ABB
Review

The corporate technical journal
of the ABB Group

www.abb.com/abbreview

1 / 2006

Contemporary manufacturing challenges

ABB

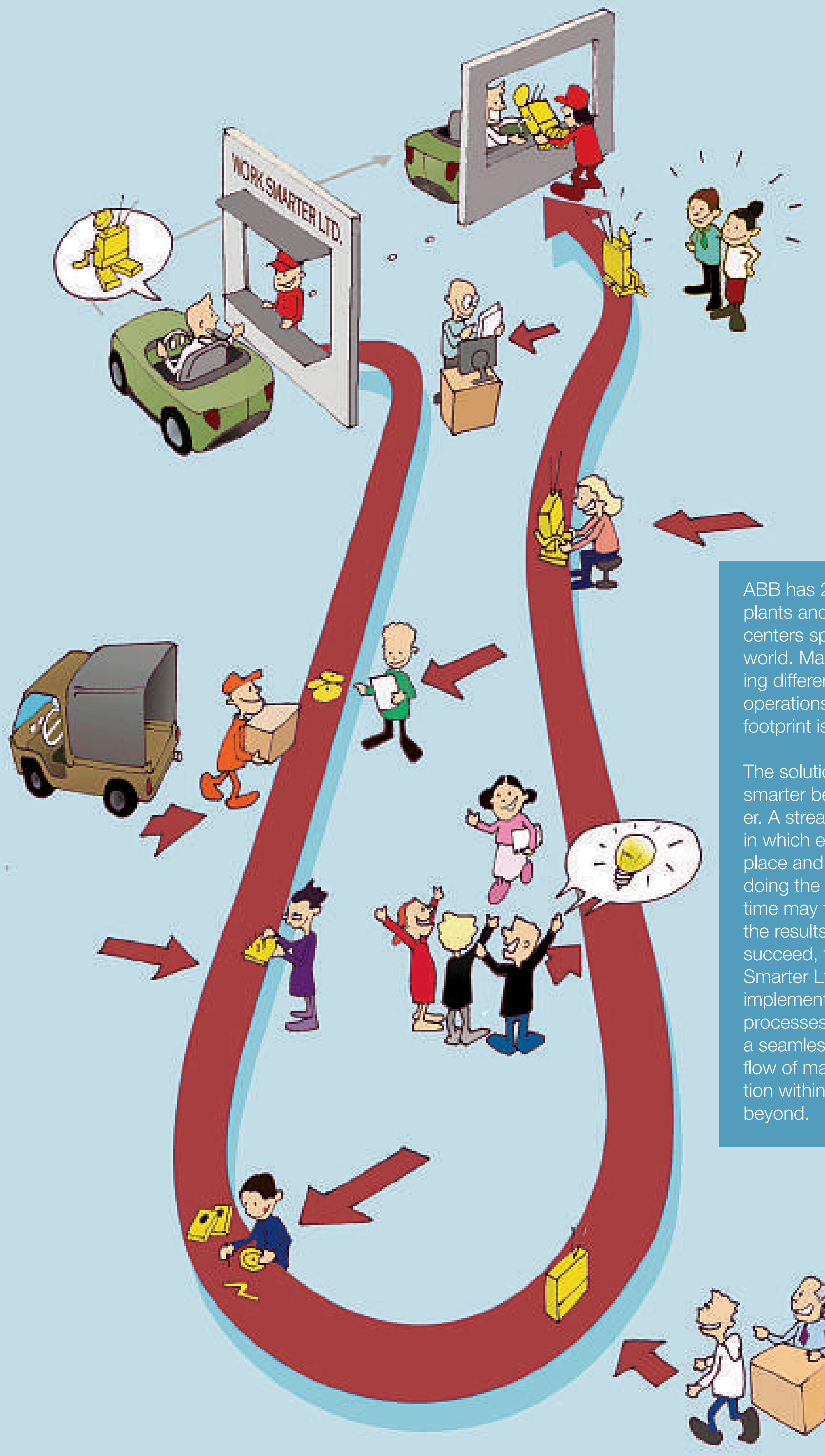


ABB has 260 manufacturing plants and 140 engineering centers spread around the world. Managing and optimizing different manufacturing operations within this global footprint is truly a challenge.

The solution lies in working smarter before working harder. A streamlined organization in which every part has its place and where everybody is doing the right job at the right time may take some effort but the results are worthwhile. To succeed, for example, "Work Smarter Ltd." has defined and implemented the tools and processes needed to ensure a seamless and continuous flow of material and information within the factory and beyond.

Contemporary manufacturing challenges

A literal translation of the word manufacturing is “making by hand”. However, time and a number of inventions and innovations have significantly transformed this meaning. Perhaps the most well-known milestone of this transformation is the industrial revolution of the mid 18th century where steam engines were used to mechanically power machines in, for example, the textile industry, thus inducing important economic and social consequences. The second industrial revolution – from 1850 onwards – changed the chemical, petroleum, and electrical industries in particular, and the 1913 introduction of moving assembly belts at Ford were a major ingredient in the competitiveness and success not only of the Model T car, but also of the company as a whole.

However, an earlier and less well-known manufacturing milestone, where production line and parts standardization concepts were already in place, took place in medieval Italy. The Arsenale di Venezia built great Venetian merchant and military fleets that made Venice one of the first great maritime powers. During its golden age, more than 16,000 people, employing jealously guarded techniques, worked astonishingly fast. When Cyprus was threatened by the Turks in 1570, the workers produced 100 ships (more than one a day) in just two months.

While manufacturing remains an important success factor for many countries, both in the industrialized and developing world, it plays a very decisive role in the overall prosperity of a company. For a company like ABB, manufacturing is of vital importance to its own performance. At the same time, our products, systems, and services are used in the manufacturing facilities of many of the world's most dynamic and successful companies.

ABB's global manufacturing consists of 260 factories and 140 major engineering centers, and this issue of ABB Review offers an insight into some of these sites and the results we have achieved by using modern tools to analyze, measure and implement productivity improvement strategies. The section devoted to demand driven manufacturing uses the company’s own factories as examples, emphasizing in particular the element of diversity, as the characteristics of our manufacturing operations vary from job shops of less than 1,000 products per year to continuous manufacturing with more than one million products per day. This spectrum ranges from standard catalogue items produced for stock, to highly complex and customized produce-to-order items with considerable software engineering content. Our Supply Chains stretch across the globe, where ingenuity is required to reconcile needs with quality, delivery speed, and market demands. As a guest contributor, Professor Jonathan Byrnes from MIT writes about the global Supply Chain and its inherent risk. Managing this risk properly is also the subject of several other articles in this issue.

Established concepts, such as the theory of constraints, design for manufacturing, and statistical process control are implemented in new and creative ways to provide our customers with high quality products. Such ingenuity is also responsible for significantly reducing delivery times over the past few years. Still, in addition to continuous improvement efforts, we are always finding opportunities to implement productivity improvements based on new technologies and principles in both old and modern manufacturing units, in cultures and countries as diverse as Germany or China, US, India, or Latin America.

Demand-driven manufacturing is the overarching principle adopted across ABB’s production units. ABB Review discusses how certain tools are used by the company to enhance its factory performances, and several articles describe specific implementations and results. Most of ABB's customers are engaged in and dependent on manufacturing, be it discrete or continuous, the production of oil and gas or electricity. As the challenges to manufacturers bear at least some similarities across industries, I hope we will provide insight and value to our readers by sharing our own experiences in the science of manufacturing.

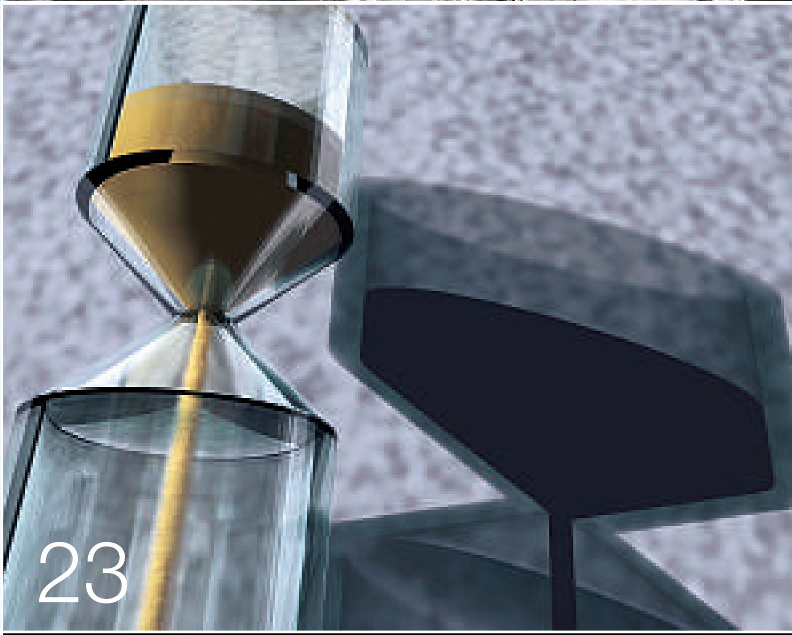
Enjoy your reading.

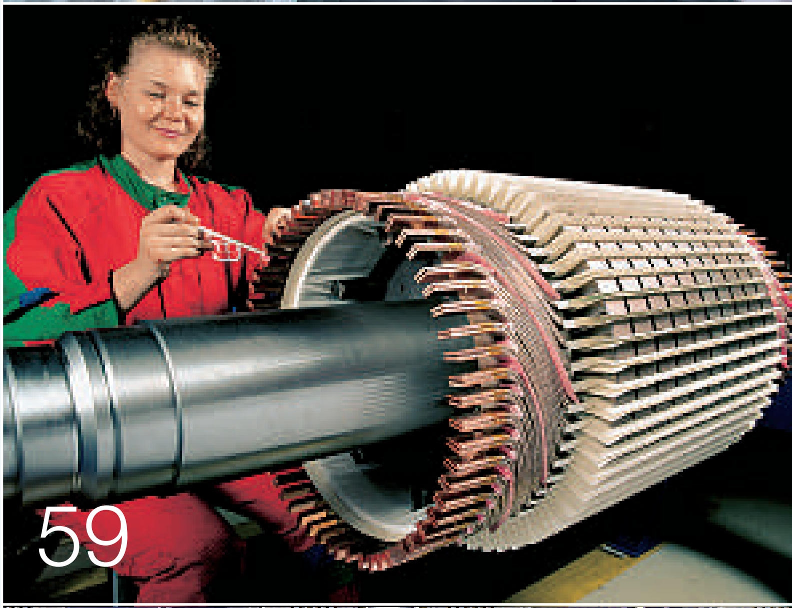
Peter Terwiesch
Chief Technology Officer
ABB Ltd.

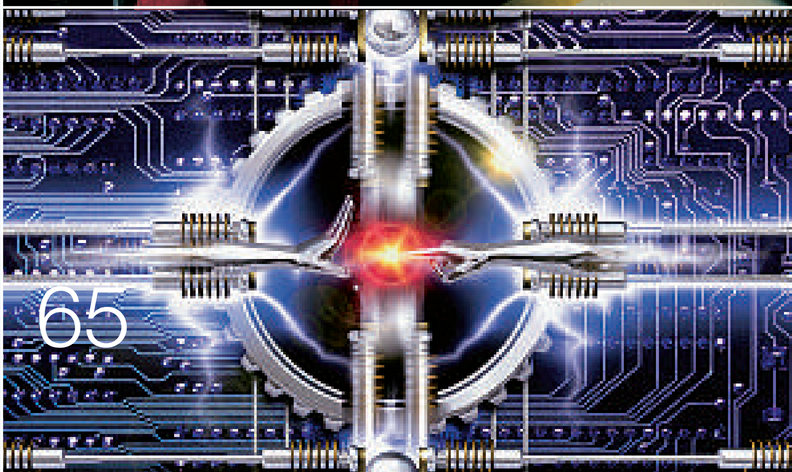
Contents

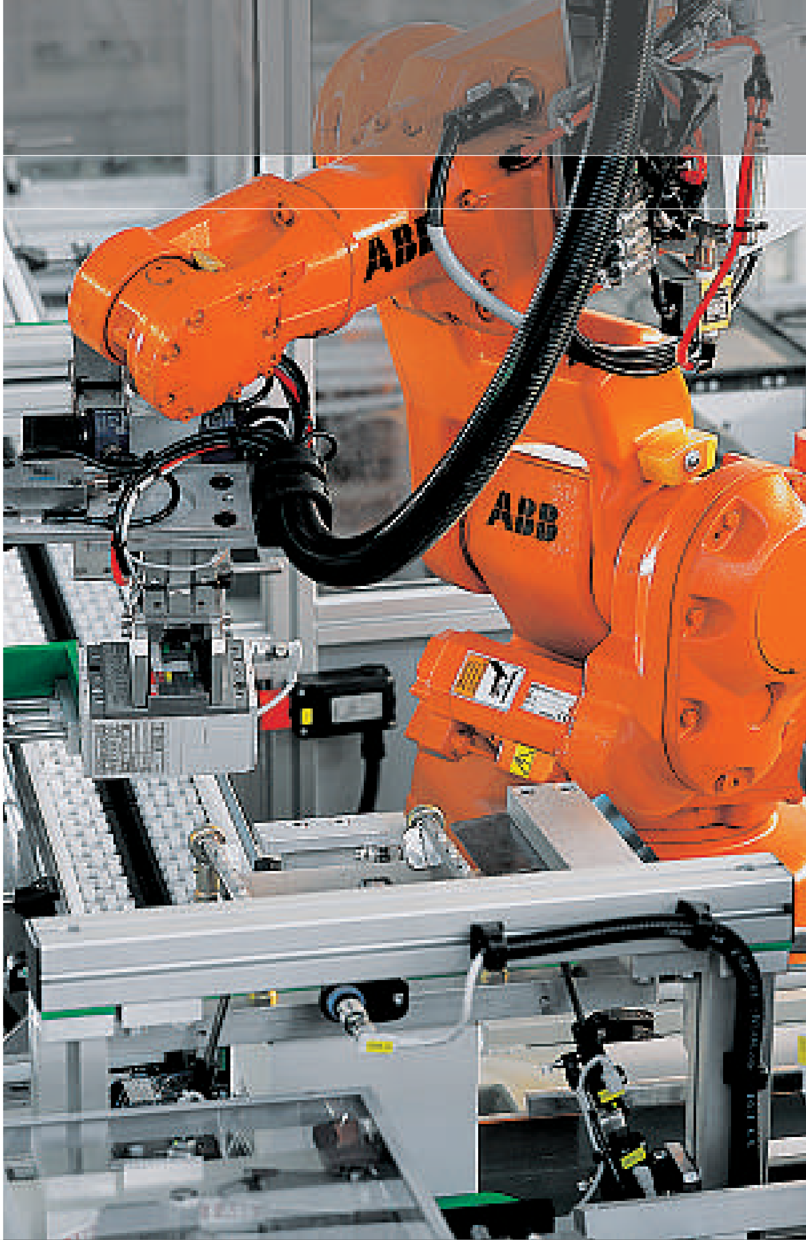
ABB Review 1/2006
Contemporary manufacturing challenges

Manufacturing technology









The science of manufacturing

Efficient manufacturing processes are based on fundamental factory physics laws

Fredrik Nordström, Piotr Gawad, Adam Nowarski

Man has been "manufacturing" since he first walked the earth. Of course, manufacturing has evolved significantly since then and it keeps on evolving. New philosophies and buzzwords regularly appear that seem to be the answer to every manufacturing manager's prayer, only to be replaced later by better philosophies and cooler buzzwords.

While most of these do contain a certain element of truth, what is more important is that managers have a profound knowledge of the fundamental laws that govern manufacturing processes, in order to apply the appropriate tools and philosophies in a correct and balanced combination. In other words, there is a need to understand the "science of manufacturing".

What is meant by the "science of manufacturing"? In a nutshell, it refers to the fundamental physics of a specific manufacturing process; not only the details, but how the parts of a production line work together as a system. The Egyptians, for example, were skilled in applying the laws of physics when constructing the pyramids. However, as mass production – and therefore speed – were clearly not issues at the time, the Egyptians were not confronted with the flow dynamics that come into play when talking about the mass production of goods or continuous processes. For this, we need to fast-forward to the first industrial revolution.

Until the middle of the 18th century, goods were mostly produced one piece at a time by skilled craftsmen. Then several inventions helped bring about what is termed the industrial revolution, when extensive mechanization of production systems resulted in a shift from home-based hand manufacturing to larger-scale factory production. The most important of these inventions was the steam engine (James Watt). The use of steam power not only allowed the localization of industrial operations without being constrained by the availability of water power, but it also provided cheaper power, enabling lower production costs, and lower prices.

Another invention came around the turn of the century (1799–1801) from the gunsmith Eli Whitney. He introduced the concept of interchangeable parts to enable products to be assembled and repaired quickly without having to rely entirely on the craftsmanship of skilled individuals. Uniformity was also achieved by having machines with jigs that made each separate part of a gun. It is clear that the foundations of the assembly line were laid early in the 19th century.

Other important innovations included those in transportation (the railways) and communications (telegraphs) which were instrumental in providing the necessary distribution mechanisms for goods and information.

The modern integrated industrial enterprise started to take shape in what is called the second industrial revolution. All elements for mass production and distribution were now in place.

The "science of manufacturing" refers to the fundamental physics of a specific manufacturing process; not only the details, but how the parts of a production line work together as a system.

The advent of mass production

The one person who will forever be associated with the advent of mass producing standardized goods using dedicated machines and moving assembly lines is Henry Ford. The moving assembly line was introduced in his car factory in 1913. The implementation of conveyors eliminated the extra handling and waiting between each station. Ford brought to life the thoughts expressed by Frederick Winslow Taylor in "The Principles of Scientific Management" in 1911 in that he created a continuous flow by "taking the work to the man" instead of "taking the man to the work". This was basically the birth of lean production in which one of the main focal points is waste elimination. This was later copied and perfected by Taiichi Ohno and his team at Toyota. In hindsight, however, the introduction of the conveyor seemed somewhat overshadowed by Ford's recognition of the strategic importance of speed. He saw that a fast process has a positive impact on throughput and inventories and would therefore enable him to keep his costs lower than those of his competitors.

Discovering the nature of variation

While Henry Ford reduced product variability to an absolute minimum (only black cars were manufactured) in his efforts to achieve production speed and drive down overall costs, there were others who concentrated on "fine-tuning" the process as a way of improving product reliability. For example, the engineers at Western Electric's Bell Laboratories experimented with various process adjustments in an attempt to improve the quality of their transmission systems, with little or no success. The statistician Walter A. Shewhart eventually concluded that any adjustments made to a process to correct fluctuations that are within the level of the random variation will only increase the variation in the process and thus degrade the performance. In other words, using intuition and best intentions – or trial and error – is like navigating through unknown territory without a compass and map. His findings led to the birth of Statistical

Generator assembly in Baden, Switzerland, 1895

Manufacturing trends

Process Control (SPC)[1] practices, which were later adapted and further developed by two former Western Electric employees, Dr W. Edwards Deming and Dr Joseph M. Juran.

Shewhart's work, published in 1931 under the title of "Economic Control of Quality of Manufactured Product", was a major scientific contribution to the entire manufacturing discipline.

The modern quality tools of today, such as Six Sigma Textbox 1, are directly derived from these findings.

The reductionist versus the systems approach

In his efforts to develop manufacturing management practices, Frederick Winslow Taylor divided the production system into separate simpler parts – reductionism – with the aim of improving each of them to maximize efficiency. He developed jigs, fixtures and other devices to support his goals of standardizing best practices, thus earning him the title of "the father of industrial engineering".

This reductionist approach is excellent when analyzing individual activities that make up the production of a part or an assembly. However, improving overall efficiency should not focus on improving each individual component of the process, but rather on how the components interact with one another and other sub-systems to form the complete production process. Performance optimization is then achieved based on the overall goals of the system.

A production system, like most real-life systems, consists of dependent events and variation. Because things

Textbox 1 Managing variation – the quality perspective

A modern manufacturing process often uses sophisticated technologies to supervise and monitor productivity and quality. These are essential, especially in a manufacturing world where managers and operators continuously seek to improve process performance.

Many different parameters must be controlled to bring about an efficient process that produces a product of exceptional quality. Accordingly, modern approaches and tools – such as Six Sigma, Design of Experiments (DOE), and SPC[1] – are required.

Of these, Six Sigma has earned itself a very good reputation. It is a disciplined, data-driven approach and methodology for eliminating defects in any process. To achieve six sigma level, a process must not produce more than 3.4 defects per million opportunities.

To enable a full understanding of the processes and to make continuous improvements, the implementation of Six Sigma requires the gathering, displaying and analysis of process data.

The statistical representation of Six Sigma describes quantitatively how a process is performing. The statistical and problem-solving tools are similar to other modern quality improvement strategies. However, Six Sigma emphasizes the application of these tools in a methodical and systematic fashion that leads to breakthrough improvements with dramatic and measurable bottom-line impact.

Six Sigma's measurement-based strategy focuses on process improvement through the application of improvement projects. This is accomplished through the use of a Six Sigma basic road map, DMAIC. The DMAIC – Define, Measure, Analyze, Improve, and Control – process is an improvement system for existing processes that fall below specification and which require incremental improvement.

To achieve the above-mentioned goals, Six Sigma uses many different statistical tools. However, the application of the SPC technique – and its associated control charts 1 – is the primary tool needed to achieve process variation.

SPC is a methodology for charting a process and quickly determining when a process is "out of control" (eg, a special cause variation is present). The process is then investigated using one or more of the process improvement tools (Pareto, DOE, Cause and Effect Diagram [C&ED], Failure Mode and Effect Analysis [FMEA]) to determine the root cause of this "out of control" condition. When the root cause is determined, a strategy is identified to correct it. The effectiveness of any changes can be verified using SPC 2.

The variation can be partitioned into two components: natural process variation, frequently called common cause or system variation (the naturally occurring fluctuation or variation inherent in all processes); and special cause variation (typically caused by a particular problem or extraordinary occurrence in the system/process).

Six Sigma methodology is a widely used in discrete and continuous manufacturing processes. ABB has experienced the far reaching benefits of Six Sigma and SPC in terms of quality improvement and profits

Within the company's research organization, an SPC system dedicated to monitoring and analyzing discrete manufacturing processes has been developed. A proven technique has been modernized, allowing ease of installation and effectiveness of decision support. It is currently being deployed, together with ABB's manufacturing execution system (MES), and is strengthened by the recent launch of a specific initiative within the group's Operational Excellence Program, which promotes the use of SPC systems in discrete manufacturing processes.

do not happen in isolation, a systems approach is needed when deciding how to best leverage performance. This is the single most important message from some of the great thinkers in the 20th century, which include W. Edwards Deming, Jay Forrester, Peter Senge and Eli Goldratt.

A good example of a system with variable and dependent events is a motorway at rush-hour. Each moving car is an event that is dependent on the movement of the other cars. The variables are different reaction times, driver skills, individual car performance, and tire and weather conditions. An increase in the number of cars will, at some point, create congestion, thus causing the flow to decrease. A "rubber band effect" is also created and is amplified along the congested queues. Drivers are forced to constantly adjust to deal with the erratic movement of the traffic.

The key to managing production is about understanding variation and its effects on the production and supply system as a whole.

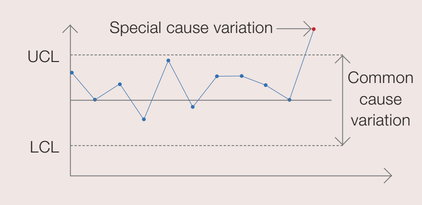
The same effect can be seen in production lines. With too many jobs on the shop floor, the flow is interrupted and the end result is poor overall productivity. This is where the reductionist approach clashes with the system approach. When striving for high local efficiencies in each sub-process, more jobs must be released to the shop floor than is optimal for a fast flow. The result will be excess Work-In-Progress (WIP), long throughput times and higher costs, not to mention reduced overall efficiency. This is another example of where intuition and best intentions without profound knowledge of fundamental relationships could lead to problems.

