Nils Leffler, Peter Terwiesch

Manufacturing is all about transforming capital, raw materials, energy and labor into products and services for customers. For societal as well as political reasons this has to be accomplished within certain environmental, safety and regulatory constraints. And there are cost drivers to consider, like the production plant itself and market prices for materials, personnel and energy.

Manufacturing companies that want to improve their bottom-line performance can no longer rely on the 'easy pickings' of the past. New strategies are called for. The total refurbishment of a plant or moving it to a lower-cost country are two, albeit capital-intensive options. But there *is* another way for plant owners to achieve the competitive edge they are seeking: by improving the productivity of existing manufacturing equipment. Since the opportunities to do this are most likely to be found in complex process areas, more sophisticated optimization tools are needed. These tools are on the way.

A manufacturer's goals are clear: to deliver more of a better product, faster and at a lower cost than its competitors. Shorter cycle times and increased production uptime are therefore at the top of the agenda. In most of the industries that ABB serves, energy, raw materials, logistics and labor are major contributors to the final product cost. To remain competitive in a global market, companies therefore have to reduce their energy consumption, material usage and distribution costs while at the same time increasing their productivity. But that is not all.

Ever-more-stringent environmental legislation and safety stipulations have to be complied with in order to operate at all. In an increasing number of countries and industries, customers and governmental bodies expect products to be accompanied by a complete audit trail. With this increase in complexity, it is hardly surprising that manufacturers look to advanced optimization techniques to enhance productivity and ensure that their business targets are reached.

The recent troubled state of the world economy has even helped here. Lofty discussions about advanced software for collaborative cooperation across the entire value chain have given way to a more pragmatic search for productivity improvements. Industry and the utility companies have come to realize that there will be no more 'easy pickings'. As a result, more complex tasks are now being tackled across all industries and in all areas, from engineering through operation to distribution. While all of these 'aspects of productivity' contribute to better results, they do so in different ways. Aggregated, they improve the bottom line, whatever the industry.

Benchmarking

Benchmarking within an industry points out some significant differences in overall performance. Pharmaceutical companies are a case in point, and a good example of a sector where there are opportunities for improvement (*see table*). The data indicate that there is a considerable upside to adopting more advanced strategies for both scheduling and operation optimization. It is interesting to also see that the figures for the different industrial sectors are very similar. This is because 'best in class' means just that, and applies to all sectors, all of which are now approaching the same performance level.

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The importance of automation

The overcapacity that exists in many industries today is forcing companies to focus on utilizing existing assets rather than on investing in new capacity. Here, automation can be a key factor. When capital is scarce, automation solutions often offer the best return on investment.

Recent decades have seen broad consolidation in all industries, motivated in most cases by companies' need for global market reach. ABB has been more than just a bystander. In fact, we can justifiably claim to have been a driver in the consolidation of the automation industry, where we are today a

Benchmarking within a sector – the pharmaceutical industry

Benchmarks KPI	Pharmaceutical company		
	Typical	Good	Best in class
Stock turn[1]	3 to 5	14	50
OTIF[2] %	60 to 80	97.4	99.6
RFT[3] %	85 to 95	96	99.4
CpK[4]	1 to 2	3.5	3.2
OEE[5] %	30	74	92
Cycle times[6], hrs	720	48	8
Safety[7]	0.100	0.050	0.010

Source: RS Benson, Smart control for tomorrow's processes. IEEE Cont.Appl.Conf., Glasgow, 2001.

Global benchmarking between sectors – 'best in class'

Global benchmarks	Engineering sector	Electronics sector	Household sector
Stock turn[1]	12	20	24
OTIF[2] %	98	98.1	99.2
RFT[3] %	99	98.7	99.5
CpK[4]	4	5	4
OEE[5] %	94	93.3	86
Cycle times[6], hrs	48	24	24
Safety[7]	1	1	1

Source: Process Innovation: Lessons from UK Manufacturing, DTI Publication 5970/5k/04/02/NP, URN 02/322, April 2002.

1) Annual turnover / total value of all stock at sales value (includes finished goods, work in progress and raw materials).
2) On-Time-In-Full: Delivery of products at the date and time requested by the customer, without product or documentation defects.
3) Right First Time at the point of manufacture with no adjustments or recycles.
4) A statistical measure of the product quality distribution. The higher the number, the narrower the spread (eg, a figure of 6 is the same as 6 Sigma).
5) Overall Equipment Effectiveness
6) The time between the start of manufacture and dispatch of the product.
7) Number of incidents per 100,000 hrs.

global leader. We actively develop new strategies made possible by advances in a whole host of areas: communications, computer capabilities, open software and pricing trends, sensor technologies and applications.

Automation suppliers need to be able to deliver products, systems and services to consistent standards, and do it globally. This is because many customers operate worldwide and prefer to rely on just a few suppliers. But it also means that expertise must be available around the clock and supported by remote connectivity tools for diagnostics and troubleshooting.

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The goal of achieving enterprise-wide decision support in real time continues to feed the trend toward deeper integration of third-party systems, such as ERP[8], CMMS[9] and GIS[10], with the automation systems. Productivity-enhancing tasks that are part of this strategy include optimal operation despite constraints, with the scope extended across departments and plants. Optimal scheduling of production orders and maintenance are becoming essential features in the asset management software that is now an integral part of the automation supply. The virtual factory, as a concept, has to be supported by algorithms that enable the optimized distribution of orders to factories around the world.

Automation suppliers must sit up and take notice of another customer requirement – improved asset productivity. The buzzword here is 'overall equipment effectiveness (OEE)', and new asset management tools are being developed to improve it. Rather than just increase the tonnage incrementally, the control system has to support speed, quality and flexibility.

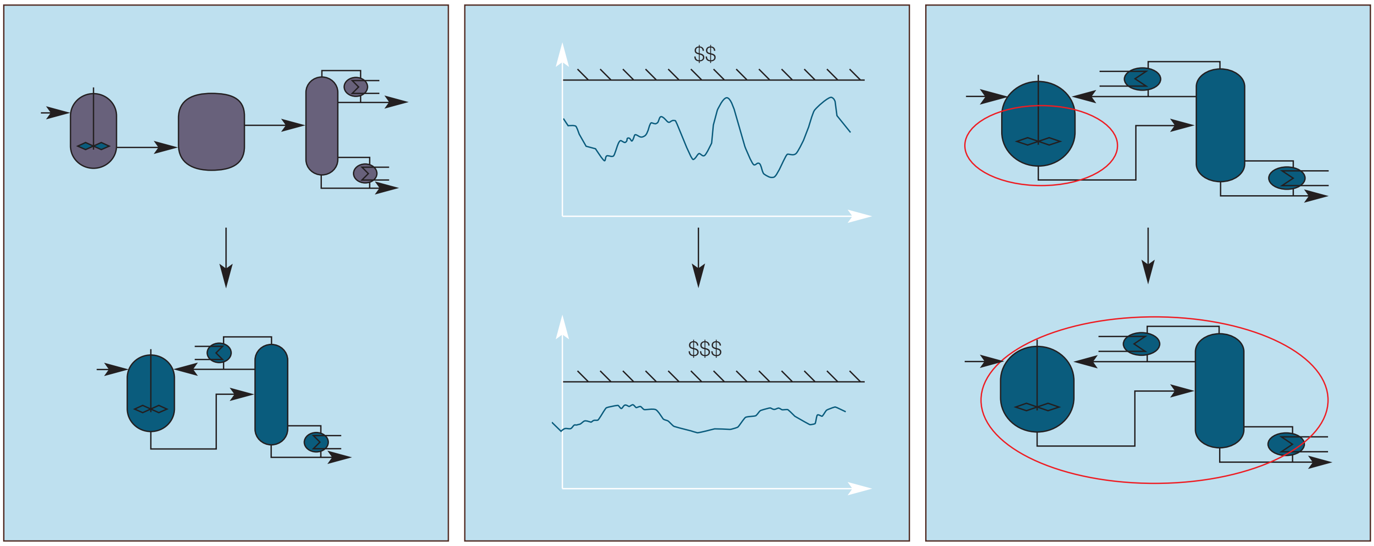
Removing the need for intermediate buffers reduces inventory, resulting in better energy efficiency with faster cash and product cycles 1a. The automation system must ensure consistent quality, high yield within the production constraints, and fast grade changes in a more dynamic environment. All businesses have to be able to deal today with hard constraints, like safety and health regulations, environmental legislation, as well as soft constraints such as product quality, with different grades demanding different market prices. And the control system must ensure smooth, optimum running of an operation within the limits imposed by these constraints 1b. It has become clear that to access further potential productivity improvements, the optimization scope has to be broadened to include larger process areas. However, this makes the tasks even more complex. The trend is away from single-unit control toward control of the complete process line, from single plants to multiple plants, and from a single optimization objective to multiple goals 1c.