The most severe "rubber band effect" is usually seen in long Supply Chains, and is more commonly known as the "bullwhip effect". Increased delay in information and material transfer causes fluctuations in stock and availability. It would seem that the key to managing production is about understanding variation and its effects on the production and supply system as a whole.

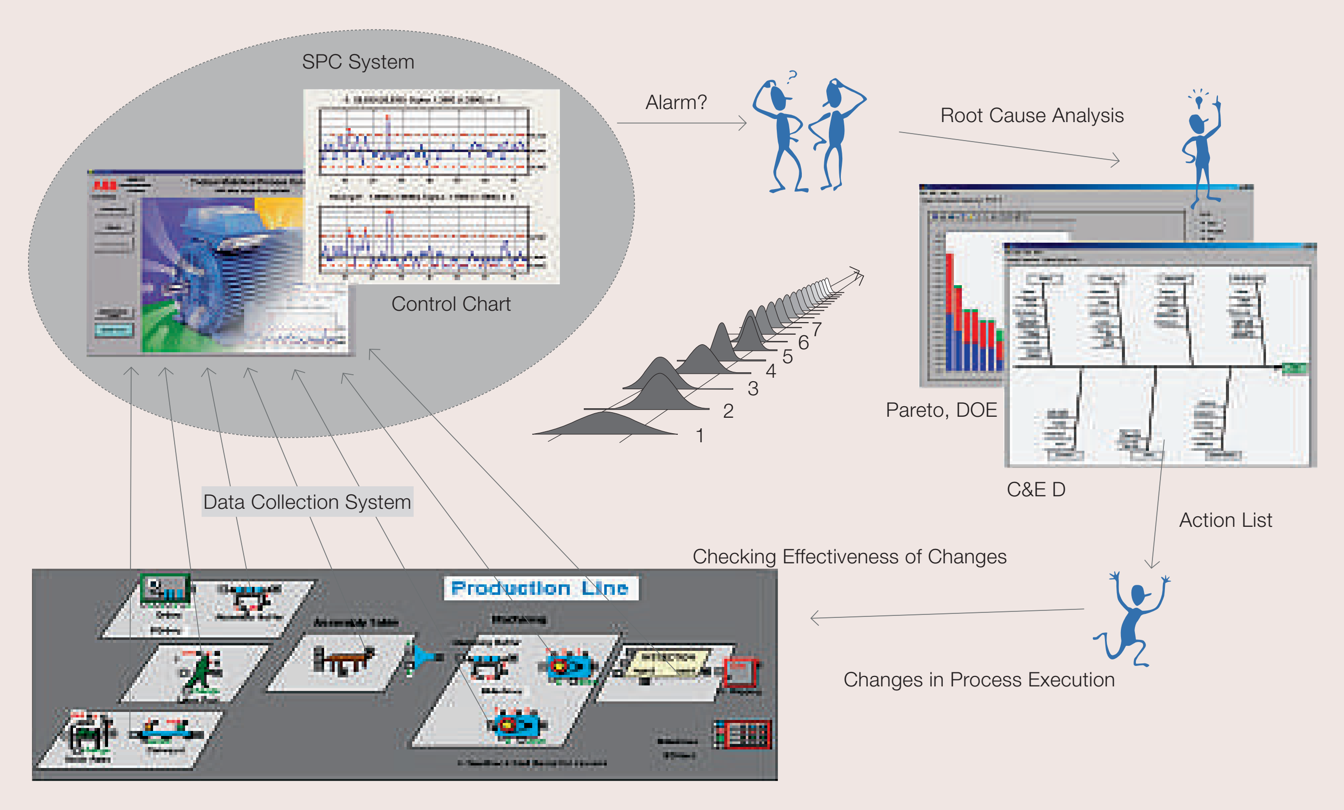
Managing variation – the flow perspective

One of the most fundamental laws of manufacturing implies that increasing variability always decreases the performance of a production system. This implies that by reducing variability, manufacturing processes become easier to manage and improve. Henry Ford and the famous Toyota Production System certainly thought along these lines. However what they seemingly failed to consider is that systems with a great degree of variation do

1 Control chart – common and special cause variation



2 Continuous reduction of variation – SPC basic road map



have the potential to improve if smart ways of managing such variation are found.

Managing variation – concepts

It was only towards the end of the 20th century that industry started to exploit the potential of producing a variety of end products from a common set of standardized parts. Two manufacturing paths are therefore available – either reduce variation or manage it 3. ABB developed the concept of Common Pull Production Practices (CP3)[1] to address both these aspects at the same time. CP3 focuses on the way production is controlled, how materials and information flow through a factory, and the way in which suppliers' processes are integrated into such a factory. Lean Manufacturing[1] and the Theory of Constraints (TOC)[1] are the underlying philosophies behind these practices.

In pull production, customer orders trigger production as opposed to a system that produces parts or pieces to a predetermined schedule. This makes the manufacturing process more coherent.

A key role in the CP3 concept is the introduction of Pull with WIP control, which is based on another fundamental manufacturing relationship, "Little's Law" Textbox 2:

WIP[1] = Production rate (PR)[1] × Throughput time (TPT)[1]

There are numerous other laws or relationships that govern manufacturing operations, many of which – Table 1 [2] – are related to those mentioned above. Understanding these fundamental factory physics laws is a "must" for efficient manufacturing management.

At the beginning of the 20th century, electric motors began to replace steam engines as the main source of power for machinery. BBC alternating current motors for one-, two- and three-phase current played an important part in this development

Textbox 2 Little's Law

Little's Law states that at any given production rate the average production throughput time is directly proportional to the amount of WIP. There are several important ramifications of this statement including:

- Firstly, if the throughput time is increased, more WIP is needed to achieve the same output. It is clear that queue times added to Enterprise Resource Planning (ERP)[1] systems to compensate for day-to-day cycle time variation, is one of the root causes of excess WIP in many plants.
- Secondly, it indicates that speed in production can be attained by limiting the number of jobs released to the shop floor. By simply "capping" WIP, flow speed can be significantly increased.

Little's Law can be seen as the "Ohm's Law" of manufacturing:

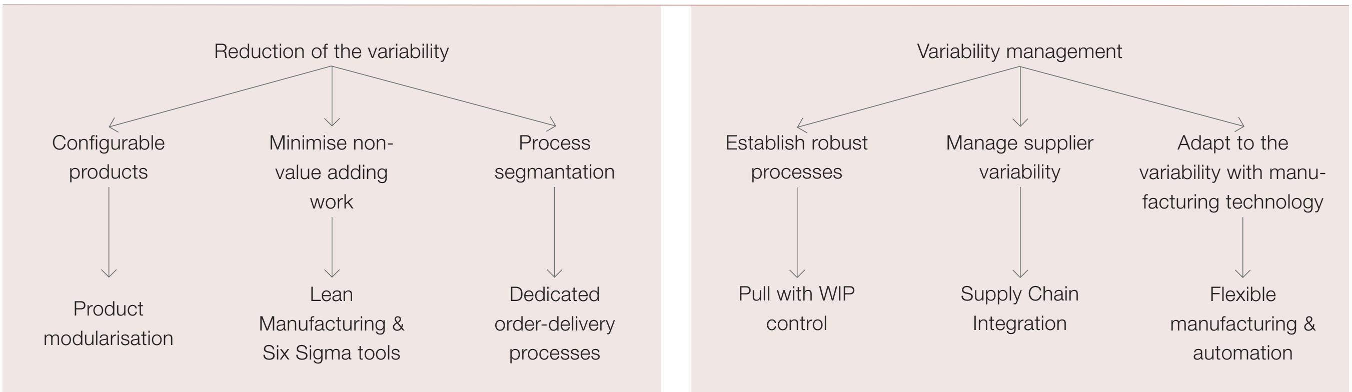
- If $R = \frac{V}{I}$, then $TPT = \frac{WIP}{PR}$ where: TPT represents the time required – **resistance** – for one product to flow through production.
- WIP represents the production **potential** in the system waiting to be completed.
- PR represents the **rate** of production flow.

Footnote

[1] See glossary an page 74. For TOC, see page 25.

[2] Adapted from "Factory Physics", Hopp and Spearman, 2000 2nd edition.

3 A set of options are indicated that either strive to reduce or manage variation



Understanding the manufacturing environment

It is important to understand each individual manufacturing environment. The variation and nature of interaction between activities differs depending on the environment. Let's first look at the process structure 4:

Table 1 A set of factory physics laws and fundamental relationships

Law (Variability):
Increasing variability always degrades the performance of a production system.

Corollary (Variability placement):
In a production line where releases are independent of completions, variability early in a routing increases cycle time more than equivalent variability later in the routing.

Law (Variability Buffering):
Variability in a production system will be buffered by some combination of inventory, capacity and time.

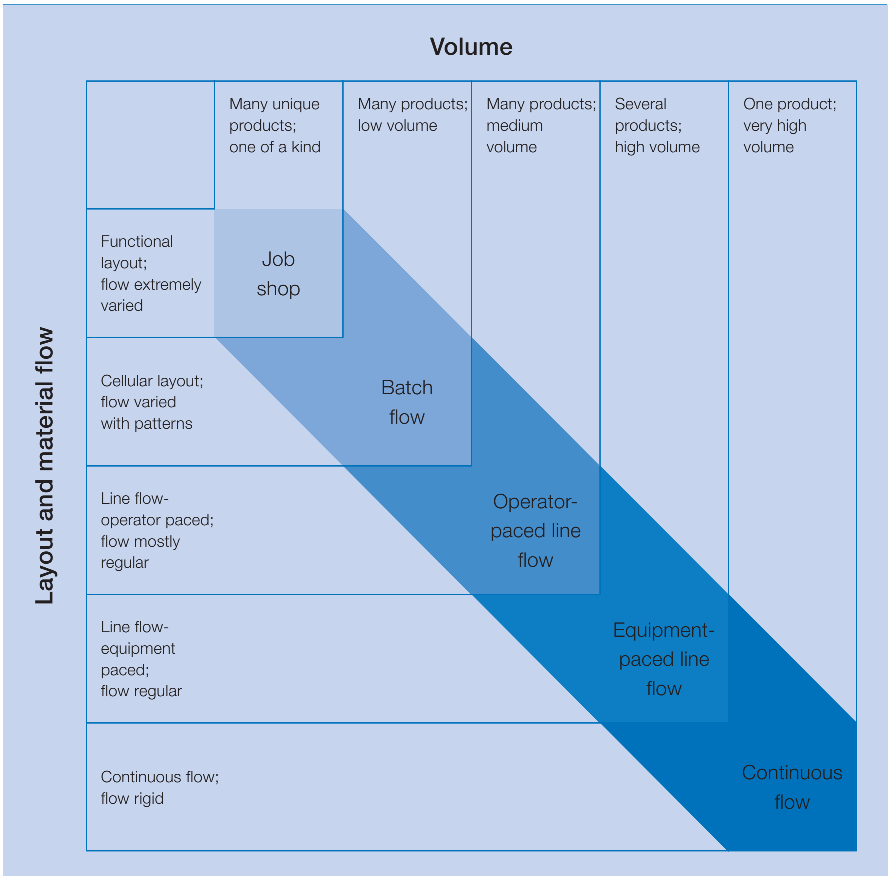
Corollary (Buffer flexibility):
Flexibility reduces the amount of variability buffering required in a production system.

Law (Capacity):
In steady state, all plants will release work at an average rate that is less than the average capacity.

Law (Utilization):
If a station increases utilization without making any other changes, average WIP and throughput time will increase in a highly non-linear fashion.

Law (Assembly Operations):
The performance of an assembly station is degraded by increasing any of the following:
- Number of components being assembled
- Variability of component arrivals
- Lack of coordination between component arrivals

4 The Product process matrix
(source: J Miltenburg, 1995: "How to formulate and implement a winning plan")



Environments located in the upper-left part have a much higher degree of variation than those in the lower right. The diagram also shows that "new" products initially produced in small amounts tend to position themselves in the upper-left part. After a successful product launch, and when initial systemic production defects have been ironed out, these products have the potential to move towards the lower-right corner.

This picture only presents one viewpoint. There are several others. The main lesson, however, is that each manufacturing environment is unique. The first step is to understand the fundamental physics of the specific manufacturing process, and especially how the parts work together as a system with special attention to the nature of variation within it. Without that understanding, any intuitive action might even make system performance worse.

If the challenges of variation are addressed with the right tools, process performance can be significantly improved. With CP3, excellent results are possible within six months. By mastering fundamental factory physics and extending this understanding to cover cross-enterprise collaboration, even more can be achieved. But that's another story.

Fredrik Nordström
ABB Oy, ABB Corporate Research
Vaasa, Finland
fredrik.nordstrom@fi.abb.com

Piotr Gawad
ABB Sp. z o.o.
ABB Corporate Research
Krakow, Poland
piotr.gawad@pl.abb.com

Adam Nowarski
ABB (China) Limited
ABB Corporate Research
Beijing, China
adam.nowarski@cn.abb.com

The manufacturing beat

Manufacturing within ABB

Steven Hegyi

For many years, ABB has been known as an engineering company. Its reputation for finding solutions to a host of challenging customer issues is well known. What is not often recognized is that ABB is also a manufacturing company with about 260 factories and production centers around the world. These factories range in size and product scope from small assembly and test centers focused on serving local markets to global focused factories with world wide product scope responsibilities. The following article takes a brief look inside some of ABB's factory types.

Manufacturing trends

ABB has many factories making a variety of different products 1. The manufacturing capabilities, production methods and business systems used in these factories also differ. While it is important for our customers to see the company as "one ABB", it is equally as important to understand this does not mean every single factory should be the same. This is because products differ in complexity and production volumes. Some factories produce high volume, low complexity products based on one basic design or design family while others make low volume, highly complex engineer-to-order products and solutions. Some are assembly and test plants that are highly dependent on outside suppliers while other factories have a high degree of vertical integration and make many of their key components. Thus, the challenge lies in determining how best to manage these differing production systems.

> Manufacturing processes are changeable and can be compared to the flow of water in a river: sometimes production is fast and sometimes it is slow.

Manufacturing processes are changeable and can be compared to the flow of water in a river: sometimes production is fast and sometimes it is slow. Sometimes production flows smoothly whereas there are times when obstacles block or slow the entire process down. One way to measure the efficiency of production flow is called "inventory". Fast processes have low inventory as a percentage of revenue while slow processes have high inventory. However, as is well known, inventory can be very expensive in terms of cash, warehouse size, poor quality, and management time and effort. Therefore, to minimize inventory, production flows must be optimized along with the supplier network connected to them. This requires an acute understanding of production flow characteristics before the optimization process begins.

The relationship between product complexity and production volumes can be classified into five basic types of production flows 2 3:

- Job Shop
- Batch Flow
- Operator Paced Line Flow
- Equipment Paced Line Flow
- Continuous Flow

These flows also represent the type of factory layout and management system that should be used for production planning and execution. This includes: process shops that are dedicated to one type of component or part; work cells where both workers and product move to work stations or machines in a pre-determined pattern depending on the product requirements; production and assembly lines dependent on either workers or machines to pace the production flows; and production lines that are dominated by closely interlinked equipment.

But the real challenge is determining how manufacturing should be run.

Each factory has a definable "beat" or in other words the pre-determined pace or rhythm that defines the maximum speed (and efficiency) at which material and work flow through the manufacturing process. In many cases, this beat can actually be heard. Different types of factories have different beats thereby necessitating different types of systems to optimize work flows. All too often however, the way factories are run is determined by Enterprise Resource Planning (ERP)[1] and/or "standardized" systems based exclusively on financial reporting desires or common IT platforms. And this can be a problem.

Job shop factories

At one time, ABB had hundreds of small, low volume job shop factories making products for local markets. These job shops typically produced

Footnote

[1] see glossary on page 74.

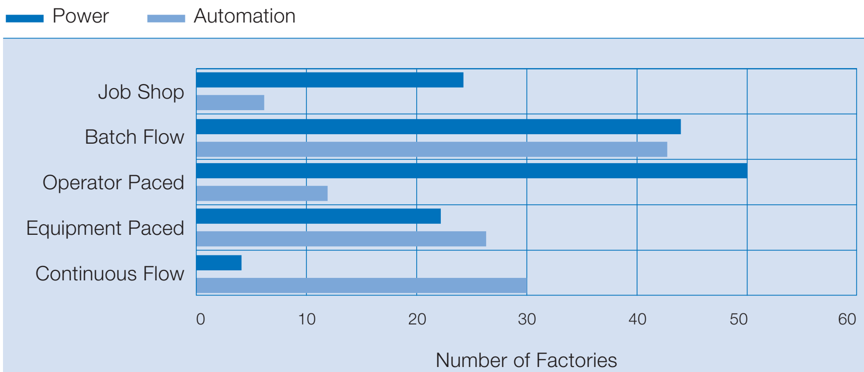
1 The size and scope of manufacturing in ABB

ABB is a large manufacturing company
- Automation products
  - 1,000,000 products/day
- Power Products
  - 1,000,000 products/year MV
  - 10,000 products/year HV

Large number of factories and software production centers
- 260 factories
- 140 software centers

Products rage from
- Complex Engineering-to-order products and systems
- Assemble-to-order configurations
- Standard catalog items

2 Production flow factory types within ABB's Power and Automation businesses



Manufacturing trends

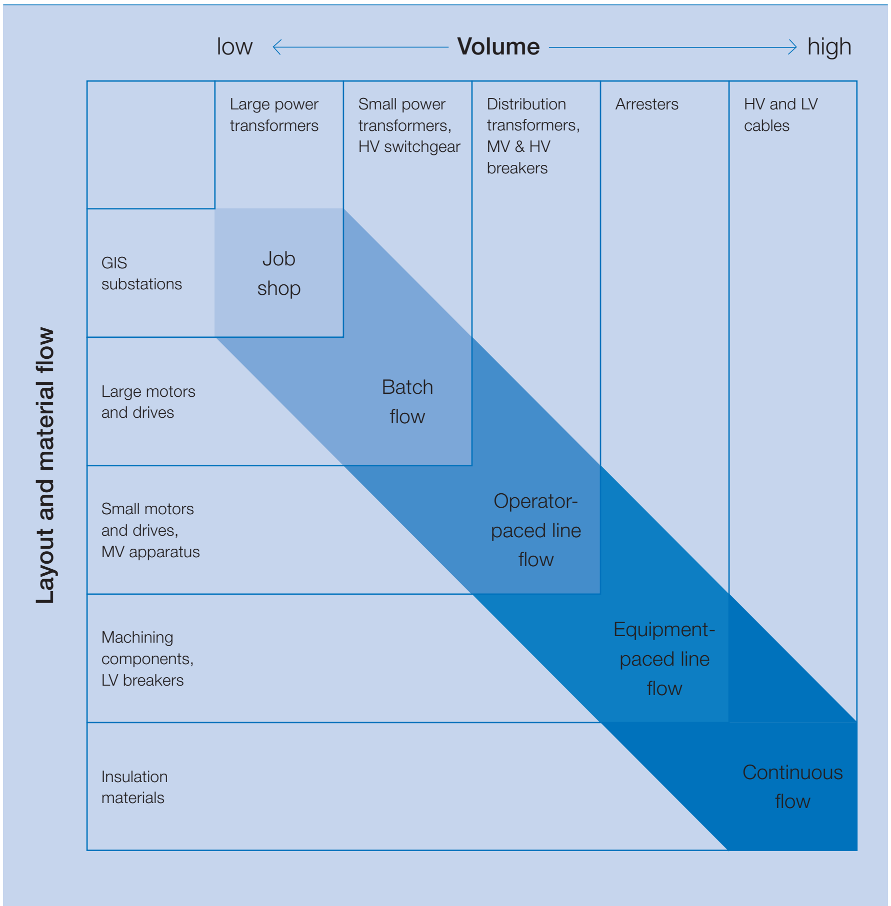
engineer-to-order products with a high degree of customization and complexity. Each customer order was a project and most required non-standard functionality or unique parts and components that put a heavy demand on Supply Management and Production Control. In a “job shop” factory, each part and component has to be individually planned, scheduled, ordered, processed and tracked in manufacturing. ABB’s large power transformer manufacturing plant (within the company’s Power business), in Bad Honnef, Germany is a perfect example. This factory produces only 50 to 60 transformers per year but each unit is a unique project requiring hundreds of hours of engineering design and thousands of labor hours in manufacturing. This is very similar to the robotic system integration factories within ABB’s Automation business. ERP systems using Material Resource Planning (MRP)[1] II are adequate in these situations although in larger factories the number of people needed to render them effective is usually quite large.

Batch flow factories

ABB shifted to the Focused Factory concept in the mid to late 1990s. This involved the redesign and simplification of many products and product families and the rationalization and elimination of numerous factories. By specializing (or focusing) a number of job shop factories on a limited number of complex and engineer-to-order product types, factory volumes were increased and throughput times shortened. Customer orders with the same or similar design requirements could now be grouped in manufacturing, and processed at the same time in “batches” instead of one at a time. This type of manufacturing can be found in a number of ABB plants including: the New Berlin, Wisconsin factory for drive systems (Automation business); the Lake Mary, Florida plant for MV switchgear; and the Lodz, Poland insulation kit center. In each case, products are designed to customer specifications even though hundreds are produced in the end.

Robot and large distribution transformer manufacturing are other good examples. The batching of products is important because it enables a factory to be arranged into “cells” of different types of machines – or work stations – for increased efficiency with less work-in-process inventory. Batch flow production starts within an individual cell then moves to other production cells or areas within the factory depending on the product design requirements. Traditional factory planning and scheduling tools can be severely tested using this concept, although some modified and customized systems in ABB have proven very effective. Planning and factory management systems based on Theory of Constraints (TOC)[2] using bottleneck management techniques have also shown potential but the wide variations in product complexity and work content are a definite challenge when used exclusively.

3 Five types of production flows (or manufacturing processes) classify the relationship between product complexity and production volumes



The batching of products is important because it enables a factory to be arranged into “cells” of different types of machines – or work stations – for increased efficiency with less work-in-process inventory.

Operator paced flow factories

As the complexity of products and production decreases, standardization of parts and components increases and the manufacturing work content becomes more uniform. Products are built on higher volume assemble-to-order production lines. This type of manufacturing is very common in ABB, especially in the group’s Power business. ABB’s MV apparatus manufacturing in Dalmine, Italy and the distribution transformer plant in Jef-

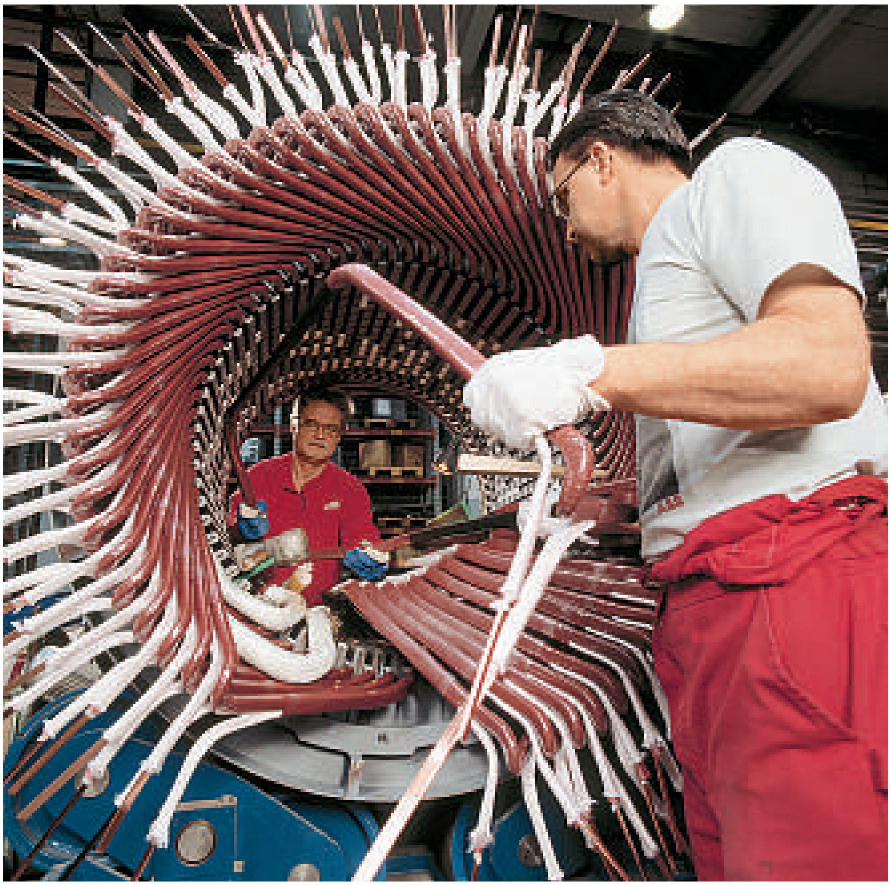
Footnotes

1) see glossary on page 74.