8) Enterprise Resource Planning

9) Computer Maintenance Management System

10) Geographical Information System

1 Aspects of productivity

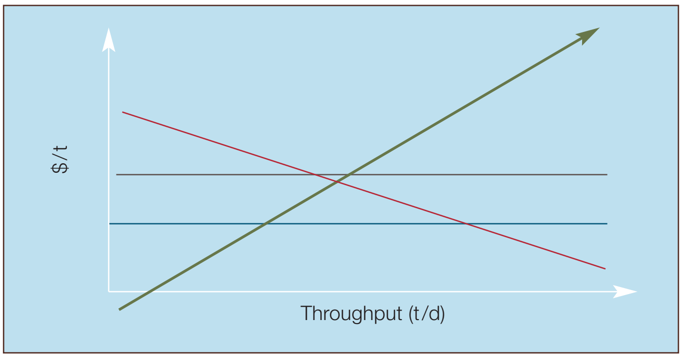


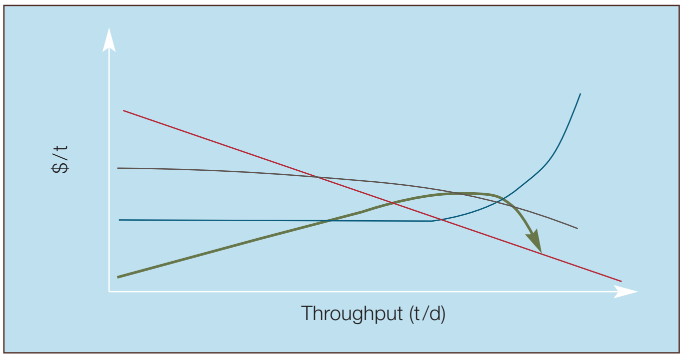
a) Inventory reduction (eg, buffer removed)

b) Optimization of constraints

c) Optimization scope extended

2 The value of real-time information





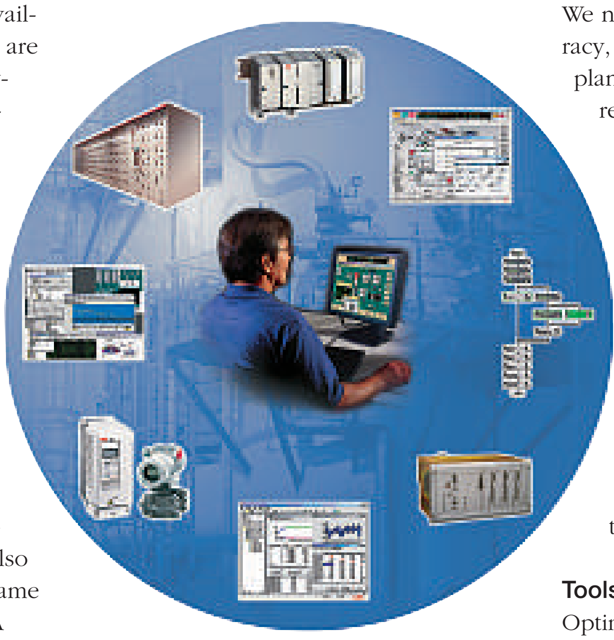
Traditional static accounting uses *average data* and indicates that order revenue and variable costs are *linear*. The contribution margin increases with production volume.

In reality, revenue and cost per ton *vary* over time and according to supply source, customer and operating rate. Max. profit is often achieved below max. operating rate, where revenues no longer exceed costs.

The value of real-time information

Communication is the key to optimizing operations across departmental boundaries. This is true whether the information is used to support decision-making or for closed-loop control, as in either case real-time information has to be delivered to the right place at the right time. Many new technologies are available for this today, and the benefits are considerable: personnel are empowered by being given access to information across disciplines; wireless communication encourages mobility and web-based services provide access to expertise. All of this is offered in the spirit of productivity improvement.

Intelligent field devices communicating over field buses provide accurate measurement data and have self-diagnostics capability. The trend toward more complex measurements with equipment capable of self-calibration is also driving product quality and at the same time reducing raw material usage. A good example of this is the demand for direct measurement of quality variables in paper production or the analytical measurement of chemical components. Every item of installed equipment has a considerable amount of documentation attached to it – manuals, drawings, spare-parts lists, operating history, and so on. Each document has to be continuously updated, and must be accessible when needed. ABB has introduced a technology that describes each device as a software object containing the properties of the real object, like a motor, as so-called Aspects. These Aspects might be



located in several different systems, such as CAD, CMMS, ERP or a control system, but the Aspect integrator ensures that all the information is both timely and consistent. An object does not necessarily have to be an actual piece of equipment, like a motor, but could be more abstract, for example an order, with information such as the original purchase specification, quantities, location in the warehouse, etc, as its Aspects.

Data consistency is essential for more advanced optimization and modeling. We need to ensure measurement accuracy, consistency between production plan and maintenance plan data, use of real-time costs and prices rather than historical averages. Use of real-time data can significantly impact the computing of the optimal production level, which might sometimes deviate from full production. In fact, the variable cost might rise steeply and non-linearly as full production is approached, while the fixed-cost contribution continues to decline linearly, resulting in maximum profit being achieved below the maximum operating rate **2**.

Tools for advanced optimization

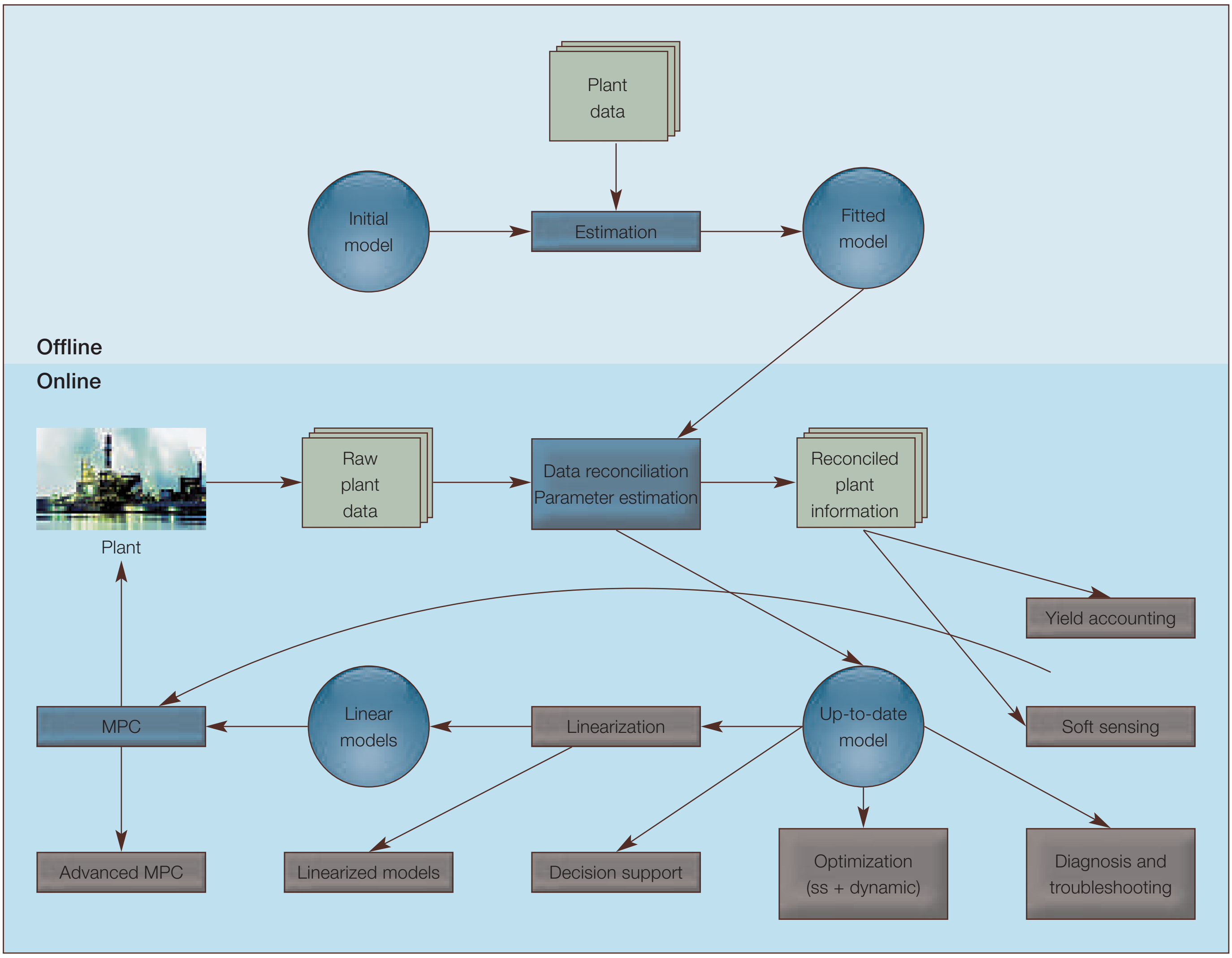
Optimizing an operation within the business constraints outlined above, and doing it across several departments or a whole plant or network, possibly across multiple plants or multiple networks, requires powerful computers and new algorithms. Process models are needed that combine on-line estimation with the laws of physics. Such models are used to determine predictive behavior over long time intervals in order to optimize production order scheduling and to calculate the best possible operating level from real-time information. Time horizons of 24 to 48 hours are very common, but even longer intervals than these are desirable. A way forward here might be clever algorithms designed around structural decomposition.