2) see textbox on page 25.

ferson City (Montana) are excellent examples. Production volumes in both plants extend into the thousands.

Automation's LV switchgear plant in Bergamo, Italy is another example. The pace of production is controlled by individual workers or work teams. Bottlenecks or production constraints are readily identified by a build up of work-in-process (WIP)[1)] inventory at a few key stages of production. The key to operator paced manufacturing is to keep a constant tempo or pace throughout factory. This constant pace not only facilitates the optimization of resources in the factory and simplifies the overall production planning process, but it also enables much of the plant's inventory to be managed through the use of kanbans and Just in Time (JIT) supply. In fact, by using a "pull" type production system (one out, one in) and applying TOC concepts, some ABB factories have virtually eliminated the need for detailed planning and scheduling of many of their factory processes.



The key to operator paced manufacturing is to keep a constant tempo or pace throughout the factory.

Equipment paced factories

Equipment paced production systems are similar to operator paced manufacturing but are much faster, have higher volumes, and less product design complexity and variation. Most parts and components have been standardized. Automation plays a major role and workers are paced by the speed of the machines. Product designs are fairly uniform in the sense that they all require the same amount of machine and/or labor time, and most client customization takes place at the end of the production line. Again, bottlenecks or constraints in manufacturing can be easily identified by WIP inventory in front of a process. Examples of this type of manufacturing in ABB include LV breaker manufacturing in Germany and Sweden's HV surge arrestor plant where hundreds of thousands of products and components are produced. Pure pull production systems excel in machine paced factories and TOC production planning is most effective.

Continuous flow factories

Continuous flow production systems are characterized by uniform designs with very high production volumes. Paper insulation manufacturing in ABB Pucaro is an excellent example. These factories make essentially one type of product or product design and operate 24 hours a day, 6 to 7 days a week. Production is continuous as it flows through the factory. Factory optimization is achieved by maximizing machine utilization. There is usually little actual in-process inventory, and JIT supply of raw materials is very common. Machine stoppages are deadly in this type of manufacturing, so preventive maintenance is a dominant factor in the production planning process.

ABB has many factories making a variety of different products. Success factors for managing and optimizing these factories dictate a clear understanding of the type process flow within manufacturing.

One size definitely does not fit all.

Steven Hegyi
ABB Power Technologies Management Ltd.
steven.hegyi@in.abb.com

Fasten your seatbelts

Global Supply Chains ahead

Jonathan L. S. Byrnes

Designing and operating a global Supply Chain these days is like driving your car on a winding country road: the faster you go, the sooner you reach your destination … unless you go too fast in the wrong places.

This edition of ABB Review includes a pair of articles exploring the yin and yang of globalization – the benefits and accompanying risks; "No risky business" (page 19) and "Shortest road to China" (page 28). The bottom line is that the economics of lean global Supply Chains make the benefits and risks inevitable, but it is the wise management of these risks that makes the difference between success and failure. Increasingly, the huge potential benefits, coupled with the complexity of risk management, make Supply Chain Management both more important and more challenging than ever before.

I recall visiting a large Mercedes plant in Germany about nine years ago. The plant was highly automated. My guide proudly explained how the robots worked and how fast a car could be made. It was very impressive.

I then asked about the cycle time that the customer would see if he or she ordered a car. The answer was that it took only a day or two to make the car, but three months to schedule its production. And another month to move it to the customer.

Today, production and supply sources are increasingly located in low-cost countries, often in Asia. This lengthens supply lines and cycle time, causing difficulties in forecasting the right quantities to produce, in responding to changes in the market, and in recovering from supply disruptions 1.

At the same time, limited transportation capacity and congestion, particularly at U.S. West Coast ports, is creating more and more uncertainty in transit times, and less and less ability to respond to market changes.

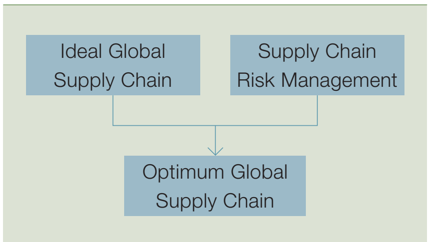
A lean global Supply Chain is a worthy goal, but the key to success lies in understanding the design and nature of the compromises needed to make it work.

All this should be seen in the context of companies driving inventories from their Supply Chains[1)] as they seek to increase the velocity of their product flow – until their Supply Chains resemble pipelines in which all products are constantly in motion. Fast, lean and robust, how can you have it all?

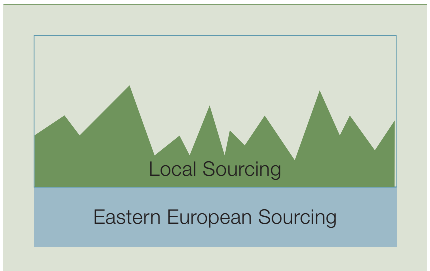
The answer lies in the analogy at the beginning of this article. Asking the question, "How can you have it all?", is like asking how you can drive the car faster and faster. The trick is to know when, where, and how to apply the brakes. This is Supply Chain differentiation, doing the right things for the right products at the right times. Without it, global Supply Chains will fail.

Consider Zara, the Spanish fashion retailer. For any particular SKU (Stock Keeping Unit), Zara sources much of the product in Eastern Europe, where costs are low but lead times are high. At the same time, it sources a portion of the same product in Spain, where costs are high but cycle time is fast. Consider Zara's demand graph in 2: It looks like waves on the ocean. The company sources the waves (fluctuating portion of demand) locally, and the underlying ocean (stable portion of demand) in Eastern Europe. This is Supply Chain differentiation in action, knowing when, where, and how to source different elements of production.

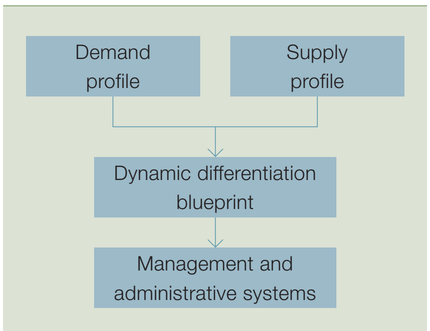
1 Optimum global Supply Chain



2 Zara Supply Chain



3 Supply Chain differentiation master plan



Supply Chain differentiation can take place along several dimensions. For example, a company might source/produce most of its products locally early in the lifecycle when demand is uncertain and stockout costs are high, then shift production abroad later in the lifecycle when demand is known and stable, and move the bulk of production closer to the market again toward the end of the lifecycle when demand is again uncertain.

For companies with fixed production facilities, inventories can play a critical role. At some points, or for some elements of demand, inventories should be higher, while at other times, supply lines can look more like a flowing pipeline. Expediting capabilities serve the same function. Here, global Supply Chain configuration is dynamic and adapts to changing circumstances.

A lean global Supply Chain is a worthy goal, but the key to success lies in understanding the design and nature of the compromises needed to make it work. Again, paradoxically, running a lean global Supply Chain is analogous to driving fast: knowing when, where, and how to apply the brakes is the key to making the whole trip go faster.

Running a lean global Supply Chain is analogous to driving fast: knowing when, where, and how to apply the brakes is the key to making the whole trip go faster.

Dell utilizes Supply Chain differentiation in another way. It lies at the heart of Dell's powerful business model. As most people know, Dell produces products using a make-to-order system, yet the company has a lead time of several months for key components. How does it do it?

The answer again is Supply Chain differentiation. While Zara focuses its differentiation on the supply side,

Footnote
[1)] see glossary on page 74.

Dell does the same on the demand side. Dell calls this "sell what you make," or demand management. This occurs on two levels.

First, in weekly meetings, the heads of Sales, Manufacturing, and Purchasing get together to balance supply and demand. If a particular product has more demand than the supply of inbound components can support, they can expedite additional components at a significant additional cost. Alternatively, they can work to shift demand to other products that have an adequate supply of components.

Developing a Supply Chain master plan is the key to unlocking the potential value in lean global Supply Chains.

Second, every customer service representative has visibility into what products can be made every day, and have incentives to steer customer purchases toward these products. They can do this by offering deals on these products, or by persuading the customers that these particular products are more appropriate purchases. Without this two-step process, Dell's ultra-lean Supply Chain simply would not work.

How can a company use the principles of Supply Chain differentiation to design and operate a dynamic, lean global Supply Chain? The most important first step is to develop a Supply Chain Differentiation master plan. This plan 3 should have four components.

- Demand profile. This is a disaggregated analysis of demand that identifies which portions are stable, which are fluctuating, how this changes over time, and what the value is of meeting the fluctuations.
- Supply profile. This is a disaggregated analysis of supply that identifies what suppliers, plants, and transporters can do, how flexible they are, and the cost and availability of volume changes.
- Dynamic differentiation blueprint. Based on the demand profile and supply profile, this specifies in advance how supply and demand can be managed and shifted over time in a dynamic, well-coordinated fashion.
- Management and administrative systems. This component of the Master Plan lays out how planning, coordination, information links, metrics, and compensation should be structured to accommodate dynamic Supply Chain differentiation (eg, if expediting costs go up, budgets need to be adjusted).

Developing a Supply Chain master plan is the key to unlocking the potential value in lean global Supply Chains. Without a Master Plan, even the best-engineered efforts may not perform as expected.

Jonathan L.S. Byrnes

Jonathan L.S. Byrnes is Senior Lecturer at MIT, where he teaches Supply Chain Management and Integrated Account Management. He is also President of Jonathan Byrnes & Co., a specialized consulting company.

Jonathan L.S. Byrnes
MIT
jlbyrnes@mit.edu
http://mit.edu/jlbyrnes

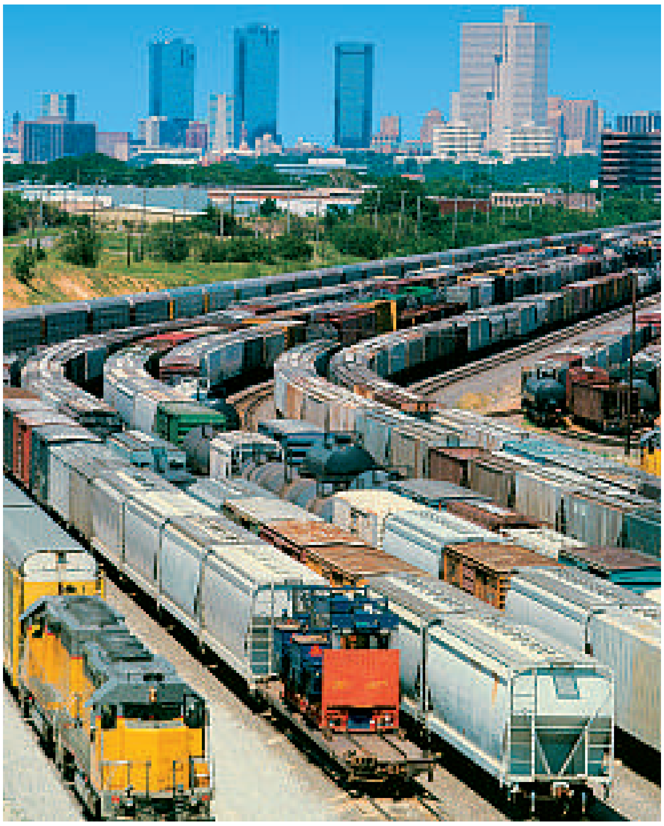
No risky business

Risk management in global Supply Chains

Bill Vick

Pressure to supply the best possible product at the lowest possible cost has, over the last decades, pushed manufacturers to continually analyze, optimize and reinvent their Supply Chains. The transition to global sourcing and "just in time" logistics, while offering significant gains in terms of costs and agility, also exposes factories to additional risks. A disruption in a sub-supplier's manufacturing or shipping process often has significant and long term repercussions for a manufacturer.

To protect itself, a company must assess its Supply Chain for risks and must implement a strategy to handle these. Risk factors include supplier and customer problems, market and currency exchange-rate developments, quality shifts, internal disruptions and delays, accidents and catastrophes.



In the current and developing climate of global communications, major companies will compete on the basis of their entire value chains and not just on the basis of local operating units. Successful companies will be the leaders in terms of time to market and speed of response. Throughput times[1)] (TPT) and replenishment times will form a fundamental pillar of competitiveness. The globalization of Supply Chains, uncertainties of supply and demand as well as shorter product technology life cycles contribute to an increased exposure to risk in the Supply Chain. Disruptions to global product flow can be extremely costly, if not catastrophic to the survival and continued success of a business. Thus, the ability to identify disruptions, recover from them and redesign to prevent recurrence is critical to future business success. In the light of the ABB strategy of "Global Focused Feeder Factories", combined with the strategy of low cost country sourcing, the stability and security of Supply Chains must be a high priority business objective.

The ability to identify disruptions, recover from them and redesign to prevent recurrence is critical to future business success.

Disruptions can come in many different forms with wide ranging impact to business. The trend towards lean/just-in-time (JIT) manufacturing, global sourcing and the increased need to be more responsive to customer demands has reduced the traditional buffers against Supply Chain disruptions. Cost savings and production efficiencies have exposed Supply Chains to significant commercial and financial risks.

Numerous researchers have explored Supply Chain disruptions and the results represent a wakeup call to the concept of risk management.

Michelman [1] found the following impact to companies experiencing disruption:

- Of businesses that have experience a prolonged disruption of 10 days or more, 73 percent close or suffer long-term impact.
- Forty three percent of businesses suffering a disaster never sufficiently recover to resume.
- Of those that do reopen, only 29 percent are still in operation 2 years later.

Textbox 1 Categories of risk

Categories of risk – Automotive Model

- Financial
- Strategic
- Hazard
- Operational

Categories of risk – Chopra & Sodhi

- Disruptions
- Delays
- Systems
- Forecast
- Intellectual Property
- Procurement
- Receivables
- Inventory
- Capacity

Categories of risk

There are several different risk models defined in literature. These vary from the fairly simple models proposed by Deloach [2] and Juttner [3], where risks are categorized as internal, external and process; to the more complex model defined by Chopra and Sodhi [4], where risks are divided into nine different categories, as shown in Textbox 1.

Regardless of the model used, there are several key questions that need to be answered when developing a risk profile. These are as follows:

- What risks are important to the company and how can they be identified?
- What is the potential likelihood of these risks and their expected impact?

Risk mapping and actions

Supply Chain risk management is not the sole responsibility of Supply Management. It is important to establish a multi-disciplinary team comprised of experts in the fields related to the nature of the risks identified. In most large organizations, the portfolio of products and risks is such that it is necessary to focus risk management efforts around the narrow group of risks that offer the highest potential impact on the business. The nature of the risk and the assessment of its probability of occurrence will determine the type of resources needed on a risk management team. The categorization of risks is one of the first tasks of a newly established risk management team. Having identified the risks in the Supply Chain, they should now be plotted on a 2-dimensional matrix map of probability 1, as shown below and the focus of effort should be those risks that are located in the top right hand quadrant.

Footnote

1) see glossary on page 74.

The process of addressing the high probability/impact risks involves three stages:

1. Disruption discovery

To reduce or eliminate the negative impact from a Supply Chain disruption, there needs to be an effective means of detection in place. Early recognition of disruptions is vital to risk mitigation. The appropriate systems need to be established to provide consistent and regular updates of key metrics.

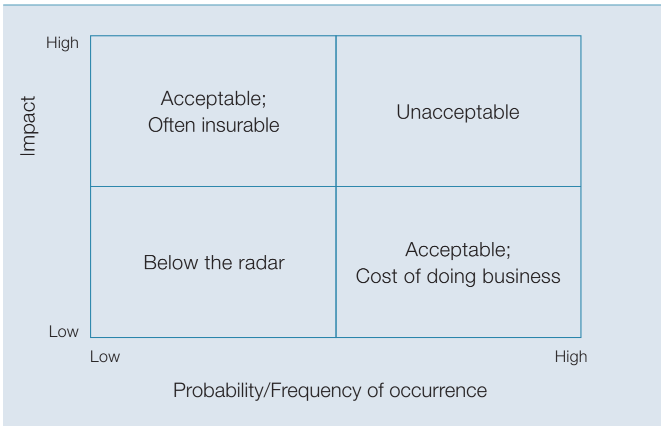
2. Disruption recovery

Once the disruption is discovered, an effective means of recovery needs to be established. This can involve proactive options such as buffers, predictive analysis or preplanned scenarios with a variety of options. Another approach is to adopt a more reactive mode, with options such as overtime, premium freight and expediting.

3. Supply Chain redesign

The nature of the disruption and the means of recovery will provide insight into how the Supply Chain could be redesigned in order to make the system more resilient and less susceptible to the risks. This can involve characteristics such as flexibility, strategically placed excess capacity and visibility. In every case, a full understanding of the total Supply Chain costs and tradeoffs is necessary in order to be able to make objective decisions.

1 Supply Chain risk map



Drivers of risk

Every Supply Chain can be defined by a number of key characteristics that drive the risks associated with the chain. These drivers can be described as follows:

■ **Supply Chain design characteristics**
The design of the Supply Chain will impact the level of risk in the chain. Factors include clustering of suppliers, transportation modes used and numbers of tiers in the Supply Chain.

■ **Product characteristics**
The product itself can be a risk driver. Factors include complexity of the part, packaging requirements, value of the product, uniqueness of the part and storage requirements.

■ **Market characteristics**
Market factors can increase levels of risk in the Supply Chain. Factors include: product demand, seasonality issues and competitors.

■ **Supplier characteristics**
The characteristics of the supply base can also have a significant impact on Supply Chain risk. Factors include supplier location, supplier relation-

ships, capabilities, flexibility and the use of proprietary technology.

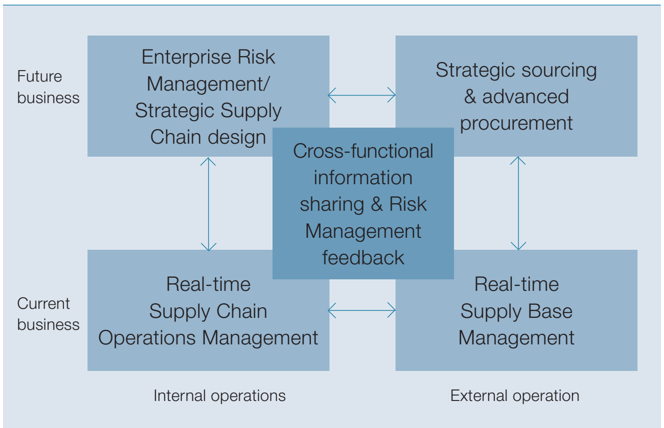
The way that these characteristics drive risk needs to be fully understood in order to design and manage a risk-resilient Supply Chain.

Risk management frameworks

What can managers do to prepare for Supply Chain risks and disruptions?

The approach is a delicate balancing act between inventory, capacity and other mitigation strategies in an environment where Supply Chains are dynamic and fast-changing. The management of risks is a complex process. Individual risks are often interconnected and the actions taken to mitigate one risk could negatively impact another. The challenge to managers is to intelligently position and size Supply Chain reserves without decreasing profitability.

2 Organizational functions with Supply Chain risk management responsibilities



Recent research carried out by the Supply Chain Resource Consortium [5] identified four risk management functions 2 and 18 best practices Textbox 2 that companies can explore to enhance Supply Chain operational resilience and risk management.

> The challenge to managers is to intelligently position and size Supply Chain reserves without decreasing profitability.

Textbox 2 18 best practices for risk management in global Supply Chains

Strategic sourcing and advanced procurement

1. Screen and regularly monitor current and potential suppliers for potential Supply Chain risks.
2. Require critical suppliers to produce a detailed disruption-awareness plan.
3. Include the expected costs of disruption and operational problem resolution in the sourcing total-cost equation.
4. Require suppliers to be prepared to provide timely information and visibility of material flows that can be electronically shared with your enterprise.

Supply base management

5. Conduct frequent teleconferences with critical suppliers to identify issues that may disrupt daily operations and tactics to reduce them.
6. Seek security enhancements that comply with the Customs-Trade Partnership Against Terrorism (C-TPAT), Container Security Initiative, and other initiatives.
7. Test and implement technologies to track containers to enhance global inventory visibility.
8. Conduct a detailed incident report and analysis following a major disruption.
9. Create "exception" detection/early warning systems to discover critical logistics events that exceed normal planning parameters.
10. Gather Supply Chain intelligence and monitor critical supply base locations.

Real-time operations management

11. Improve visibility of inventory buffers in domestic distribution channels at a part level.
12. Classify buffered material by its level of criticality.
13. Train key employees and groups to improve real-time decision-making capabilities.
14. Develop decision-support tools that enable the company to reconfigure the supply chain in real time.

Enterprise risk management/strategic Supply Chain design

15. Develop predictive analysis systems that incorporate intelligent search agents and dynamic risk indexes.
16. Construct damage-control plans for likely disruption scenarios.
17. Understand the cost trade-offs for different risk mitigation strategies.
18. Enhance system-wide visibility and Supply Chain intelligence by using improved near-real-time databases.

None of the companies surveyed had implemented all 18 of the best practices, nor is it suggested that all 18 are necessary in order to develop an effective risk management program. A few well placed best practices can significantly improve the awareness, resilience and disruption management capability of an organization. Doing something is always better than doing nothing, and a cost/benefit/impact analysis should always dictate the actions and their relative priorities.

Bill Vick
ABB Inc.
Raleigh NC, USA
bill.vick@us.abb.com

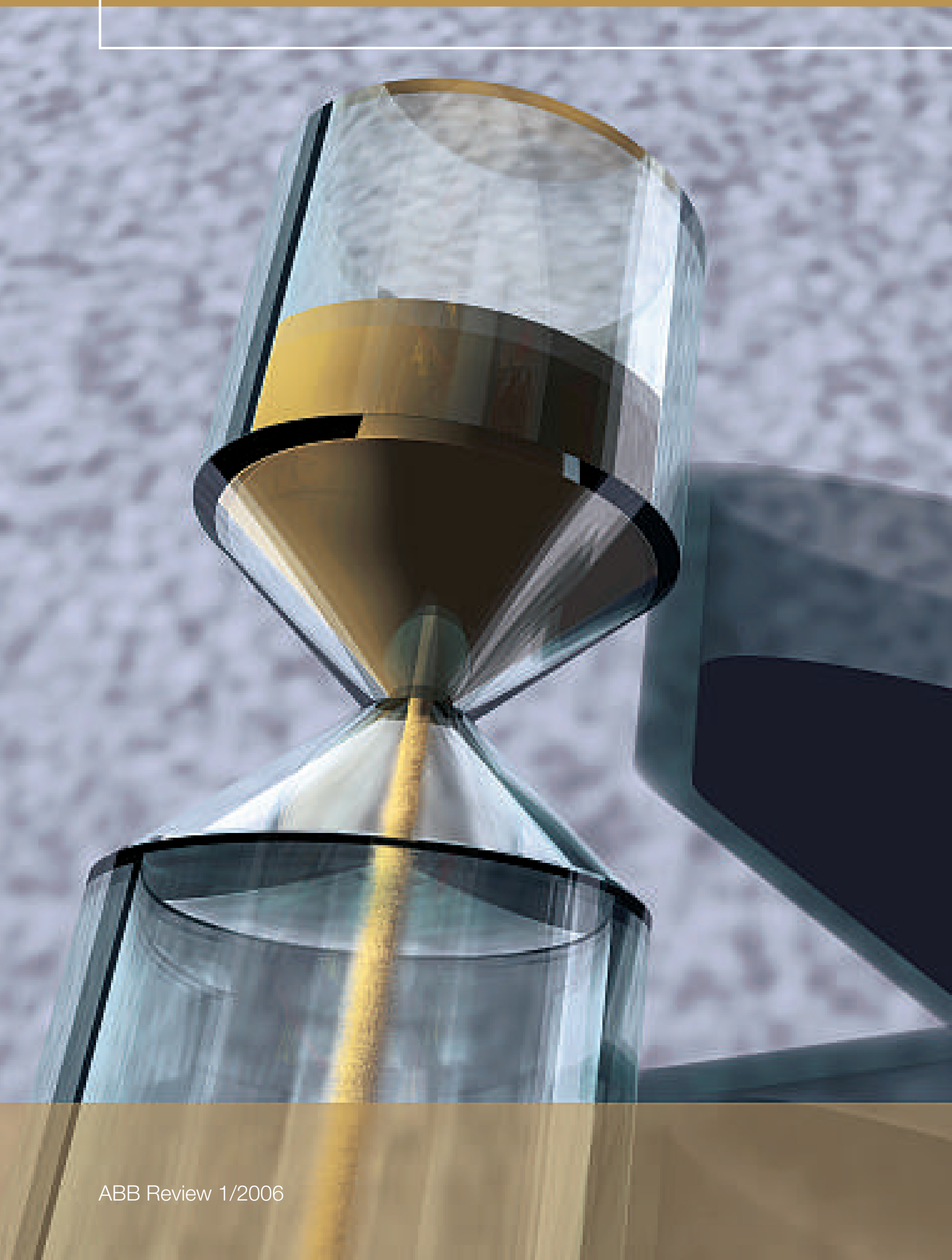
References

[1] Michelman, Paul. HBR 2005
[2] Deloach, James
[3] Juttner, U et al. Supply Chain Risk Management. International Journal of Logistics, 2003
[4] Chopra, X and Sodhi Y Sloan Management Review, 2004
[5] North Carolina State University Supply Chain Resource Consortium. Supply Chain Management Review January/February 2005

Successful navigation of uncharted territory

Coping with moveable bottlenecks in discrete manufacturing

Antonio Gonzalez, Luis G. Nebra, David Sanz, Krzysztof Sowa-Piekło



It is often heard that time is money. This is certainly true for Supply Chains. A swift throughput implies not only fast delivery, but also high productivity as resources are freed quickly. In analogy to a sand-glass where the neck constrains the sand flow, the slowest stage of a Supply Chain limits overall throughput. Just as the glass does not function without sand, the Supply Chain slows unnecessarily when its bottleneck runs below capacity. Strategies exist to prevent this, but for most of these the bottleneck is a single production stage. What happens if the bottleneck shifts between stages due to product variability?

To improve advanced planning and scheduling at the production Supply Chain of ABB's transformer plant in Zaragoza, Spain, a planning tool called DIVINER 3.0 has been developed to manage moving bottlenecks. It uses the order backlog to predict the future evolution of the production Supply Chain, anticipating changes instead of reacting to them when they occur.

Demand driven manufacturing

When a production line builds customized variants, the challenge of effectively handling Supply Chain bottlenecks grows if, instead of always manifesting itself in the same process stage, the bottleneck shifts from one stage to another. The associated control problem becomes highly dynamic and difficult to solve efficiently. Reformulating the dynamic problem as a sequence of fixed bottleneck solutions has resulted in major performance improvements at ABB's transformer plant in Zaragoza, Spain.

The importance of accurate scheduling

A strategy for accurate scheduling of the entire manufacturing Supply Chain must synchronize the entire workflow, stretching from suppliers through manufacturers to wholesalers. The end-customer can be given an accurate and reliable date of delivery.

An optimized schedule not only provides precise completion dates for each production phase but also uses these to tighten the flow along the whole chain.

> A strategy for accurate scheduling of the entire manufacturing Supply Chain must synchronize the entire workflow, stretching from suppliers through manufacturers to wholesalers.

Not such a simple world

Discrete manufacturing is a broad field in which challenges vary broadly from one industry to another. At the extremes are mass-manufactured consumer goods, where large quantities of identical products are produced, and for example, shipbuilding, where it is rare for even two fully identical ships to be commissioned. ABB's Zaragoza plant has a mixture of these two concepts leading to a hybrid environment. Discrete manufacturing can be divided roughly into two categories:

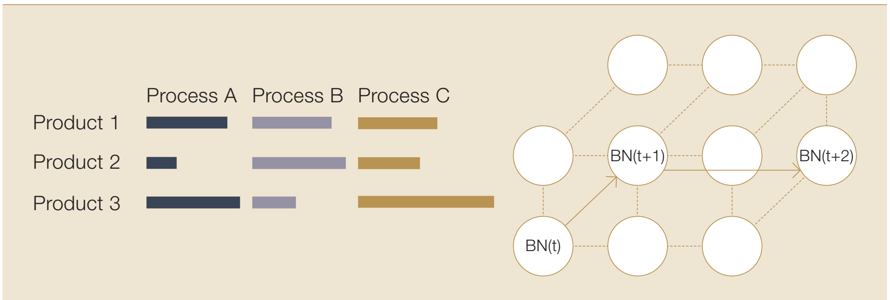
- *Mass production* (make to stock): High efficiency and low costs are a "must". The "make to stock" model disconnects the production rhythm from market fluctuation. This is especially the case for consumer goods, where the customer expects a very short lead-time from ordering to delivery. Normally, production volumes are very large, with long production series of the same product and short cycle times. The uniformity of production means that the bottleneck always occurs in the same place. This high predictability is reflected in the optimization strategy. A lean Supply Chain is the key market qualifier[1] for this style of production (especially on the European market). The principal remaining variability is the natural randomness (quality rejections, breakdowns, failures, sick leaves, delays etc), which can be absorbed by a relatively small buffer.
- *Custom production* (make to order): Products are designed to order and this customization causes inherent variability. Besides the same omnipresent non-deterministic variability that effects mass-production, further variability is caused by customer specifications. The production bottleneck and cycle times are order-dependent and therefore variable. An agile Supply Chain is the key element for being successful in this type of market.

Can these two strategies be successfully combined so that custom production can be reduced to the variability of mass production? Can a line be both agile and lean?

To answer this question, one should consider the model for managing complex, highly variable environments using the Theory of Constraints (TOC) Textbox on next page. It is observed that in each process with interdependent events, there is always one point with the lowest throughput. This bottleneck determines the production rate of the whole process. If the bottleneck is fixed, it can be used as the control point. In this case, the rules and links between processes do not change with time. CONWIP[2] and CONLOAD[3] are examples of this type of control philosophy. In such a case, pull signals[4] (typically using cards) control the flow in the system.

These approaches focus on systems with a fixed bottleneck. From the point of view of traditional production technology the moveable bottleneck problem is uncharted territory; the solution requires original thinking. One significant difference between a "make to stock" philosophy and a design to order one is that a variant defined by a customer specification can feature in the latter, leading to "non-standard" production. Such customized products will have different cycle times per operation.

1 Multi-project job shop environment with moving bottleneck as a result of product and process variability



Footnotes

1) The key market qualifier is a resource that, at a minimum, every company must have to compete in a given market.

2) CONWIP (CONstant Work In Progress) is a line-scheduling strategy in which a new job is allowed to enter the line whenever an older one leaves, or more generally, the number of jobs in progress is kept below a defined threshold.

3) CONLOAD (CONstant LOAD) is a refinement of Conwip that additionally takes into account processing times.

4) A pull signal is a signal that requests the replacement of an exhausted resource.

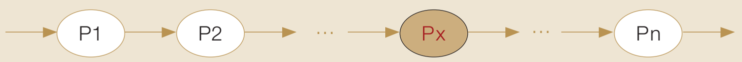
In such a multi-project environment where a large number of different units are produced, a shifting of the bottleneck over time is likely if the variability of products is sufficiently high. This is the case at the Zaragoza plant 1.

One way to avoid movement of the bottleneck is to over-dimension every process. This over-dimensioning is called protective capacity. It is a simple but costly mechanism for transforming dynamic bottlenecks into fixed ones, thereby permitting a single control point. However, this approach requires a larger-than-needed investment. The protective capacity acts as a buffer against variation, but as with any inventory, not all features of excess capacity are beneficiary. The optimal dimension (and affordability) of the protective capacity must be determined.

The size of the protective capacity will depend on the variability of the process. The greater the variability, the more excess capacity will be required. A "design to order" manufacturer wishing to adopt a make to stock control strategy could use this approach. Depending on the customer specification, some processes may be

How to control the chain with TOC

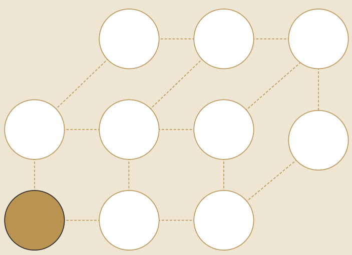
In every system composed of individual processes there is always one process with the smallest capacity. In other words, this process will be the slowest of the chain, and have the longest cycle time.



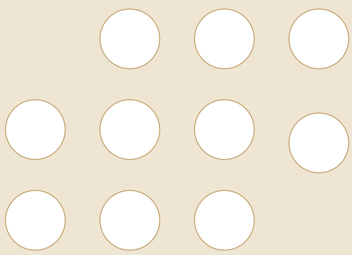
The throughput of the whole system is determined by the slowest process (Px), marking the tact cycle of the output. Px is called the bottleneck, acting as the constraint of the complete flow.

The Theory of Constraints (TOC developed by Eliyahu Goldratt) focuses the control of the system on the bottleneck. Since the output is limited by the slowest process, the other processes should depend on the bottleneck to avoid any inefficient stock between process stages. In other words, the bottleneck is the master process dominating the flow.

The dependences between Px and the other processes are used to permit the whole system to be controlled by acting only over Px. It is much easier to control the complete system focusing on one point, than having to deal with a more complicated one with many degrees of freedom.



One point to control the system

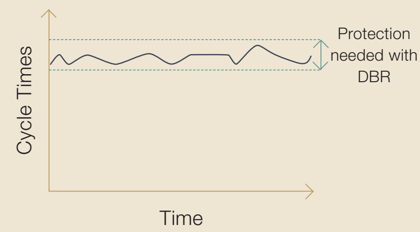


More than one point needed to control the system

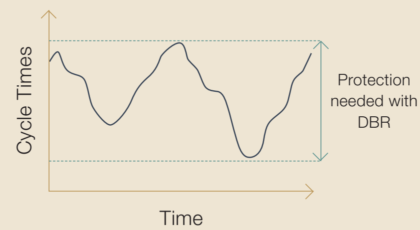
In this way, there are five steps in TOC showing how the chain should be controlled in order to obtain best operation:
1. Identify the bottleneck (BN) in the System.
2. Decide how to exploit it.
3. Subordinate the other processes to the BN.
4. Try to remove the BN.
5. If the BN is removed, return to step 1.

Px is protected by buffers immediately preceeding it trying to avoid any starvation of the bottleneck. If Px is stopped, then the output will be directly reduced. All other buffering is unnecessary. In the same way, in a project management strategy, buffers (time) protect the processes belonging to the critical chain.

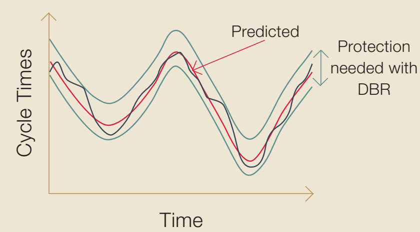
2 Required protection with DBR for standard processes with natural variability



3 Required protection with DBR for design-to-order processes with changes in product mix



4 Required protection with Diviner for design-to-order processes with changes in product mix and natural variability



overloaded with one product while others are running below capacity with another.

Essentially, over-dimensioned buffers reduce the interdependency of subprocesses. Some companies are faced with process cycle times whose average value is similar to their standard deviation. The correlation coefficient between processes is around 0.3–0.4. This shows that the processes within the system are almost independent. In such cases, a huge protective capacity is necessary to keep the bottleneck in the same place (more than 25 percent of the perfectly balanced capacity). Bitter facts, indeed! There is, however, another solution.

DIVINER 3.0 analyses the variability resulting from the product mix in backlog and uses this to optimize the future behavior of the system using discrete-event simulation.

This solution makes use of the fact that the variability is not totally random. A "make to order" factory has an order backlog that it can use as planning data. In this way, the protective capacity can be divided into its two component parts: the basic "make to stock" style capacity 2, and the additional "make to order" style component 3 resulting from customer specification variability 4.

An important market qualifier in Europe is the price. There are considerable rewards for reducing protective capacity. Can such reduction be safely achieved in this type of environment?

Advanced control with DIVINER 3.0.

An analogy can be drawn between the pull methods based on a fixed bottleneck strategy (eg, CONWIP, CONLOAD) and a typical control system diagram. Because the Pull production control reacts to discrete events (a part is produced, a buffer is built up or emptied, etc), the feedback of the system is computed from the signal of the previous step. The resulting analogy is shown in 5.

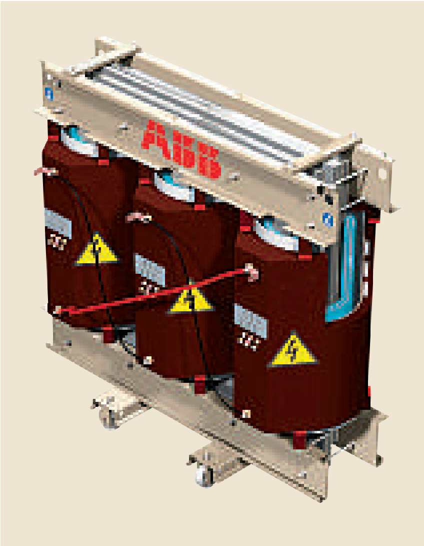
As the variability of the cycle times can in part be studied in advance once the customer specification is available, these data can be used to predict the behavior of the system. Such a strategy is proactive instead of reactive. Moreover, since the bottleneck is dependent on customer specifications, the cycle times of the orders in backlog can be computed and a prediction of the location of the bottleneck is possible. The discrete-event system simulation is the basis of a tool used for predicting the behavior of a system. With these ideas in mind, a possible control diagram is shown in 6.

This strategy is the basis of a predictive control in production. A movable bottleneck would be dealt with by trying to act before events happen: Supposing the bottleneck is in process A, but it is known that it will move to process B; process B could continue working at high volume to exploit the future bottleneck to the maximum. Such a buffer management philosophy not only focuses on the current bottleneck, but also on future ones. Such solutions can be obtained using a predictive control analogous to that of advanced automatic systems combining feedforward terms with feedback information.

This approach leads to a minimization of costs because:
- The control system is proactive, instead of reactive (as it would be in DBR[5]): Remedial actions are taken before problems occur, making interventions less costly.
- The protective capacity can be reduced, allowing the bottleneck to move and thereby reduce the excess cost as well.

The Zaragoza plant has reduced its TTPT (Total Throughput Time), from order to shipping, almost by half.

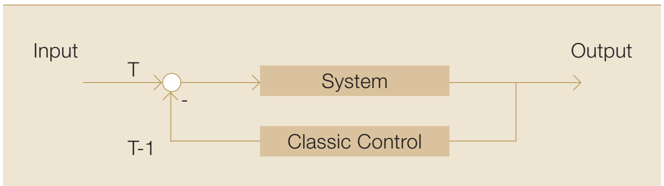
DIVINER 3.0 analyses the variability resulting from the product mix in backlog and uses this to optimize the future behavior of the system using discrete-event simulation. Buffering



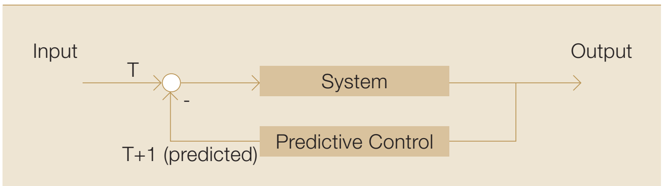
Footnote

[5] DBR: Drum-Buffer-Rope is an expression for the application of TOC to scheduling. The "drum" represents the bottleneck that can draw work into the system by the "rope", so keeping inventory to a minimum. There is only one area of queuing, and that is the monitored "buffer" in front of the bottleneck that protects this from adverse effects such as unreliable suppliers, employee absence and last minute customer requests.

5 Analogy from automation system for PULL production control model



6 Proactive model of control with application to manufacturing system



limits are reduced to their minima while still protecting the system against (only) the natural variability of standard mass production 4. The resulting protective capacity is lower than would be expected with DBR.

The theory sounds most attractive. In practice, many enticing theories fail to deliver usable results because they cannot be applied in real-world production environments. The best part of this theory is that the applicability is fully supported by line performance results from the Zaragoza factory since the start of the project in 1999.

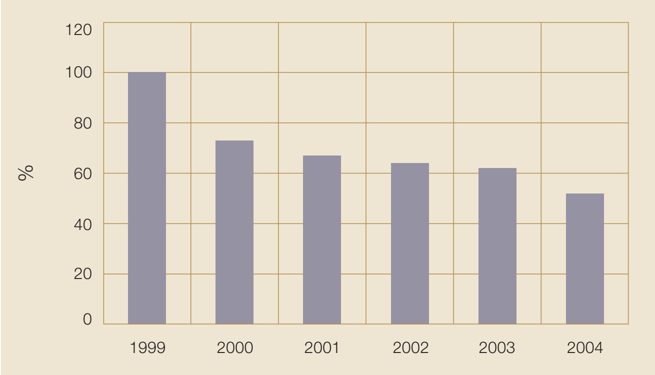
Success along the line

The best way to evaluate the result of the application of this strategy is to look at the most representative KPIs (Key Performance Indicators) associated with its performance:

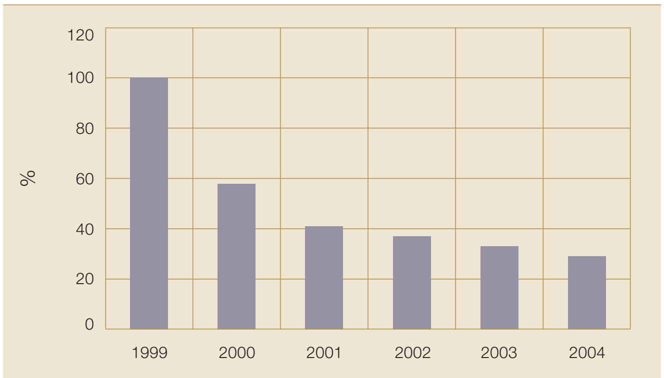
The Zaragoza plant has reduced its TTPT (Total Throughput Time)[6], from order to shipping, almost by half. Today it is 48 percent lower than in 1999 7.

Production TPT (Throughput Time)[6] has been reduced to only 29 percent of 1999s level 8. Today on-time-delivery of transformers is 96 percent against 70 percent in 1999 9. The plant's production volume has grown by 245 percent since 1999.

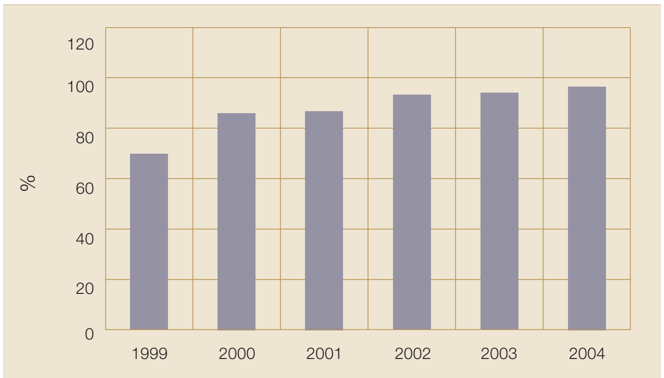
7 Total throughput time (TTPT) was reduced by almost half



8 Production throughput time (TPT) has been reduced to 29 percent of its 1999 level



9 Better scheduling leads to better on-time-delivery



Production transformed

The most important conclusion, and perhaps also the most profound one that the team at the Zaragoza plant has learnt is that if an organization feels something must change, then fear of the unknown is not the best advisor.

The navigating of uncharted waters needs courage and imagination.

Asking questions that go against the grain of common practice and the courage to break out of the mold – sometimes even transgressing perceived theoretical limits – are the best tools for achieving improvements. They foster the spirit of continuous improvement and reward the persistence that bears fruit, leading to better solutions and broader competence.

The Zaragoza team had to face a serious challenge to remain competitive in a very complex environment. It showed how the limits that were thought to be absolute could be overcome.

These results have demonstrated that it is possible to control a Supply Chain with a movable bottleneck and, moreover, that this is the right method to cope with high variability productive systems while keeping costs low (agile and lean) by avoiding protective overcapacity.

This effort was recognized in 2005 by both of Spain's most prestigious logistic innovation awards: The Pilot Award and CEL Award (granted by the Spanish Logistics Centre, Spanish member of the European Logistics Association).

ABB's Zaragoza factory has gained a very high reputation among its customers. This could be achieved only through the combination of a customer-centric approach, a continuous improvement attitude and the openness to innovative solutions for Supply Chain planning and scheduling.

Antonio Gonzalez
Luis G. Nebra
David Sanz
ABB Power Technology, S.A.
Zaragoza, Spain
antonio.j.gonzalez@es.abb.com
luis.garcia@es.abb.com
david.sanz@es.abb.com

Krzysztof Sowa-Piekło
ABB Corporate Research
Kraków, Poland
krzysztof.sowa-pieklo@pl.abb.com

Footnote
[6] see glossary on page 74

Shortest road to China

Reducing the duration of the Supply Chain between factories in Germany and China

Jukka Konttas

Faced with increasing demand in China's fast-growing circuit breaker market, the Supply Chain from ABB AG Calor Emag in Germany to ABB Xiamen Switchgear Co., wasn't meeting ABB's standard for an acceptable on-time delivery and delivery time of goods. The plant increased inventory levels to speed up deliveries but this was only a partial solution. Inventory requires a substantial commitment of capital, so the two companies joined forces with a manufacturing team from ABB Corporate Research to ensure acceptable delivery times while at the same time allowing inventory and capital to be released.

Value Stream Mapping (VSM)[1] techniques were used to analyze the whole Supply Chain and identify lead times and inventory levels while modeling the current state of operations. The analysis revealed that it took at least four months – from the time the order was placed on Germany to its delivery – to supply vacuum interrupters and embedded poles to the Chinese factory where they are assembled into circuit breakers.

Because the Chinese market requires a delivery time of one to two weeks for medium voltage circuit breakers, the Chinese factory had to have an enormous stock of vacuum interrupters and embedded poles to meet the delivery schedule expected by their customers. Clearly something had to be done.

To cut the replenishment time so that it equaled the shipping time from Germany to China, a central stock of finished goods was established at the German factory.

The theoretical solution

The solution lay in cutting the replenishment time from Germany to China. Consequently this would provide better service and a potential inventory reduction as well.

Replenishment time included China placing orders with the German factory in Ratingen (*transaction time*), which then ordered components from its sub-suppliers for in-house assembly and testing (*order lead time*) and, finally, shipping. Altogether this chain of events normally took 16 to 18 weeks of which shipping by sea, because it was deemed to be the most economical transportation method, required six weeks. In special cases faster transportation methods other than sea freight have been used to increase the level of service.

Footnote

[1] See glossary on page 74.

The overall aim was therefore to cut the replenishment time so that it equaled the shipping time from Germany to China. This was achieved by establishing a central stock of finished goods at the German factory. There was also a target to reduce the transaction, transportation and order lead time as much as possible. Engineers then set about finding ways of achieving this.

Turning theory into practice

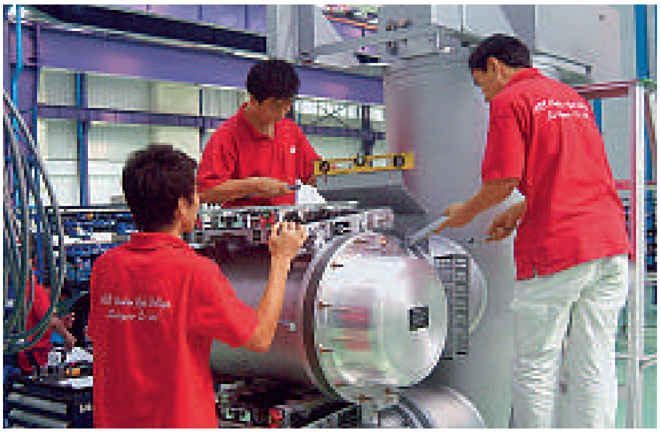
The first part of the solution involved having a centrally-located plant warehouse in the vicinity of the Ratingen factory. The purpose of this warehouse is to supply as much equipment as possible (depending on the business plan and service level agreed upon) directly from stock.