Today's control systems are equipped with toolkits that contain P, PI and PID controllers – the 'workhorses' of the automation industry. While condition monitoring of rotating machines is common enough, condition monitoring of control loops is anything but common. In fact, a typical plant could well have 30 to 40 percent of its loops running on manual because of poor tuning. That such a plant would be performing well below par hardly needs saying. Fortunately, automatic tuning packages that solve this problem are available.

Every company, whatever its business, must ultimately be interested in being able to control its operations from an economical standpoint.

In the area of more advanced control, the current trend is toward model predictive controllers (MPCs), but controllers based on quadratic cost functions or linear controls with state constraints are also widely used. The MPCs being adopted today are mostly single input, single output (SISO) types. Multiple input, multiple output (MIMO) controllers with linear constraints are also gaining in popularity. The algorithms most commonly used where nonlinear constraints exist are gain-scheduling algorithms. Optimization algorithms normally focus on steady-state conditions with transient behavior (grade changes) handled in small ramps. Ob-

3 Control models change over the process lifecycle, being continuously updated with the help of real-time data
ss Steady state



ject-oriented modeling is becoming more popular as the relevant tools and programming languages are developed.

In the near future, real-time dynamic optimization of transient conditions, hybrid modeling of process dynamics and mixed-integer programming will all be included in the toolbox of the process engineer. Ultimately, economic optimization of process operations, including lifecycle aspects, will be the solution of choice for industrial customers.

Such a toolkit for optimal control will have many different interactive components 3. The models themselves will change over the process lifecycle, being continuously updated with the help of real-time data.

4 The economic objective functional

$$\min \sum_{t_i=t_0}^{t_N} [C_A(t_i)+C_E(t_i)+C_M(t_i)+C_L(t_i)-R(t_i)]$$

Asset costs

Energy costs

Material costs

Labor costs

Product revenues

Economic optimization

Every business, whether it manufactures products, provides services or distributes electricity over a network, must ultimately be interested in being able to control its operations from an economical standpoint. Normally, this translates into minimization of the 'cost minus revenue' functional 4. The more elements that are taken into account, the more realistic the control strategy will be. However, this comes at the cost of an exponential increase in complexity.

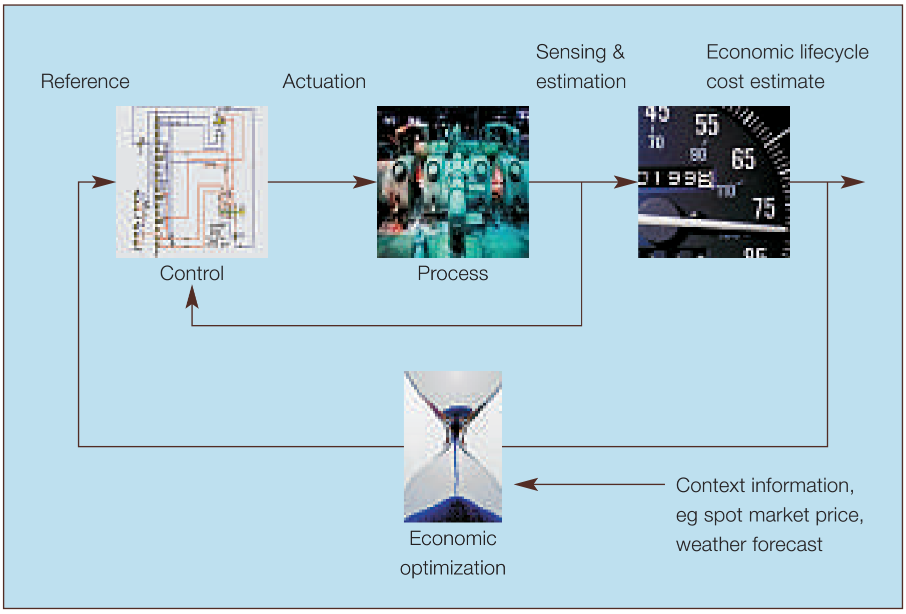
The minimization of this so-called economic objective functional over time is subject to the hard and soft constraints described before as well as to the dynamic behavior of the different components, since several of them change over time. What the industry ultimately wants is to be able to calculate these control strategies on-line, based on real-time data. A closer look at the individual components shows how:

- *Asset costs* depend on two different phases – the design and the lifecycle. The latter depends on the residual life expectancy and on maintenance and inspection costs, which might be a function of operating strategies.
- *Energy costs* have a thermal and an electrical component. In each case, companies can either purchase the energy or generate it themselves. Costs vary with market prices and fuel type. The export of excess generation can be included in the formula by inserting a negative cost factor.
- *Material costs* are dependent on market prices, the quantity and discount strategies. Inventory costs can add to the dynamics by bringing factors into play like the storage of intermediate products in buffers or final storage of the end product.
- Finally, the *labor costs* depend on several factors – manned shifts, inspection, and maintenance frequency, the plant's location, among others. In practice, this cost element has a significant impact on the outcome of any optimization attempt.

All of the above costs are balanced against the *product revenues*, which vary with changing market prices.

5 shows how, by implementing an outer economic optimization loop, operating setpoints are provided to the inner control loop.

5 Asset lifecycle: Implementation of an outer economic optimization loop enables operating setpoints to be provided to the inner control loop.



Frontiers of advanced control

As demand for more sophisticated mathematical modeling of industrial processes grows, we can expect to see intensive R&D efforts in several areas. At the top of the list are improved ease of use and robustness of algorithms in an on-line setting. Since plants can be seen as homogeneous entities, we can expect to have to deal with more complex problems. Going beyond a single site, we will tackle the virtual plant with mul-

tiple production lines, located around the world. Research in the application area will look at ways to decompose these larger tasks and apply distributed problem-solving techniques, such as agent approaches, without introducing sub-optimization.

Non-linearity, transitions between steady states, dynamically changing constraints, and abnormal event handling, are all problems that industry is familiar with and would like to have on-line, real-time solutions for. Prediction and advanced scheduling must be able to cope with longer time horizons with variable time intervals.

Data consistency and data quality is another area in which further research work has to be carried out. Mass balance techniques can compensate for measurement errors caused by sensors 'drifting' or failing. This ensures a degree of consistency, but further improvement is possible. Using predictive maintenance to improve asset management of sensors, rotating machines and actuators, is a proven means of eliminating unplanned production stops.

Ease of use has two facets. On the one hand, the models must be designed for easy interaction and be comprehensible to the operators. On the other, it must be possible to generate them from the plant topology as it is described in the P&I (Process and Instrumentation) diagrams. It is important for the data to be entered just once. Economic data should originate from ERP systems. Lifecycle dimensions should be built into the overall models.

We can say, in summary, that asset and energy aspects of productivity deserve more emphasis in modeling, control and optimization. Recent advances in automation have simplified the industrial application of control and optimization, but there is a constant need to improve the modeling and engineering as well as the usability of the models. To reach these desirable features we still have a way to go, but even small steps in this direction promise to have a significant impact, as further articles in this issue of *ABB Review* will show.

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Reference

[1] **P. Terwiesch:** Frontiers in industrial process automation – a personal perspective. Invited plenary lecture, IFAC ADCHEM, Hong Kong, 2004.