Such a warehouse, with shared inventory for the Chinese and other global markets, has several benefits including:

- Inventory levels are kept considerably lower than the sum of locally kept inventories, mainly because of risk pooling.
- The bound capital does not tie up transportation costs and custom fees.
- Replenishing components based on incoming orders (known as a "supplier pull system") is more cost-effective and has less risk than demand forecasting used previously.

The order transaction process between China and Germany was streamlined and simplified, resulting in a reduction in the time required – from five days to one day – and a near-elimination of transcription errors. This solution now provides the German factory with up-to-date, online information about order intake and stock levels in China. Large potential orders can be communicated even before contracts are signed to: provide vital information about available inventory; and give advance notice to the German factory in situations where supplies have to be ordered.

ABB Xiamen Switchgear Ltd., China



An inventory calculator has been introduced to set targets for quantities held in stock. This tool allows the calculation of the appropriate stock levels based on historical as well as forecast data, with the aim of meeting future demand in China and other markets served by the plant warehouse. Statistical measures, such as deviation in quantities demanded, are applied within this tool.

A reduction of almost 70 percent in the duration of the Supply Chain between Germany and China has made a considerable difference to the overall business.

Clear results

Eighteen months later the overall results have been impressive. Replenishment time, ie, from the time the order is received in Germany until the goods arrive in Xiamen China, was cut from 18 weeks to 5 weeks by implementing plant warehouse. Also lead times were reduced as follows:

- The order transaction process (between Xiamen and Ratingen) went from 5 days to 1 day by having online orders.
- Order lead time at the German factory fell by roughly 80 percent, from seven weeks to two. Marked improvement stemmed from the introduction of "pull production" in which work is undertaken based on customer orders and not a forecast of possible demand. (Production based on demand forecasts, known as push production, can result in unnecessary production and delay the delivery of actual customer orders.)
- Material lead time at Ratingen fell from 4 weeks to 0 because of raw-material buffers at the factory.
- Shipping or transportation time, door to door, was reduced from six weeks to five. Space is now secured by using a standardized logistic scheme. Once a week a container is taken to a ship on which, by default, space is reserved. Special packaging is used to avoid damage.
- Inventories are down 40 percent despite strong market growth in China.

A reduction of almost 70 percent in the duration of the Supply Chain between Germany and China has made a considerable difference to the overall business. The participants worked with mutual trust towards the same goal of optimizing the overall business rather than the individual businesses. This cooperation has led to win-win results with the competitiveness on the Chinese market substantially strengthened and considerably higher productivity in both factories.

Jukka Konttas
ABB Corporate Research
Oy, Finland
jukka.konttas@fi.abb.com

Driving force

Success factors in global high volume manufacturing

Tero Manner

The factors needed to bring about success in high volume production must be taken into account at the design stage. These include: a lean and efficient Supply Chain guaranteeing 100 percent component availability at all times; and where there are multiple manufacturing facilities across the globe, a management team that is capable of supporting a multi-cultural production environment.

A case in point is ABB's AC Component drives business. How can the demand for fast delivery be harmonized with the need to keep logistics and production costs low? With an annual unit volume in the hundreds of thousands – and growing by 50 percent every year – this is not as arduous as it might seem.

In today's market, small drives are now seen as components, much like coils or potentiometers. As customers are more concerned with what these drives can do rather than how they do it, together with the fact that they are cheaper than ever, small drives are finding their way into many and various applications.

ABB component drives[1] are a category of basic and compact drives – what you see is what you get – aimed at simple low power applications like fans, exercise machines, access barriers and washing machines. The beauty of these "fist-sized" drives is that the number of options and variants are kept to an absolute minimum making installation and operation of the component drive very simple.

The current structure of ABB's Component drives business consists of five factories (Finland, USA, India, and two in China) each performing final assembly and extensive testing. ABB supplies the completed units to regional logistics centres appropriately located within the main markets. 1

The need for speed

Because customers now demand rapid service, processes are being designed with fast delivery in mind. The key to such delivery is centralized inventory, in which all component drives are stocked and ready to ship.

Customization is no longer a problem in terms of speed, thanks to advancements in semiconductor technology and software capabilities coupled with developments in manufacturing

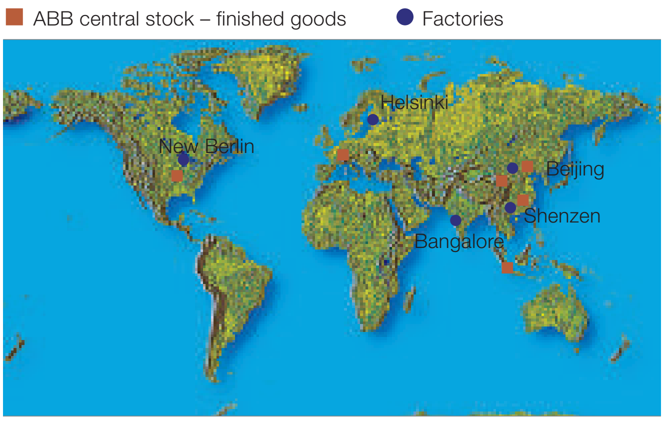
Footnote

[1] Paakkonen, Mika "ACS50 – sizing up the consumer industry" ABB Review special report on Motors and drives, pp 14–16.

process technology. In fact, customer-specific changes are part of the service provided.

ABB's five logistics centers enable fast deliveries as well as flexibility. In many areas, units can ship in less than 24 hours. Transportation at medium and slow speed is also offered at a reduced price, thus leaving it to the customer to decide how important fast delivery is.

1 ABB AC Component drive factories and central stocks



High volume lines must be separated from low volume lines or products requiring special attention. This ensures a smooth flowing and "rhythmical" constant high volume output without interruptions. The product design must be complete before it is allowed onto a high volume line.

Well trained and motivated employees are a necessity if high volume production is to succeed. Therefore training programs must be conducted at all times. The correct labor capacity must be able to match market demand. By splitting the work-tasks into small entities, capacity can be brought quickly on line either from neighbouring ABB factories or the outside.

High volume production

Successful high volume production is highly dependent on several factors described in the following paragraphs.

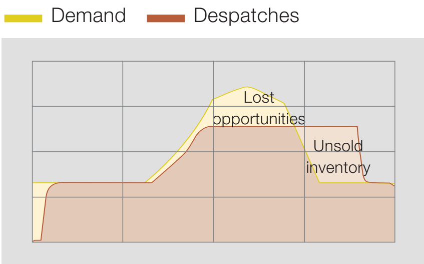
The first factor focuses on quick assembly. For this to be possible, a product should be designed with as few components as possible (ideally less than 20). In addition, the assembly must be easy and error free, meaning the assembly process must be "tried and tested" at the design phase. Quality concerns must be tackled early on. The design should be modular to allow subcontracting and manufacturing optimization. Design for manufacturability and assembly, DFMA, is hence crucial.

The key to fast delivery is centralized inventory, in which all component drives are stocked and ready to ship.

These points have been taken into consideration in ABB's drive business and the result is that some models of component drive take less than half an hour to assemble.

Adequate logistics also play a part. This starts with an electronic ordering system integrated directly into the production system. Customer information is cascaded electronically to the supplier network. The flow of components must be constant, at the lowest possible cost with 100 percent availability to support a three-shift operation. Packaging material must be located at the assembly stations and designed for ease-of-use and to protect the product during transportation.

2 Component drive global stock turnover

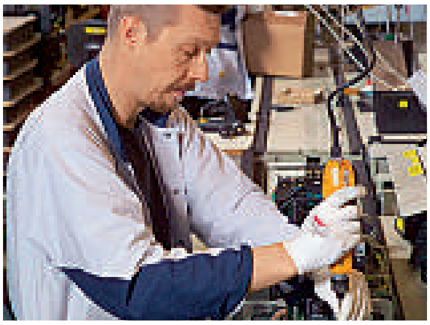


Cost sensitivity in high volume manufacturing requires close monitoring of a few key metrics such as:

- Units produced/employee hour worked. This measures productivity.
- Units passing final test when tested the first time measures first pass yield (FPY).
- Component availability must be 100 percent.

High inventory turnover

High inventory can compromise quality, and the distance between low-cost countries and major markets lends itself to inflated levels of inventory in transit and in the warehouse. The way to approach inventory is by tracking orders, and keeping careful watch over sales and the broader market. By tracking sales and inventory, the ebb and flow of demand can be monitored



and responded to rationally. Systematic analysis that exploits the benefits of the ERP[2] system, combined with quick decision making concerning the optimal means of transportation, is the best remedy for high inventory levels, 2 3.

Bad quality costs millions in logistics

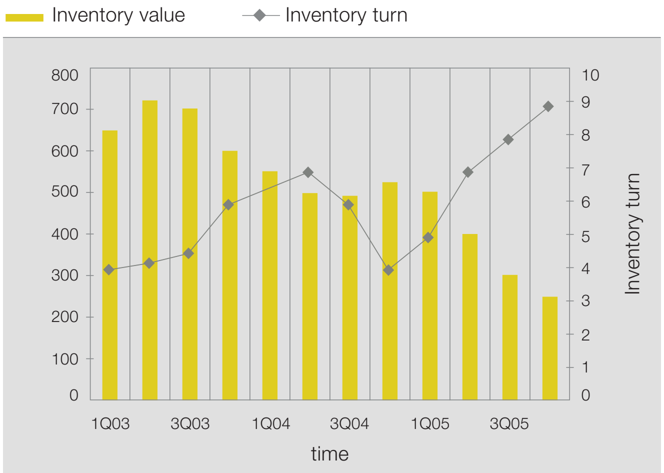
Maintaining low logistical costs in a global business requires superior quality. Air freight is 10 times more expensive than sea freight. With high volumes and long distances, sea transport is realistically the only competitive option, although some companies also use roads and railways. Compensating poor components or bad product quality by using air freight or other express modes of transportation may easily eliminate any profit. In addition inventory scrap and warranty costs must be financed. Good quality and good logistical planning are essential success factors in any high volume business.

> The need for competitive pricing requires constant attention to quality along with a continuous hunt for low-cost suppliers.

Low cost country production – global supply management

The need for competitive pricing requires constant attention to quality along with a continuous hunt for low-cost suppliers. Quality and performance must be ensured at all times. The challenge is to calculate the actual process cost associated with low-cost country sourcing whether for factories or warehouses. These cost elements include the ramp-up cost, increased material cost for components and finished goods, quality issues, risk associated with long Supply Chain and the delivery cost. Experience combined with careful analysis will result in a well founded decision as to whether outsourcing a component makes sense.

3 Determining the right levels and locations of inventory to meet customer commitments while minimizing costs



Supplier network management

The relationship between a factory and its supplier is essential to ensure a world-class process Supply Chain. Open communication, good delivery performance and high quality are very important. Other points to be considered include:

- Time and resource investments should be decided in co-operation with the supplier when ramping up a new component in production. Setting up the supply process together ensures attention to quality and prevents delivery problems.
- Quality processes and procedures must be clear. With long transportation distances there is no room for poor quality. This requires good manufacturing and in many cases extensive quality control and this is the responsibility of both parties. That is why all components are tested by the suppliers and then again at the ABB factory before the Component drives are sent to customers.
- An important way to approach improvement is through the Engineering Change Notice (ECN) process. This process includes all revision change issues and associated data relevant for proper communication and follow-up to ensure all the changes are implemented as intended.

Cultural differences must be understood

Global manufacturing encounters many interesting cultural business differences, and when properly managed these can be turned into strong advantages. Manufacturing with global sourcing does not conflict with local cultures as long as management is sensitive and adaptable to these issues.

Therefore, managers must learn to value the differences, creativity, and richness that diversity brings to the workplace. As the workforce changes, so must management strategies. Part and parcel of any diversity initiative is the ability of a company to recruit and retain a diverse workforce.

The principle of best practice is adopted in all ABB drives factories but in each case with a cultural twist. Communication between the international factories is arranged through regular information sharing sessions so that similarities are found and viewpoints agreed on. These efforts at understanding the other give everyone a chance to create a work culture that is neither totally one nor the other. It facilitates a gathering of ideas and efforts, creating beneficial synergies for everyone involved.

Tero Manner
ABB Oy,
Helsinki, Finland
tero.manner@fi.abb.com

Footnote

2) See glossary of page 74.

The *Express Line*

Transformer manufacturing in the fast lane

Rikard Kallberg

ABB Components manufactures tap-changers and bushings for transformer factories at its plant in Ludvika, Sweden. The market trend is towards shorter delivery times, and for many transformer factories, component deliveries are time critical. If the suppliers to those transformer factories cannot shorten their delivery times, opportunities may be lost.

ABB has risen to this challenge and introduced an *Express Line*. The Supply Chain process has been redefined to deliver transformers faster than previously thought possible.

As a supplier, ABB Components needs to meet short delivery times. To meet this demand, the *Express Line* was created through the PICSEL project (see textbox on page 35). The main target of the project is to facilitate the delivery of custom-made tap-changers and Bushings in 4 weeks.

The project was formed as a CP3[1] (Common Pull Production Practices) project in December 2003. The CP3 concept was developed by ABB Corporate research in Finland. Being a CP3 project, the backbone is the ABB Gate model[1]. The Gate model gives structure and support for all parties involved in the project.

During the analysis phase the order-delivery process was analyzed with VSM. It was recognized that even if everything went smoothly and without disturbances, ABB would still not be able to meet the target of four weeks delivery time. The order-delivery process was simply too long. In PICSEL the VSM[1] was utilized in two steps. First it was used for mapping the current process, and then to create a vision of the future process. The vision included CP3 tools such as, Continuous flow, PULL-production, replenish-based supply.

Pull arrangements work with less WIP than traditional Push arrangements and this improves the TPT (throughput time). A short TPT is necessary for the Express Line.

The *Express Line*

When analyzing its process, ABB found that it could save a week by avoiding manual order design and possibly another week through some careful Supply Chain Management (SCM)[1]. In order to do this, standardization was necessary. ABB Components are delivered to customers all over the world; hence the company needs to be able to meet a broad range of different standards. Creating an express line that can be automated to handle ordered designs, fulfils set short delivery times and that suits as many customers as possible is quite a challenge. All products from this factory are custom-built, so a standard "one-size-fits-all" solution was definitely out of the question.

By analysing customers buying pattern from the past two years, ABB formed a base of what could be a suitable platform. The goal was to form a set of "building blocks" that would fit as many projects as possible.

Supply Chain Management (SCM)

Perhaps the biggest challenge when developing the *Express line* was the SCM work. The tasks were to secure all *Express Line* material for production within 5 days from order date and reduce total inventories.

The chosen method for many volume articles was a replenish-based two-bin approach. The strength of this system lies in its simplicity both for ABB and its suppliers. As it is a "pull" system it helps reduce inventories, is insensitive to changes in demand and is easy to maintain.

Some items are order specific, and are needed within 5 days. This calls for more advanced SCM strategies. An example is the tank for the UZ-type tap-changers. Before PICSEL the supply lead-time was three weeks. The supplier had to manufacture these from scratch as far as cutting, welding and painting in the customer specific colour are concerned. In order to cut the lead-time to a third, ABB entered a two-bin arrangement with the supplier, who now stores tanks ready for painting. When ABB orders a tank, the supplier sends the correct type directly to the paint shop and ABB receives the finished tank when needed. This is a win-win situation: ABB gets a short delivery time, better OTD (on-time delivery) and the supplier can plan their work better.

The *Express Line* may be a prerequisite for four-week deliveries, but the promise of fast delivery time is worth nothing if it cannot be met. This calls for a robust order-delivery process. In order to deliver on time to customers,

Footnote

[1] See glossary of page 74.

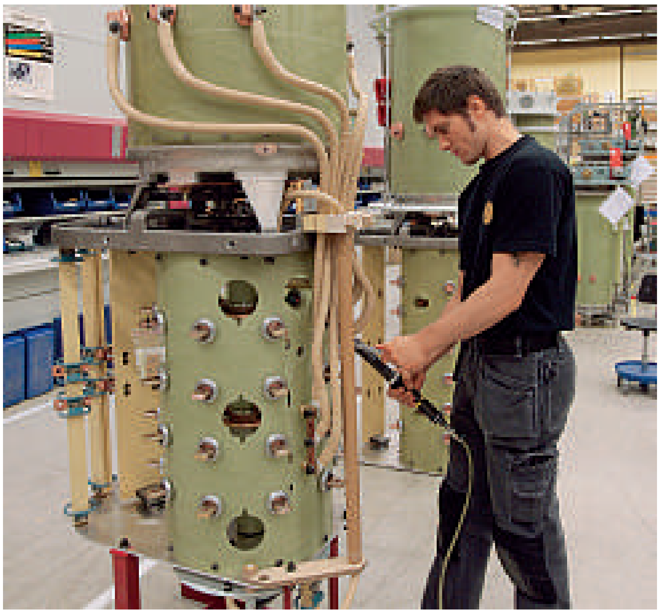


ABB must receive all internal and external deliveries on time. For external suppliers these routines are clear, but internal customer-supplier relations need support. The development of PICSEL Gateways created a backbone for the whole order-delivery process.

Change Management

Due to lack of proper change management, many fine efforts have ended up in nothing. When working with change, the toughest issue is often to make the changes sustainable. Unfortunately there is no general recipe on how to achieve this. In PICSEL, a communication plan was set up; lack of communication definitely makes changes harder to achieve. Communication must be of high quality, not necessarily in terms of spectacular Power Points but in it's essence. As many people as possible must feel why the change is important for the company and them. In order to get a better common understanding in the power of PULL approaches, the project implementers played a PULL game with all affected personnel. The game played is called Process Samba and simulates a factory. The result of the game was astonishing!

PULL production

In order to reach the set targets, the production also needed improvement. The essence of CP3 is Pull. Pull arrangements work with less WIP[1)] than traditional Push arrangements and this improves the TPT[1)] (throughput time). A short TPT is necessary for the Express Line.

Shop floor related TPT was reduced 25 to 60 percent and WIP dropped 35 to 65 percent.

The Ludvika plant uses CONWIP as a production control method. CONWIP is a WIP-limiting tools and is utilized in four of the production lines. There are many advantages in limiting WIP: Production can focus more on more important issues, it is easier to keep the workplace orderly, inventories are kept low and TPT gets shorter.

On one of these production lines, CONWIP was not found to be suitable, as several production flows merged within this line. It was still necessary to keep WIP limited and the method chosen was a TPT constraining detailed planning in conjunction with clear production rules. This detailed planning is made from the bottleneck (the testing area). The resulting plan authorizes work from all upstream cells and synchronizes the flow.

Results

The *Express Line* was inaugurated in Spring 2005 for UBB and UZ type tap-changes. The latest addition to the *Express Line* is the UCG products and the new UBB, UC and UZ ordering data sheets have now been prepared. More and more customers are taking advantage of what the *Express Line* has to offer.

Besides a working *Express Line*, the plant enjoys other improvements as its processes have become leaner. Shop floor related TPT was reduced 25 to 60 percent and WIP dropped 35 to 65 percent. Supply OTD improved from 88 to 95 percent at the same time as supply lead-times reduced to 50 percent in average. The TTPT dropped to four weeks for the products on the *Express Line* and "Confirmed order on time requested" and OTD improved dramatically.

ABB will continuously improve this process and make the *Express Line* broader to suit customers' needs even better.

Rikard Kallberg
ABB Components
Ludvika, Sweden
rikard.kallberg@se.abb.com

Breaker factory of the future

Designing a world-class breaker factory in Pennsylvania

Gerald Lee

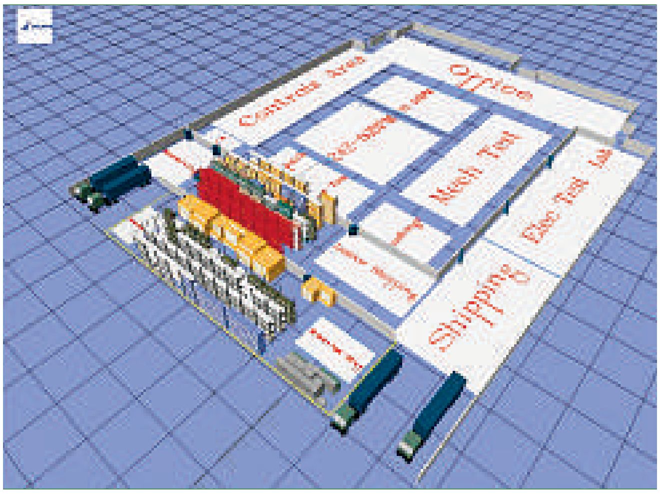
The world-class ABB high-voltage breaker facility in Mt. Pleasant, PA opened in April 2003 and serves as the US headquarters for high-voltage power technology products. This new facility has been designed to produce SF_6 dead-tank circuit breakers for use in applications from 38 kV to 800 kV. However, on a more impressive note, lead-times, floor space, capacity and productivity have all been greatly optimized. How this was done will be explained in the body of this article.

Demand driven manufacturing

ABB's SF_6 dead-tank circuit breakers 1 were formerly produced at an ABB facility in Greensburg, PA, but as the HV breaker business was experiencing unprecedented demand leading to backlogs as long as 80 weeks for some products, it became clear that the business had outgrown its facility. In addition as demand and leadtimes grew ABB's competitors saw an ideal opportunity to enter these more lucrative markets.

1 A typical 145 kV dead-tank breaker

2 Simulation was used in the design and testing of the production processes. The results were instrumental in determining plant layouts, capacity, and material flow



Background

ABB Greensburg was located in the middle of a residential area, and this complicated shipping and delivery. The facility was housed in four separate buildings, some of which were over 100 years old, forcing people and materials to move between the buildings.

Breaker design had also changed over the years and the factory doors were no longer wide enough or tall enough to accammodate the new products. The factory floor was at different levels, thus requiring excess material handling. Some raw materials had to be stored out of the factory, a fair distance from where they were used. This inevitably led to unnecessary cleaning and handling.

The most impressive achievement by far is not any new technology but rather that a culture of continuous improvement has been sustained and nurtured at the new facility.

Analysis was undertaken to define an approach that would best resolve these production issues while reducing lead times on factory orders. The best option was found to be a new facility in a nearby technology park located outside of Mt. Pleasant, PA. A key factor which led to this decision was the proximity of several other breaker factories, meaning an abundance of qualified suppliers and a skilled workforce. Another very important factor included access to major highways.

World class design

The old Greensburg facility already made a top-quality product with lean production techniques. Even so, the move to the new facility was seen by management as an unparalleled opportunity to improve all aspects of the business and every effort was made to use it to its best advantage.

The management team identified opportunities to:

- Reduce lead times
- Increase capacity
- Improve productivity
- Improve on-time delivery
- Improve flexibility
- Reduce Work in Progress (WIP)[1)] and raw material inventories
- Reduce floor space
- Maintain a focus-factory concept

Primary targets for improvement were manufacturing and information flow. Agile manufacturing techniques were employed for product and process flexibility, shorter cycle times and quicker delivery. Several design techniques were employed to verify the factory lay-out and the factory flow: Simulation technology was used to design the layout and decide on square footage. The final design was almost a carbon copy of the 3D simulation model. In addition, the model proved to be instrumental in cost savings 2. Techniques such as Theory of Constraints (TOC)[2)] were employed to address bottlenecks in production. Using setup reduction techniques at the bottlenecks, throughput and boosted capacity at the constraint improved by 33 percent.

Many improvements were made in the handling of materials: Parts were brought to the point-of-use; bar codes were introduced to improve accuracy in inventory and eliminate lost parts; and parts were kitted prior to assem-

Footnote

1) See glossary on page 74.

1) See page 25.

Demand driven manufacturing

bly to ensure that breakers could be finished with greater efficiency.

A wireless data-collection system was installed to eliminate the need for a paper trail with each breaker. Previously, reports could be as long as 80 pages. The new system now flags all errors and allows operators to electronically indicate that a critical step in production has been completed. Finished reports can be sent to the customer electronically and stored on the ABB network.

The move

It was determined early on that there could be no disruption of customer service when the move was made to the new state-of-the-art facility. The move had to be as seamless as possible.

Much attention was focused on coordinating the activities of contractors and vendors. This was necessary due to a number of systems that were new to the factory including improvements in leak testing, SF_6 gas handling, and material storage and retrieval systems.

In addition, a lot of attention was paid before the move to physical and personnel resources. This meant that processes were phased into the new facility in a logical order so that services were not disrupted. For a short time managers had to deal with running two separate factories.

Highlights

The first breakers were shipped on April 9, 2003 – after the first week of full production at the new facility 3.

3 The first 5 breakers were shipped from the new facility on April 9, 2003 – the first week of production

Customers feel ABB has taken breaker manufacturing to a new level. This is important considering there are three major breaker manufacturers in a 50-km radius of the Mt. Pleasant facility.

Several improvements have already been sustained over a three year period:

- Productivity is up 10 percent.
- Capacity has increased 37 percent, due to work removed from bottlenecks.
- The need for floor space is down by 15 percent.
- The need for storage space is down by 38 percent.
- WIP is down by 15 percent.
- Rework is reduced by 40 percent.
- Materials are now stored near point-of-use, inside the factory or under covered storage.
- Improved cleanliness has led to fewer flashovers.
- Improved flow has meant less product travel, increased velocity.

Customers feel ABB has taken breaker manufacturing to a new level. This is important considering there are three major breaker manufacturers in a 50-km radius of the Mt. Pleasant facility.

But the most impressive achievement by far is not any new technology but rather that a culture of continuous improvement has been sustained and nurtured at the new facility.

The move to the new factory allowed the team to install new processes with the knowledge that there was no going back to the old way of doing things. This has not only helped the workforce to understand that change was inevitable but it has also allowed them to view further changes as something very positive.

Gerald Lee
ABB Corporate Research
Raleigh, NC, USA
gerald.lee@us.abb.com

Smart manufacturing

NOKIA and ABB working together in a successful productivity improvement partnership

Jarmo Heinonen

The Smart Manufacturing Concept has been central to NOKIA's efforts to sharpen its focus on production technologies that enhance the flexibility and competitiveness of it's nine manufacturing facilities. The company has successfully adopted a strategy of forming efficient networking with best-in-class partners. One of the latest partnerships is an expanded collaboration with ABB in performance based maintenance.

Demand driven manufacturing

Globalizing world-class concepts has always been a challenge. Telecom companies in particular, such as NOKIA Textbox 1, require a combination of flexibility and a systematic approach to maintenance. These features call for excellent change management procedures, and the ability to adapt to constant technology changes in a variety of cultures.

This and more have been achieved at NOKIA's Komárom production plant in Hungary Textbox 2 and title picture. Not only is this plant proof of NOKIA's capability to ramp-up a world-class production unit in a short time, but Komárom has grown to become a very big mobile phone plant in terms of volume of production.

So what's the secret behind this success?

Performance Service

To begin with, the product range in the telecoms industry is becoming increasingly broader. Market innovations mean new models are pushed into production faster than ever.

> Performance Service minimizes the total maintenance spent over the life-cycle of the equipment.

At the Komárom factory, Timo Kahelin, the plant manager, reinforces this point when he says that production volume increased significantly in 2004 to satisfy the growing market demand even as the number of variants also increased substantially. While this in itself is very impressive, plant management also wanted to develop the factory to be world-class in productivity. According to Kahelin, "we certainly saw big opportunities in plant performance improvement during 2004."

NOKIA understood that a maintenance strategy deeply tied to the production strategy was needed to remain globally competitive. However, according to Timo Elonen, director of Manufacturing Solutions organization, maintenance today is actually "a misleading definition, we rather talk about Performance Service."

Performance Service minimizes the total maintenance spent over the life-cycle of the equipment. Systematic management of internal and third-party maintenance activities is a key contributor to this optimization process, and a key technology is the effective

Textbox 1 NOKIA

NOKIA is a leading international communications company, focused on the key growth areas of wireline and wireless telecommunications. NOKIA is a pioneer in digital technology and wireless data communications, continuously bringing innovations to the highly competitive and growing telecommunications markets. NOKIA is also actively involved in international R&D cooperation, including the development of standards for third generation mobile telephony.

NOKIA's was founded in 1865 by Fredrik Idestam. The ground work for telecommunications was laid in the 1960s, as NOKIA was researching the field of radio transmission in its electronics department. In the late 1970s, mobile phones and telecommunications infrastructure products were developed for both domestic and international customers. It was in the 1980s and 1990s that NOKIA became a global leader in digital communication technologies.

The company's ability to exploit the opportunities created by continuous technological and market change has helped it develop into the company it is today.

Textbox 2 NOKIA Komárom

NOKIA'S Komárom production plant in situated in Hungary. It is ideally located in the heart of Europe close to the motorway rolling from Budapest to Vienna and only 8 km from the Slovakian border, enabling flexible use of the workforce to match continuously growing needs.

After only nine months construction, Komárom delivered its first handset to the European market in 2001.

Key sub-suppliers are located in Komárom's industrial park ensuring fast lead time and seamless co-operation. There is a specific industrial park association with the responsibility to develop the park as a whole and to provide common support processes as well as to manage the industrial relations with the Györ community. The Board consists of plant managers from the industrial park. It meets on a regular basis to direct the sustainable development in the working community of over 10,000 people.

use of a computerized maintenance management system. Integrating maintenance methodology with a focus on the effectiveness of the production, eg, increased line performance, is essential to enhanced productivity. And of course, cost optimization pressure never ceases to exert its influence.

According to Timo Kahelin, it was ABB who opened Komárom's eyes to maintenance as a tool to improved productivity and not just as a tool for fire-fighting and preventive repairs. NOKIA regards ABB as a world leader in maintenance management – in 2002 the company was selected as the maintenance provider for Salo operations in Finland. A performance based service agreement was signed with ABB in March 2005 and by May 2005, the Komárom plant embarked on the creation of a service culture (based on well developed core processes) when 158 line service people and tens of third-party suppliers started systematic service under ABB management. "However this is a big task and there is still a lot do as we move forward from the start-up phase, ABB needs to work hard to keep on track", Kahelin states.

Martti Salomaa, the head of NOKIA Komárom's Engine Operations adds that "ABB's Full Service® concept Textbox 3 takes into account both technological and cultural issues and is therefore welcomed by our employees at our Hungarian plant. Together we have more knowledge and can cover more issues, and this increases people motivation as well as enhancing overall competence." Today Performance Service is considered one of the key contributors to increased performance of the engine lines and assembly cells.

NOKIA's maintenance strategy has been further refined based on its experiences. ABB has not only had an important role in benchmarking other NOKIA plants, but has also been invited to advise on the formulation of the company's maintenance strategy.

OEE[1)], Textbox 4, has quickly become a key element to drive maintenance for better performance. Together, NOKIA and ABB have defined an optimal way of capturing OEE from critical equipment as well as from the line as a whole. This common definition provides a sound basis for systematic analysis based on the work that can be assigned to improvement teams. Because the mobile market is growing continuously, an increase of just one percent in OEE has a tremendous bottom line effect.

Life-cycle capability improvements

As part of the manufacturing process in the telecoms industry, ways of increasing the lifetime of production equipment should be included. This means making constant trade-offs between introducing new production technology and using existing equipment for longer periods of time. The flow-through of components over the life-time of a single line in NOKIA's factories is calculated in hundreds of millions rather than in millions.

In answer to this, NOKIA and ABB are jointly researching the lifecycle modeling of production equipment to increase relevant knowledge as the basis for technological decision mak-

Textbox 3 ABB Full Service®

ABB's Full Service® contracts are globally co-ordinated long-term performance based agreements in which ABB commits to maintain and improve the production equipment performance and reliability for an entire facility.

Customization for electronics and telecommunications

By understanding the specific needs of clients in the electronics and telecoms industry, ABB's Corporate Research and the Maintenance Performance Center for Electronics (located in Finland) worked together to develop a full service concept. The result is an industry specific customization of the ABB Full Service® business concept, which can be deployed globally to key brand owners and their tier one suppliers.

Over the years the ABB Full Service® concept has evolved from traditional maintenance into the performance partner of the customer. Its definition crystallizes how global and local activities are balanced, and it defines the two key performance indicators that must be improved by the implementation of a lifecycle production management agreement.

Textbox 4 OEE – Overall Equipment Effectiveness

OEE is the industry accepted tool to measure and monitor production performance. It can be applied at the machine, manufacturing cell, or plant process level.

It incorporates three basic indicators:

- *Availability* or uptime (downtime – planned and unplanned)
- *Performance Efficiency* (Actual versus design capability)
- *Rate of product quality output* (percentage of good products produced)

OEE = Availability × Performance Efficiency × Rate of product quality output

ing. This is an area where ABB's experience in the process industry is especially valuable. The production development approaches used within process industries converge with methods applied in high volume discrete manufacturing; hence experiences can be shared productively.

To utilize ABB's total capability for performance improvement, NOKIA and ABB have opted for the widest possible scope in their productivity support model.

Improving production line performance

The co-sourcing of performance services – as NOKIA and ABB have set out to do in Komárom – is revolutionary to the industry. Separate technical service activities are no longer isolated but are managed under one performance based service agreement. To utilize ABB's total capability for performance improvement, NOKIA and ABB have opted for the widest possible scope in their productivity support model. Elements contained in this model include:

- Productivity targets that are cascaded from the production strategy by utilizing a specific strategy process. This process defines the key issues in terms of an MMMP[2]. Eleven specific process steps for productivity improvements are then scheduled to be in line with telecoms clock-speed and finally visualized for everybody by clearly displaying the development steps.
- The management keeps all the former decentralized functions under tight control, focusing instead on facts through KPIs. People are trained and motivated to take on the challenges defined by each development step.
- Improvement of OEE is the key. World-class targets are set and maintenance technologies are deployed to boost continuous improvement.
- A large part of the required work is carried out by third-party suppliers. Their role is to develop equipment technologies that perform better and with higher reliability.
- One of the key challenges is to manage the set-up time of a product change in the line. Several techniques, such as SMED[3] have been adopted to eliminate downtime and yield loss.
- Equipment aging in this relatively new plant will be tackled with life-cycle studies utilizing FTAs[4] common with other plants.
- A key requirement of the agreement is that the program be tailor-made for the Hungarian plant, while at the same time it must be easy to benchmark with other plants.

Bálint Ecker is ABB's resource manager at the Komárom plant and he says that even though the first six months have seen huge changes in what were once considered traditional working procedures, people have embraced this new culture of preventative maintenance. Over time, additional systematic tools, such as CI teams[5] and MAXIMO[6] and RCA[7], will be added.

The task in Komárom has been and will continue to be a challenging one. Because of fluctuating market conditions, the manufacturing process is compelled to respond quickly to change. However, with the support of ABB and other partners, NOKIA managed to stabilize production just as the season reached its peak (which incidentally was in the autumn of 2005). New production records are daily achievements.

Jarmo Heinonen
ABB Performance Services
Helsinki, Finland
jarmo.heinonen@fi.abb.com

Footnotes

1) OEE = Overall Equipment Effectiveness. Contact ABB Performance Services on our specific solutions for both the discrete and process industries.
2) MMMP = Maintenance Management Master Plan, a specific approach which integrates customer's industry specific targets with ABB systematic Full Service® concept.
3) SMED = Single Minute Exchange of Die, specific approach to shorten ramp-ups and changeovers, one of the key tools customized by ABB.
4) FTA = Fault Tree Analysis is a specific tool to track und understand possible faults and their mechanism.
5) CI Teams = Continuous Improvement teams. Contact ABB Performance Services for world-class approach to implement Total productivity Maintenance as part of a service contract.
6) MAXIMO = commercial maintenance management software with which ABB can quickly implement systematic maintenance.
7) RCA = Root Cause Analysis tool that ABB uses to analyze production and maintenance data as well as to continuously seek improvement possibilities.

More colors, less waste

ABB Cartridge Paint System: Cutting costs and reducing environmental impact

Osamu Yoshida

How many different colors should an automaker offer its customers? A famous pioneer supposedly said, "You can have it in whatever color you want so long as it's black". Today, however, it goes without saying that automakers seek to improve their market position by offering customers as many choices as possible.

But how many choices are possible? Diversity is largely limited by production line logistics. Until now, to change color, the painting apparatus of a robot had to be thoroughly cleaned. This wastes paint and solvent, adds to pollution and costs time and money. All good reasons not to change color more often than is absolutely necessary.

But imagine being able to switch color without losing paint or time, and while reducing solvent waste by more than a factor of ten. With ABB's innovative cartridge bell system, this vision becomes reality.

Demand driven manufacturing

When a modern car gets into a fender-bender, it's increasingly unlikely that the local body shop will bang the bumper back into shape. Neither will the manufacturer pull a spare out of stock; instead a whole new bumper module will be built specifically to meet the individual need.

This saves on inventory costs, but it makes the paint operations at automakers and their subsidiary suppliers far more complex; not only do they need to paint bumpers for current-model cars, but must also be able to paint small lots of replacement parts for older models.

During the normal production run of a car model, some ten colors are required. For a bumper line, however, that number can often be as high as 50 or 60, and consequently the number of units painted in any one color is limited. Even so, an entire paint line has to be operated to ensure the same quality as the original product.

Whether using hand spray guns or robots, long paint supply lines and atomizers must be thoroughly cleaned with solvent between each paint change. Both paint and solvent are wasted, increasing costs and causing negative impact on the environment (particularly solvents, which contain volatile organic compounds, or VOCs, which are a serious source of pollution). Not the most efficient way to produce bumpers – or any other painted product requiring different paint colors.

The solution came out of an internal brainstorming session. ABB thought that having a traditional paint line with many different paint tanks and all the lines and hoses needed to paint just a few bumpers was a terrible waste not only of paint and solvent, but also of time, labor and money. Why not move the paint tank to the end of the robot arm itself? The total amount of paint needed didn't have to be too much, only 350 to 500 ml, so if a way could be found to put a small tank – a cartridge – on the robot, only the atomizer itself would have to be cleaned with solvent. Each cartridge could be dedicated to one color, so keeping cleaning to a minimum.

As carmakers struggle to position themselves in a highly competitive global market, offering consumers a greater choice in color and features is one way to set themselves apart.

Working closely with a major Japanese automaker, ABB began to pursue the idea – applying it not only to bumpers. As carmakers struggle to position themselves in a highly competitive global market, offering consumers a greater choice in color and features is one way to set themselves apart.

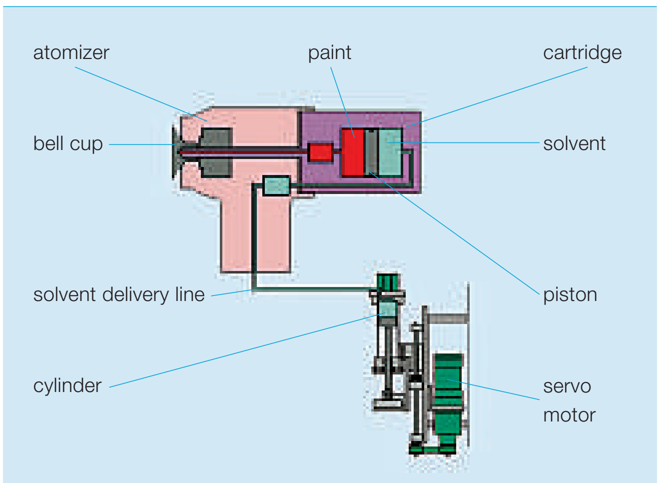
At the same time, the cartridge concept promised to reduce VOC (volatile organic compounds) emissions and paint waste, an important consideration in a time of increased environmental awareness and tighter legislation. ABB thought the concept might also increase the total efficiency of automotive paint operations. They set a number of goals for the project. One was to practically eliminate paint and solvent loss caused by paint change. The other was to reduce material loss at color change from approximately 120 ml of solvent and 32 ml of paint to just 10 ml of solvent: the amount needed to clean the bell cup.

There were several initial technical hurdles that had to be overcome. First was that the time for a cartridge change had to be 10 seconds or less. If this could not be achieved, painting operations would have to slow down – not an option for automakers!

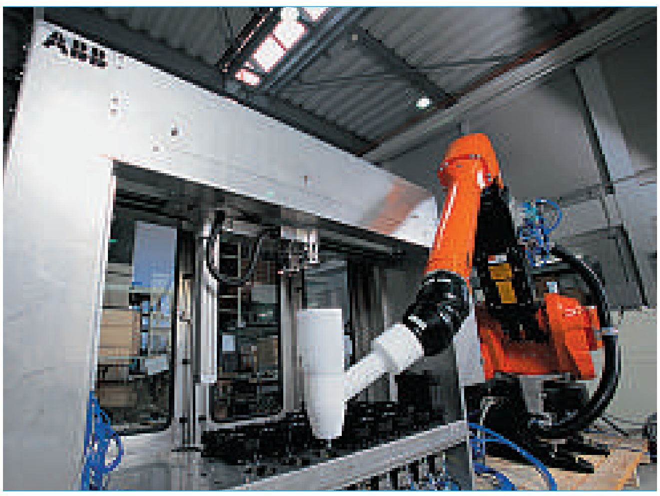
Next was the question of how to hold the cartridge in place in the robot arm. Vacuum pressure was the obvious answer, but it had to be very carefully controlled.

To increase coating efficiency and reduce paint loss, paint robots use elec-

1 ABB's cartridge bell system (CBS). The proximity of the paint to the bell cup minimizes paint and solvent loss when the color is changed



2 A paint robot changing its cartridge in the manipulator. The empty cartridge is automatically refilled



trostatic painting. In traditional hand painting, only a small part of the paint actually adheres to the body – often as little as 20 percent. ABB is the inventor of, and world leader in electrostatic painting. This technique greatly increases the transfer efficiency of the painting process. A negative electrical charge is applied to the paint droplets as they emerge from the atomizer; the car body is grounded. The result is that the paint is not simply sprayed onto the car body, but is actually attracted to it electrically. The major issue raised by this method is sparking. A spark can easily ignite the flammable mixture of vaporized paint and solvent and air. The developers had to find the ideal pressure to hold the cartridge in the robot arm. Too much of a vacuum would have led to sparking.

As these hurdles were cleared, a working concept began to develop. A conventional robot painting systems involves large tanks for the main color, smaller tanks for special colors, a tank for solvent, paint supply lines leading to a Color Change Valve unit (CCV), and a Flushable Gear Pump unit (FGP) mounted on the robot to regulate paint flow. They all have to be cleaned for paint changes. In the new concept 1 the robot was to be separated from the paint delivery system. There would still be paint and solvent tanks, albeit much smaller for special colors. These would feed to a cartridge handling unit, where the paint would be filled into the cartridges. Each cartridge would contain a piston driven by solvent to force out the paint as painting progressed. A full cartridge would contain only paint below the piston, and no solvent; as solvent was pumped into the cartridge, the paint would be driven out, until the piston was fully extended with only solvent above it. The robot required only a solvent-filling line; all other lines would be single-usage and lead only to the cartridge station. A surprisingly simple and straightforward idea! At least, as an initial concept.

3 An ABB technician inspects a CBS installation

The cartridge change time requirement made the supply and the removal of solvent in the cartridge an important issue to overcome. What was desired was an almost instantaneous and constant delivery of solvent to the cartridge, resulting in a similarly constant and smooth delivery of paint, with both varying by less than ± 10 ml during the painting operation.

The solution was fairly straightforward, involving the addition of a third valve to the solvent control unit and modifying the shape of the cylinder head inside the cartridge. The result was flow of both solvent and paint from stop to full flow in less than 0.2 seconds, with flow that varied by only ± 3 ml – far below the target figure. This was better than the development team expected, and it really made the system very attractive for the market.

First realized in the late 1990s, the system – now called the Cartridge Bell System (CBS) – is being applied on automotive production lines not only in Japan, but also in Asia, the US and Europe. As intended, it is a streamlined approach to painting. The exchange unit can be flexibly adjusted with as many colors as needed 2, with two cartridges for each color (one being filled while the second is in use). When a cartridge is empty, the robot arm swings over to pick up a newly filled cartridge 3, set in place by the cartridge handler and held in place by the robot using negative air pressure.

In the meantime, the first cartridge is being filled. The solvent from above the piston is used to prepare fresh paint. When the time for a color change has come, only the atomizer bell is cleaned with solvent; the robot then simply begins to work using a different pair of cartridges.

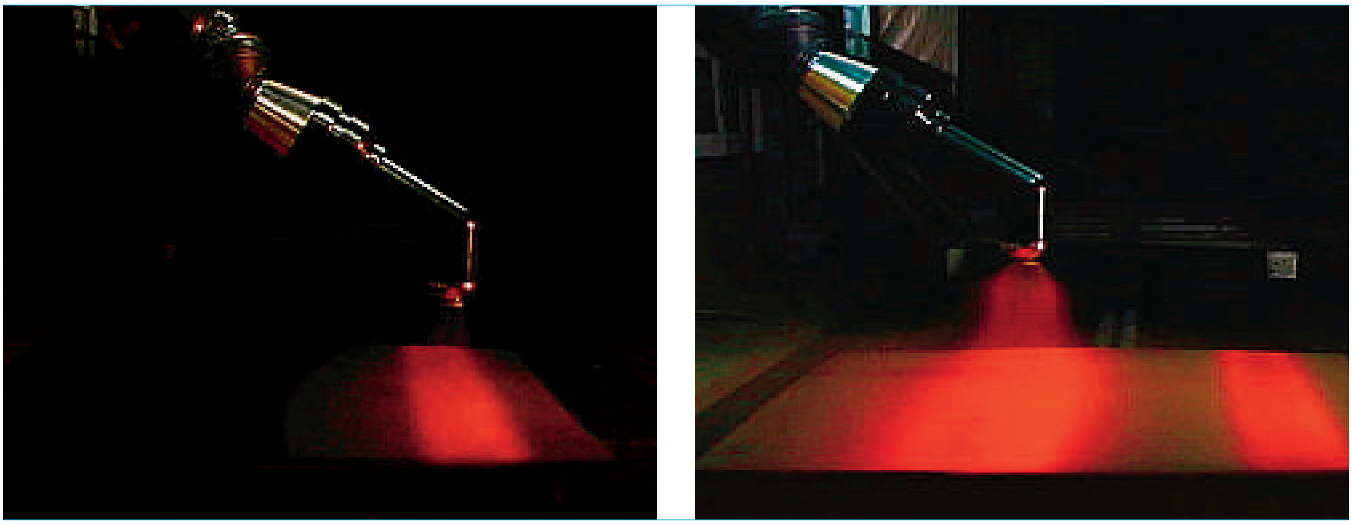
Significantly, this approach leads to safer electrostatic painting, because only the cartridge itself needs to be charged and isolated from ground – no small concern with a charge of –90 kV. Up to 90 percent of all the paint is transferred to the automobile body, hugely cutting paint losses. And small-lot paint runs are far easier to handle, and much more efficient and affordable.

The results from a major Japanese automaker speak for themselves:

- A 27-percent reduction in running costs – a savings of ¥ 3 billion/ US$ 26 million – over the manufacturer's annual production of five million vehicles.
- A 45-percent reduction in VOC emissions during painting, from 65 grams to 35 grams per square meters.

Demand driven manufacturing

4 The pattern control (PC) bell small (left) and large (right)



- Improved productivity, with smaller runs of greater numbers of colors, and the possibility of paint-to-order production.

As environmental regulations have become more stringent in recent years, car manufacturers are obliged to switch to waterborne, rather than solvent-borne, paints. Water, naturally, is the ideal solvent, non-polluting and safe to handle. The major problem in the use of waterborne paints comes from the difficulty in utilizing electrostatic painting technologies. Waterborne paints are much more viscous than solvent-based ones, making them harder to vaporize (yet, on the car body, they also tend to remain wet and run more, since water is not as volatile as solvent). Water is also more electrically conductive than solvent. The charged paint supply system must be isolated from the ground, resulting in a system that can be hard to maintain and is potentially dangerous. The result was that electrostatic painting with waterborne paints was impossible for many years.

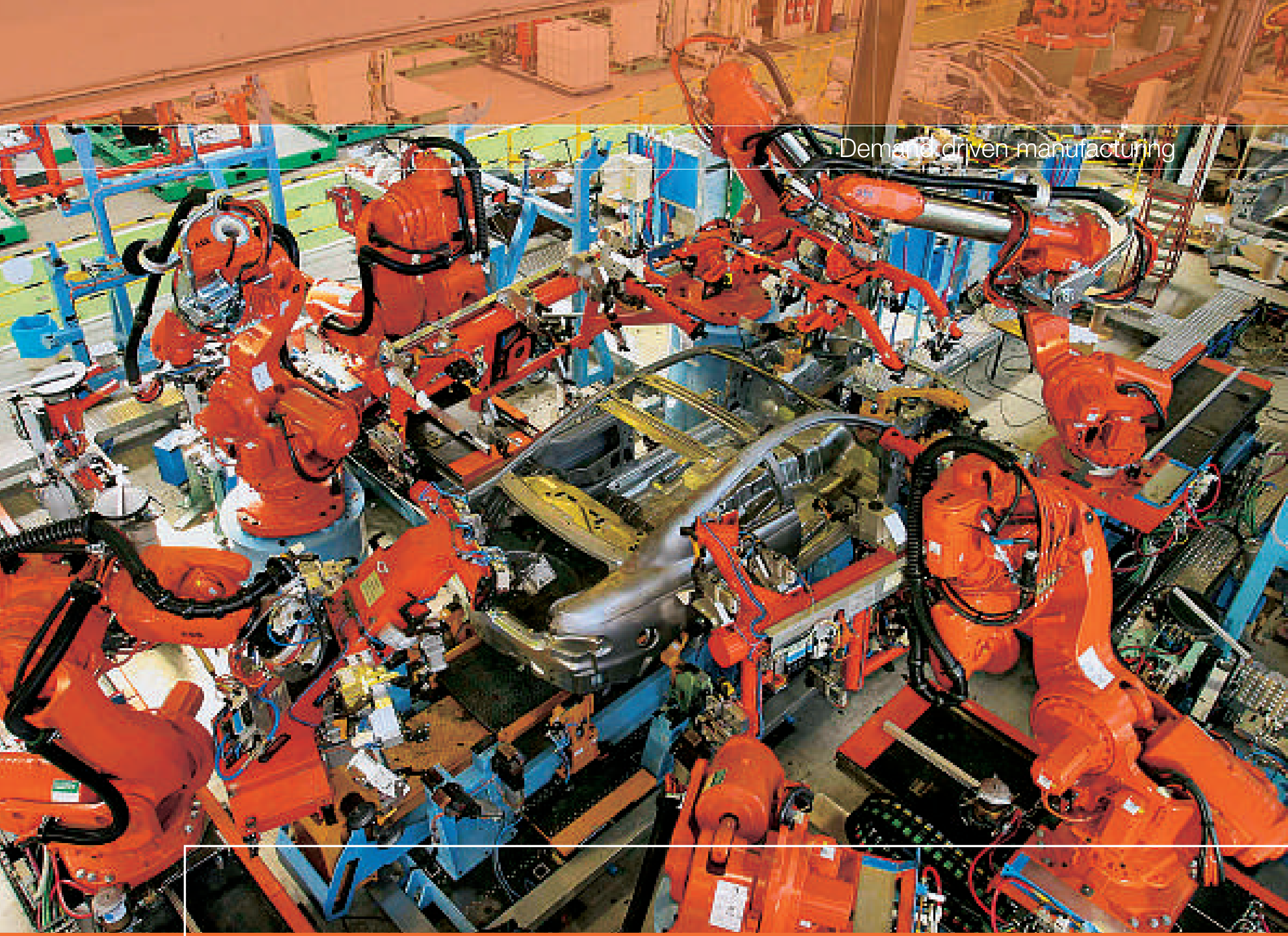
To cope with this, ABB developed the COPES-IV Bell Atomizer. A bell atomizer has a cup shaped part, the bell, which spins rapidly, flinging the paint off and creating a fine mist that provides superior coating properties. Compressed air spins the bell and shapes the paint mist. ABB engineers succeeded in fitting the COPES-IV with external electrodes that indirectly charge the paint particles, making electrostatic painting with waterborne paints possible. This type of atomizer, exemplified today by ABB's G1 COPES bell, is now used by European automakers, where stricter EU environmental laws significantly increasing the rate of conversion to waterborne paints.

ABB engineers succeeded in fitting the COPES-IV with external electrodes that indirectly charge the paint particles, making electrostatic painting with waterborne paints possible.

ABB robotic paint solutions are continuously evolving to meet market demands for lower investment, maintenance and operating costs and reduced environmental impact. One variation of the CBS system is the Flushable Cartridge Bell System (FCBS), which provides reduced maintenance costs. Especially when used with waterborne paints, where the problems associated with cleaning by solvent are eliminated, the system allows the cartridge to be cleaned during operations, cutting on routine overhaul of the cartridges. The FCBS has been highly regarded, again particularly in Europe where waterborne paints are today the norm in automobile production. Japanese and Asian auto production has not been as swift to move to waterborne paint, but there are plans to remedy this in the coming years. At the cutting edge of paint transfer technology is the Pattern Control (PC) bell 4. Automobiles and other objects to be painted do not only consist of open, flat surfaces, but have pillars and other smaller surfaces alternating with wider spaces such as hoods and doors. The PC bell allows for on-the-fly changes in paint spray width – narrow on a pillar and broad for the hood, for example – providing outstanding control of the amount of paint being applied. Combined with ABB robots, this is the future of robotized painting guaranteeing maximum transfer efficiency with minimum paint consumption.

ABB Paint Technologies makes it much easier to be a bumper manufacturer – or an automaker, a white-goods manufacturer or any other operation requiring paint color variation and greater response to individual demands – thanks to ABB Paint Technologies.

Osamu Yoshida
ABB Automation Manufacturing
Tokyo, Japan
osamu.yoshida@jp.abb.com



Spot on

Accurate spot welds with equalizing software

Lennart Sundstedt, Christian Müller, Åke Olofsson

When a spotwelding gun homes in to its target, a precise control of its position and pressure is vital. Such a control system must compensate for the gun arm deflection under the effects of the pressure it applies. The electrode tips (one on either size of the sheet) must contact the sheet at precisely the same moment to prevent bending of the sheet. Once in the right position they must apply the right pressure to weld, again, without deforming the sheet. Additionally, the wear of the electrodes must be taken into account.

In the past, mechanical equalizing systems based on pneumatics were used. ABB's servo-controlled *Software Equalizing* breaks new ground by offering far greater accuracy and flexibility leading to higher weld quality – and that while reducing the need for maintenance.

ABB Robotics provides flexible software solutions for various spotwelding applications. Dedicated software options exist for welding with pneumatic as well as with servo guns. *RobotWare Spot Servo* is a software package for welding with servo guns. It shares a common controller and internal motion control logic for controlling the gun's servomotor and the six axes of the robot. Hence, no external drive control unit is required and the control of the servo gun is fully synchronized with the movements of the robot.

As a further development, ABB Robotics is now introducing *Software Equalizing*, a motion-control software that replaces the conventional mechanical (pneumatically or electrically controlled) equalizing equipment mounted on spotwelding guns. *Software Equalizing* reduces the cost of equipment, reduces the need for maintenance and provides a higher weld quality.

A spot of history

Industrial robots entered the spotwelding scene more than thirty years ago. At the time, the accuracy of robots, fixtures, clamping devices and welding guns was poor. These inaccuracies were overcome by deploying mechanical equalizing devices, 1, making the gun flexible when closing the gun and building up the force in the tips prior to commencing the weld.

Over the years, robots have become more accurate and tolerances in metal sheets and clamping devices have been reduced. Servo controlled spotwelding guns are replacing pneumatic guns. As a result, the positioning accuracy of the sheet metal, and the repeatability of robot actions are so high that their variations show practically no influence on the spotwelding result.

There are, however, still other inaccuracies and effects during the spotwelding sequence that influence the weld quality. These include:

- Deflection of the fixed gun arm
- Inaccuracies in programming
- Tip wear.

Unless these are adequately compensated, the metal sheets can bend, warp or be damaged during welding. Failure to achieve the programmed squeeze force in the metal sheet can cause poor weld quality and residual strain in the metal. There is still need for an equalizing solution.

ABB Robotics is now introducing Software Equalizing, a motion-control software that replaces the conventional mechanical (pneumatically or electrically controlled) equalizing equipment mounted on spotwelding guns.

Software Equalizing

A typical spotwelding cycle is depicted in 2. In 2a, an IRB6600 robot with open gun approaches the weld position. The gun is closed 2b 2c at the weld position. Force is built up in the gun, ie, deflection takes place (force control replaces position control). When the force has been built up, the gun is closed and spotwelding takes place. Force in the gun arm is released, the gun opens and the robot moves the gun to the next position 2d (switching from force control back to position control).

ABB Robotics' *Software Equalizing* replaces the traditional mechanical equalizer with a package of easy to use functions that reduce costs (simpler guns, less maintenance, no compressed air to the gun) and makes programming as well as operation easier and faster. Features include:

- Gun arm deflection compensation
- Teaching support
- Tip wear monitoring and compensation
- Automatic release of fixed gun arm.

These functions are discussed below.

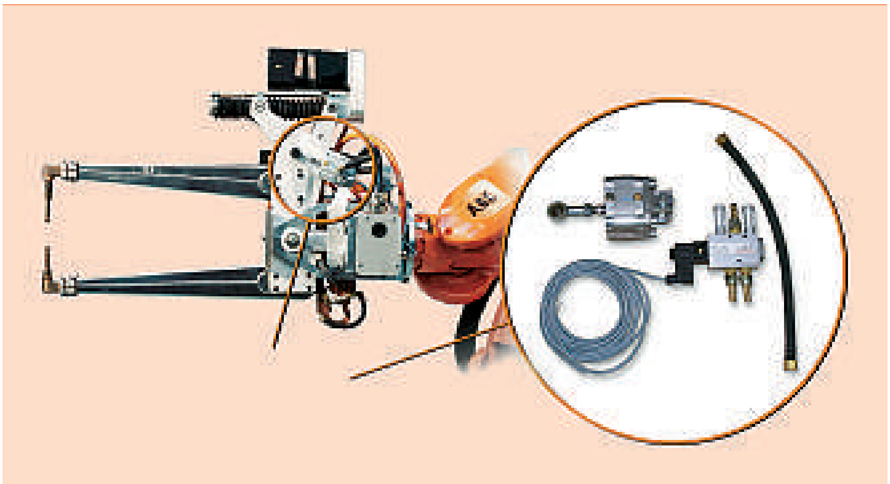
Gun arm deflection compensation

When the spotwelding gun closes to commence welding, the fixed gun arm will inevitably bend on account of the applied force. As a result, the position of the weld is inaccurate. To compensate for this bending, and to obtain the programmed squeeze force in the metal sheets, the gun position has to be corrected. This was previously achieved through mechanical equalizing.

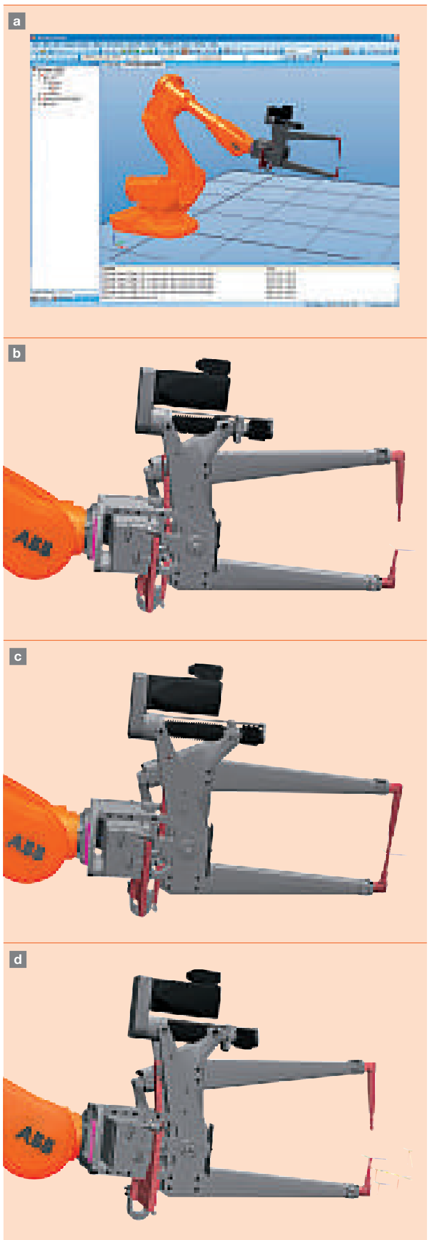
To replace this mechanical equalizing functionality by software means introducing additional movements of the fixed gun arm, either by acting on the gun itself (which then needs an additional gun axis), or on the six axis of the robot. ABB's approach uses the existing motion control software of the robot to achieve these movements. The internal motion control software fully coordinates the compensating movements of the robot with the force build-up in the gun. The same occurs when the force decreases after welding.

Detailed studies and measurements show that when *Software Equalizing*

1 A servo gun with a mechanical equalizer; such equipment was common prior to the introduction of *Software Equalizing*



2 Views of a typical spotwelding cycle, created with ABB's RobotStudio software



3 Flexpendant in *"Weld position Touch Up"* mode

is used, there is no bending of the metal sheet prior to or during welding. There is no other force present than the squeeze force applied in the gun tip. The compensating movements can also be perfectly synchronised with the movement of the gun during the force control phase. This means that welding is performed with practically no stress or strain in the metal sheets and the weld quality is consequently improved.

Since ABB's solution uses internal motion control logic and software to adjust the position of the fixed gun arm tip, the behaviour remains identical, regardless of gun orientation. As a comparison, a mechanical equalizer usually provides different gun arm deflection compensations for different gun orientations. A gun that works well when it closes in a horizontal position, might fail to compensate adequately in a vertical position. Tuning and trimming of the gun for good compensation in all orientations can be a tedious and time-consuming task.

By using the internal motion control logic and the robot to adjust the position of the fixed gun arm tip, ideal synchronization with identical behaviour, regardless of gun orientation, is allowed.

The gun arm deflection compensation functionality works for both X-type and C-type[1)] servo guns and in the same way for both robot carried guns and stationary guns. The only gun specific information that must additionally be provided is the deflection characteristic (gun arm deflection as a function of force and time). Such facts are usually available in the gun's datasheet.

Footnotes

1) The term "X-type" is applied to welding guns of scissor configuration (electrodes perpendicular to gun arm as in 2) and "C-type" to direct-acting configuration (electrodes in axis of gun arm, with one electrode in the direct continuation of this arm and the other attached via a C-shaped bracket).

Teaching support

Accurate programming of spotwelding positions is a prerequisite for good welding quality. The use of *Software Equalizing* increases the need for precise programming of positions. ABB Robotics software now includes a feature called *Weld-position Touch up*, making it easy to fine-tune programmed positions.

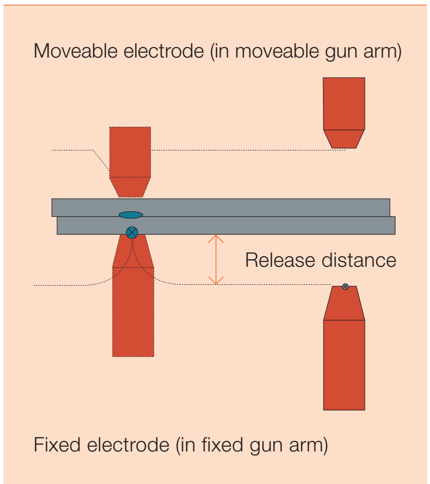
Weld position Touch Up is a function provided in manual mode (ie, during programming or updating of the program). In touch-up mode 3, all programmed instructions (except welding) are executed as normal. Each time the robot reaches a weld position in the program, it stops at the welding position and a touch-up dialogue appears on the FlexPendant Textbox.

The position of the fixed and movable gun arm tips can be incrementally adjusted using a single soft button on the FlexPendant. The position of the fixed gun tip is moved towards or

FlexPendant

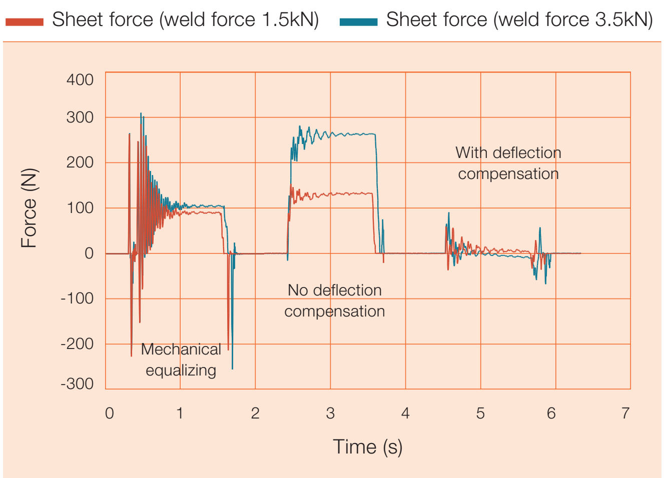
The FlexPendant 3 is ABB's handheld robot-user interface device. The ergonomic device designed for use with ABB's IRC5 controller weighs less than 1.3 kg and has a color touch-screen and a user friendly interface.

4 The electrode tips are withdrawn to a predefined release distance to prevent scratching of the sheet during movement



away from the metal sheets in predefined (adjustable) increments.

5 Force in metal sheet for welding forces of 1.5 + 3.5 kN



Tip wear monitoring and compensation

Spotwelding tips (electrodes) are continually worn down through use. As a result, the actual positions to which the gun is moved prior to welding must be adjusted for this wear. *Software Equalizing* incorporates a user-friendly tip-wear measurement and compensation functionality.

The total wear on both tips is determined by closing the gun "in the air" (without sheet) at a predefined force. The difference in the closed position of the gun is then measured, and this value is used to adjust the gun stroke. This guarantees constant gun closing times (and thus constant cycle times) as well as constant weld forces.

To simplify programming of spot welds as much as possible for the user, the robot automatically moves the fixed gun arm a pre-programmed distance perpendicularly away from the sheet while opening the gun.

Tip wear on the fixed tip can be calculated either over the expected relation between its wear and the total tip wear, or can be measured with the help of a fixed reference plate and a special "move"-instruction. For robot-carried guns, the reference plate is fixed in the working area of the robot. The actual position of the fixed gun arm tip is identified with a search-function, moving the tip towards the reference plate until a defined force is reached. In case of stationary servo guns the reference plate is mounted on the robot's gripper instead and the robot moves it towards the fixed tip of the gun. Because the robot itself is the measuring device, no additional equipment is needed.

This functionality not only provides accurate tip wear data, but also enables automatic tip wear supervision. Alarms can be set for critical cases, eg, when tips require dressing, replacement or have been lost.

Other methods, such as a light beam, can also be used for measuring tip wear.

Automatic release of fixed gun arm

When guns with mechanical equalizing systems are used, the fixed gun arm tip is automatically released from the sheet on opening the gun. Using *Software Equalizing*, an extra robot movement is required to release the fixed gun tip from the sheet. This is to prevent the tip from scratching the metal sheet while moving to the next weld position.

To simplify programming of spot welds as much as possible for the user the robot automatically moves the fixed gun arm a pre-programmed distance perpendicularly away from the sheet while opening the gun. The release movement can be directly followed by a corner zone and the next "move"-instruction to another area. The release distance **4** is set by the user and can be defined individually for every gun.

Verification of *Software Equalizing*

Functionality and performance have been thoroughly verified by force and high speed video measurements on various gun brands as well as for all ABB spotwelding robot types. For the measurements shown in **5** and **6**, a standard ABB X-gun of type SRT-M-E mounted on an IRB6600/225 robot was used. The throat depth of this gun is 645 mm and the maximum weld force is 3.5 kN. The deflection is then 4.7 mm.

The force measurements were performed with a very stiff metal sheet mounted on a standard force sensor. The setup permitted measurement of the force introduced in the sheet only perpendicular to its surface. This force bends and possibly even damages the sheet and should be compensated by the equalizing system.

As shown in **5**, mechanical equalizing produces forces on the sheet mainly during the closing and the opening of the gun. These are the reaction forces from the inertia of the gun when the tips contact the sheet. The equalizing force that remains during welding is due to a slight gun imbalance in the weld position.

When no mechanical equalizing and no deflection compensation is used (weld position of the fixed tip directly on the sheet) the remaining force on the sheet depends on the weld force and thus on the deflection of the fixed gun arm. This shows how important a good compensation of the gun arm deflection is.

Functionality and performance have been thoroughly verified by force and high speed video measurements on various gun brands as well as for all ABB spotwelding robot types.

The results for *Software Equalizing* show that there is only a minimal perpendicular force on the sheet during the weld, and that this is independent of gun orientation and weld force.

The performance of *Software Equalizing* can also be shown by monitoring the bending of a very thin sheet (which requires almost no force) with a high speed camera 6. This test shows how accurately the deflection of the fixed gun arm is compensated during the force build up.

6 shows a sequence of pictures from the movement of the gun to the weld position, closing of the gun to sheet thickness and the force control with the build up of the weld force (3.5 kN). In this case the sheet thickness is about 1.0 mm.

6a shows the movement of the gun to the weld position and the closing of the gun. The fixed (lower) tip approaches the metal sheet to the predefined release distance (5 mm in this case) before moving to its weld position on the sheet. During this movement, the gun is closed synchronized with the robot movement to the sheet thickness. This ensures that both gun tips reach the sheet simultaneously, regardless of the programmed speed.

6b and 6c show the force control phase with the build up of the weld force. In both cases, the force control is identical and the same gun force (3.5 kN) is applied.

6b shows the behaviour of the setup without any effective mechanical equalizing. The gun used actually has an active mechanical equalizer, but since the metal sheet does not provide any reactive force, the mechanical equalizer fails to compensate the gun arm deflection.

6c shows the same sequence with *Software Equalizing* activated. In comparison to mechanical equalizing, the gun is held in position by deflection compensation. The deflection of the gun is exactly compensated throughout the force build-up phase and practically no movement of the metal sheet occurs. By eliminating this risk of bending or damaging the sheet, a high weld quality is attained.

The performance of ABB Robotics' *Software Equalizing* shows it can replace mechanical equalizers on servo guns and provide far higher deflection equalization.

Benefits

The performance of ABB Robotics' *Software Equalizing* shows it can replace mechanical equalizers on servo guns and provide far higher deflection equalization. A function to adjust for inaccuracies introduced during programming is available. The fixed gun arm deflection and tip wear are compensated for by software. *Software Equalizing* utilizes internal motion control to adjust the position of the spotwelding gun with the robot's six axes. No additional drive unit or other mechanical equipment is needed besides what the robot controller already provides.

The benefits include:

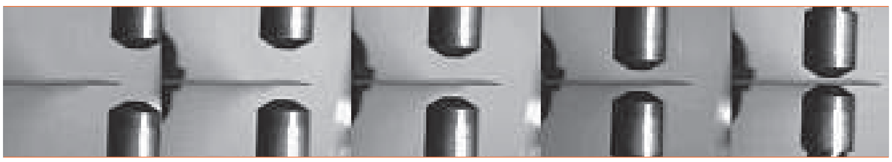
- No mechanical parts that can wear or jam. This in turn reduces the risk for, eg., tip stick.
- Less time to tune and trim the mechanical functionality.
- Reduced maintenance and higher availability.
- Simpler, lighter and thus cheaper guns.
- Compressed air no longer required by the spotwelding gun, leading to simpler dress packs and less equipment.
- No effect of gravity; behaviour is repeatable independently of gun orientation.
- Enhanced user friendliness because of programming support, automatic release of fixed gun arm, tip wear monitoring etc.

A patent is pending for parts of the *Software Equalizing* functionality.

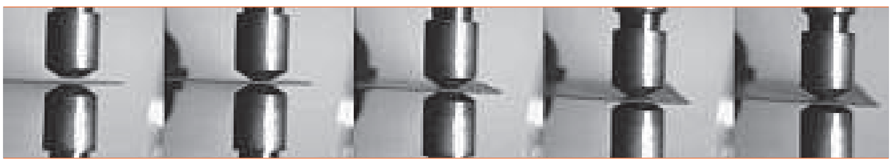
More information about ABB's software for BiW (Body in White) applications can be found at www.abb.com/robotics.

6 High-speed camera pictures of gun closure

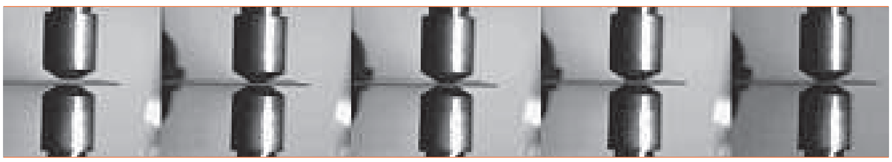
a Moving gun to weld position



b Force control without mechanical equalizing

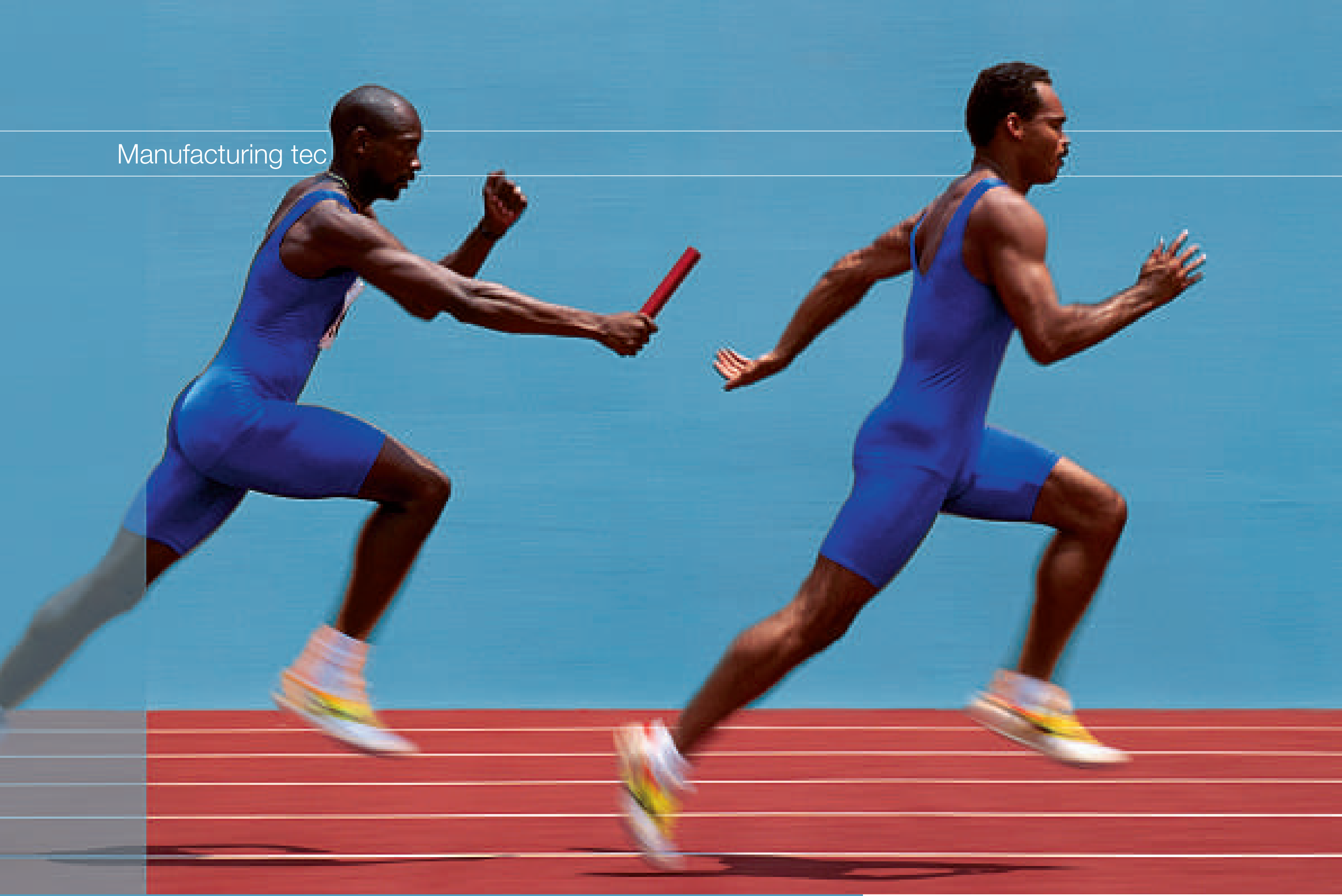


c Force control with *Software Equalizing*



Lennart Sundstedt
Åke Olofsson
ABB Robotics
Västerås, Sweden
lennart.sundstedt@se.abb.com
ake.olofsson@se.abb.com

Christian Müller
ABB Corporate Research
Ladenburg, Germany
christian.h.mueller@de.abb.com



Operational Excellence

Manufacturing Technologies Program: Path to Operational Excellence

Karol Kaczmarek, Johanna Tidström

Operational Excellence is critical to maintaining and advancing a company's competitive edge. It results in world-class quality, productivity and customer service. In today's marketplace where technological innovation, outsourcing, e-business and global competition are prevalent, it is becoming increasingly important for companies to pursue Operational Excellence. In this pursuit, the implementation of modern manufacturing techniques is essential for a successful outcome.

In ABB a Manufacturing Technology Program was formulated to leverage Operational improvements in ABB's manufacturing businesses. The program serves as the technological backbone for the Operational Exellence focus areas.

Many definitions exist for Operational Excellence. What they all have in common is that they lead to top quality and high productivity and to the delivery of goods and services to customers, on-time and at competitive prices. It is becoming increasingly important for companies to pursue Operational Excellence in today's world of technological innovation, outsourcing, information technology and global competition.

ABB Corporate Research has a Manufacturing Technologies Program focusing on operational developments in the manufacturing businesses.

A definition that is used in ABB is: *Operational Excellence is the aspect of business performance that makes ABB the natural choice for customers.* This translates into consistently delivering products and services on time, increasing the value of products and dynamically accelerating business processes.

Manufacturing technology

Operational Excellence has become part of the company culture and is being translated into the strategies of various manufacturing businesses within ABB. The complexity in size, scope and type of manufacturing processes, employed in more than 400 ABB factories and major engineering software centers worldwide, requires research and development activities to find ways of managing and optimizing manufacturing operations – referring to an earlier article[1]; one size definitely does not fit all.

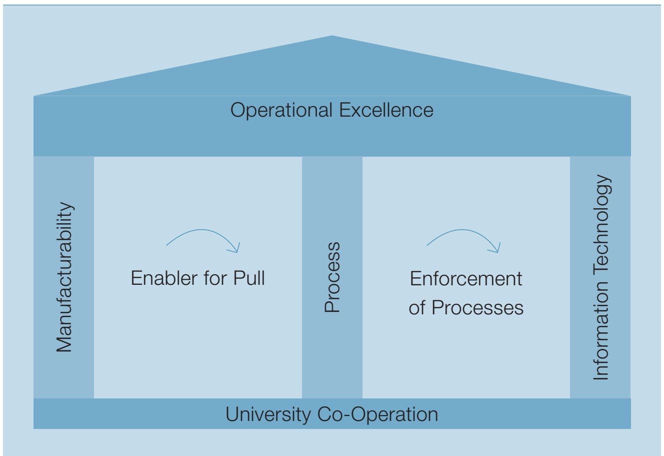
ABB Corporate Research has a Manufacturing Technologies Program focusing on operational developments in the manufacturing businesses. Research and development projects are done to analyze and fill the technological gaps in the Operational Excellence focus areas. To name just a few, these focus areas include optimization of the value chain of interlinked factories, streamlining of the product portfolio to leverage product offerings, consistently redefining the manufacturing footprint as well as the development of resources and management skills.

The ABB Corporate Research Manufacturing Technology Program builds on three pillars of competence: manufacturability, manufacturing processes and information technology 1.

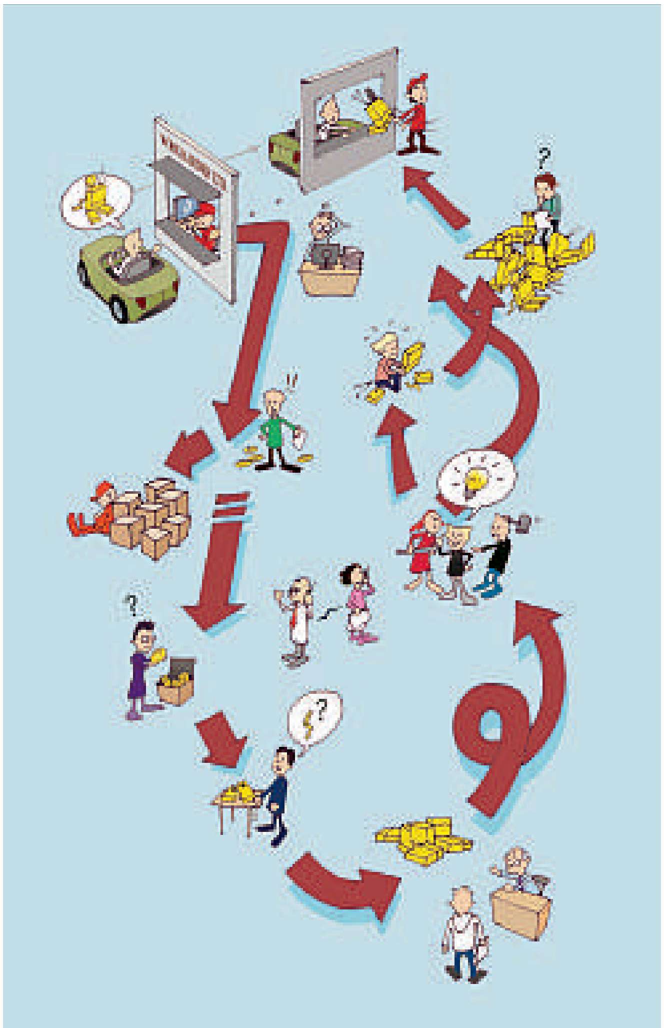
Manufacturability

ABB products are known for meeting customer requirements with regard to their functionality, performance and reliability. Moreover, to compete in the marketplace they have to be produced in a cost effective way. This translates into an additional set of requirements: easy to manufacture, assemble, package, transport, service and finally at the limit of the product's life cycle, ease of disposal.

1 The three pillars of the ABB Manufacturing Technologies Program



2 These people may be working hard but the overall process is wasteful and inefficient. No wonder the customer doesn't get the quality he deserves



Manufacturability can be defined as the discipline that handles these requirements in the manufacturing environment. In the design stage of a product, it concurrently considers all aspects of product manufacturing. There are a number of so called DFX methods and tools that support manufacturability: design for manufacturing (DFM), design for assembly (DFA), design for cost (DFC), design for variety (DFV), etc.

In general, the concept of manufacturability aims at product simplification, standardization and modularization that in return enables proactive variety management (mass customization) in front-end processes. It also allows the implementation of pull production and replenishment methods in the manufacturing process. A product that is built of standard modules can be configured in many ways to match individual customer requirements (in ratings, performance, features, fixtures, etc.). A product that is easy to fabricate, consists of standard modules, is customized downstream and promotes favorable practices in its production process.

The concept of manufacturability is discussed further in the article "Simplicity pays" on page 55 of this edition of ABB Review.

Processes

In order to be competitive plant management requires accurate, timely and complete information from multiple perspectives. The material flow through each production step is triggered by the relevant flow of information – an essential part of the production process.

Footnote:

1) "The manufacturing beat" page 12.

Manufacturing technology

In addition to information flow, material flow processes are analyzed and developed to reduce the variability (delays, rework, quality problem, etc.). Variability endangers the continuity and speed of the movement of information and material. This results in decreased performance of the overall system eg lower throughput. Therefore, the focus in the processes is on reducing and controlling the variability in the entire order-delivery process, including office, production and supplier integration.

Manufacturing processes are designed to ensure continuous flow of material and partly manufactured products through all stages of the manufacturing and assembly operations. The product flow is meant to be continuous and fast. In a broader perspective, development is done to optimize the global internal value chains and enhance manufacturing flexibility and mobility.

The concept of manufacturing processes is discussed further in "The science of manufacturing" on page 6 of this edition of ABB Review.

Information Technology

Once the production processes on the shop-floor are running at a smooth and high speed, time is right to secure its performance through automation. The prerequisite for this optimization step is the efficient flow of information.

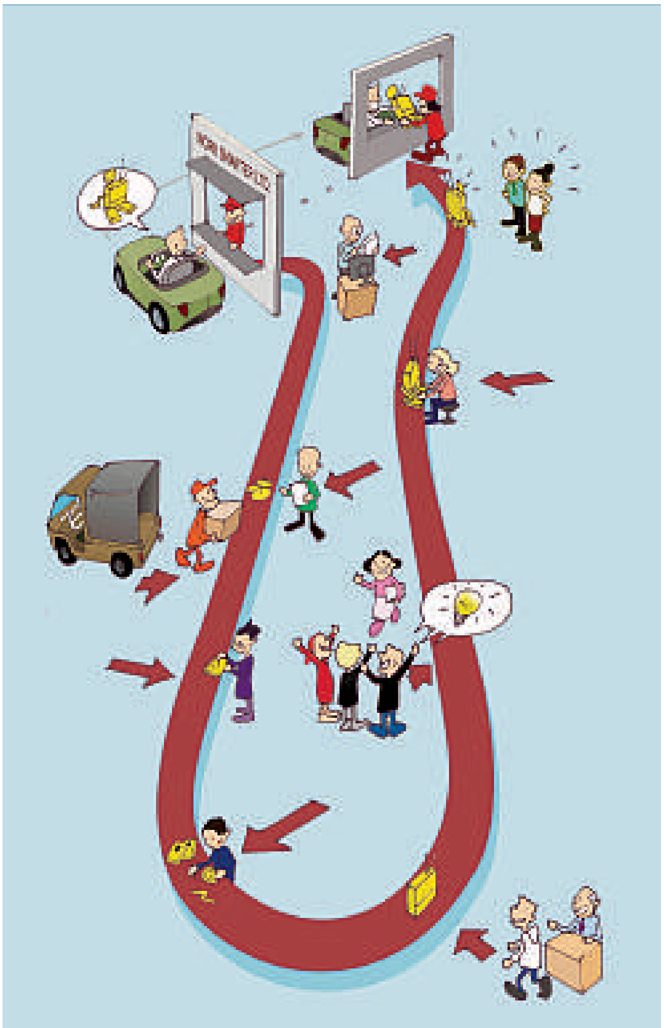
The major role of IT tools on the shop-floor is to enforce the processes that move the material in a continuous and fast manner from work station to work station and from supplier through manufacturer to the final customer. In its manufacturing plants, ABB promotes IT solutions for these purposes.

To fulfill its vision of Operational Excellence, ABB has invested in a program driving modern manufacturing technologies and practices into its many factories. The principles of Information Technology are discussed further in "NEMESIS" on page 59.

The major role of IT tools on the shop-floor is to enforce the processes that move the material in a continuous and fast manner from work station to work station and from supplier through manufacturer to the final customer.

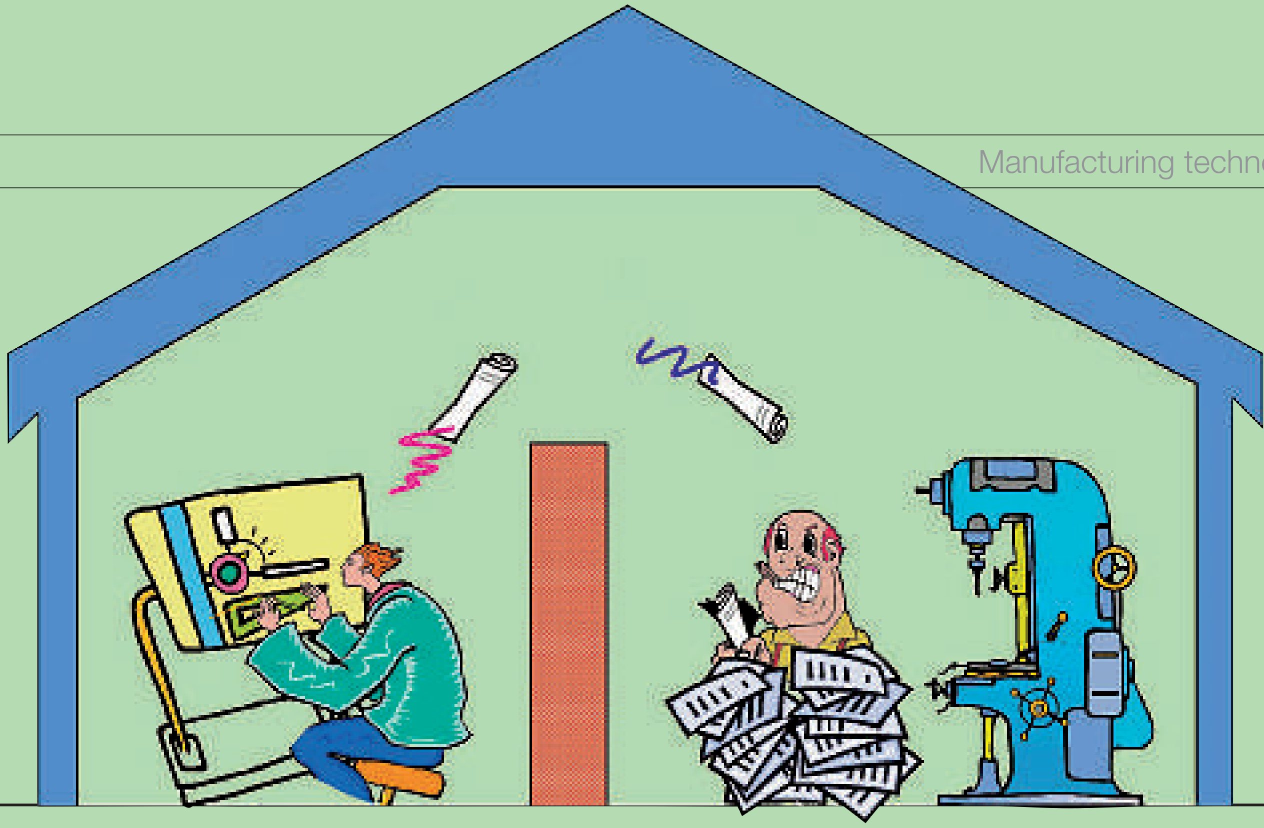
The three pronged approach described in the Manufacturing Technology Program has been rolled out in many production facilities with excellent results. With the operation in control, attention can be focused on the Supply Chain and the logistics of getting the finished product to the customer. A holistic manufacturing solution takes all these three processes into account and ensures their harmonic symbioses, thereby working smarter before working harder, as is not the case in 2. A streamlined organization in which every part is in its place and everybody is doing the right job at the right time may take some effort to achieve, but the results are worthwhile 3. Waste and inefficiency are reduced. Quality and customer satisfaction rise. There is a clearer flow of information making it easier to recognize disturbances before they occur and to react to these proactively. Several articles in this issue of ABB Review describe the pitfalls, the risks and the solutions to some of the issues related to the implementation of modern technology to support Operational Excellence as a competitive advantage.

3 Introducing Operational Excellence has transformed Work Harder Ltd into Work Smarter Ltd. Both the company and its customers are better off



Karol Kaczmarek
ABB Power Technologies
Zurich, Switzerland
karol.kaczmarek@ch.abb.com

Johanna Tidström
ABB Corporate Research
Vaasa, Finland
johanna.tidstrom@fi.abb.com



Simplicity pays

Design for manufacturing and assembly (DFMA) in ABB

Tomasz Nowak, Marcin Chromniak, Robert Sekula, Lucas-Lu Gao

Increasing competitiveness is an accepted fact of company life. For as long a people can remember, companies have been exclaiming how competitive the current world market is. There is no doubt this same sentiment will be uttered in the foreseeable future and beyond.

The ability to efficiently develop and produce high quality, reasonably priced products that meet customer expectations is essential to continued profitability and global competitiveness.

However, the ways in which companies have been doing this have been changing with time. The methods that worked yesterday will not necessarily suit today's or tomorrow's market. In this context, manufacturing and assembly oriented product design plays an important role.

ABB has realized this simple engineering philosophy and is applying "Design for Manufacturing and Assembly" (DFMA) techniques to great benefit.

Back in the early days of product design and manufacture, sequential engineering, with its specialized, but separated development steps (ie, "I design, you produce" philosophy), took pride of place. Development activities such as design, technology, testing, and service were performed by different departments. This approach worked very well for Ford's first manufacturing line at the beginning of 20th century where the Model T car was produced. The Frederick Taylor philosophy – any complicated job can be transformed into a sequence of straightforward seperated steps – was also applied to product development processes. These approaches still work today for production processes where simple, standard goods are created.

However, the inadequacies of sequential engineering became apparent as: companies grew and expanded into other continents; technologies advanced; and problems became more complex. For one thing, organizational structures within a company meant many departments were no longer in the same country let alone under the same roof. At best, vital communication and collaboration was reduced to an absolute minimum.

This, added to technical problems of increasing complexity – not to mention shorter time-to-market – very often resulted in designs that, put simply, could not be manufactured!

What was needed therefore was a concurrent engineering approach that focused more on teamwork and information exchange between the various departments, no matter where the location. In recent years, several methods have been proposed, including Quality Function Deployment, Robust Design, Collaborative Manufacturing, Rapid Prototyping, and Design for Manufacturing and Assembly (DFMA). Of all these methods, DFMA probably stands out as being the most powerful.

In very general terms, DFMA is a set of methodologies and principles that guide the process of proactively designing products to optimize all lifecycle functions (fabrication, assembly, test, procurement, delivery and service).

DFMA for novices

Reducing costs and time-to-market has become two of the most important elements for a company's success. Crucial to achieving this is the reduction in the number of prototypes created. For this to happen a culture of analysis must become the norm.

During the development stages of a new product, cost and cost drivers must be carefully considered. Yet they tend to be neglected simply because designers lack a reliable method of managing and understanding them. DFMA helps project teams analyze and understand the cost effects of their design decisions anytime during the product development cycle. It provides a strategy for identifying early cost drivers and develops tactics to reduce their impact throughout the manufacturing process.

DFMA consists of two complementary methodologies: Design for Assembly (DFA) and Design for Manufacturing (DFM).

Design for Assembly (DFA)

During the early stages of design, control of part count is paramount to maintaining cost targets. DFA is a technique that helps simplify products by focusing the attention of design teams on part count and part count reduction. It allows engineers to determine the theoretical minimum number of parts that must be in the design for the product to function as required. When unnecessary parts are identified and eliminated, unnecessary manufacturing and assembly costs can also be eliminated. In other words, fewer fabrication and assembly steps are required, and manufacturing processes can be integrated or even reduced. Costs related to purchasing, stocking, and servicing also decrease as the number of parts is reduced. Additionally, inventory and work-in-process levels will go down with fewer parts.

There are two basic principles to DFA:
- The best-engineered part is no part at all!
- If the part cannot be eliminated, minimize the time required to grasp, align and assemble it.

Part reduction strategies involve incorporating multiple functions, if possible, into single parts 1. In particular, this applies to components which are not absolutely essential for product operation, or which are not required by standards (norms) or customers.

DFA recognises the need to analyse both the part design and the whole product for any assembly problems early in the design process. DFA analysis looks for three aspects:
- Relative movement: if there is an essential relative movement between active components, then it is likely different parts are needed (or part count reduction becomes impossible). However, some changes in component material and the manufacturing process must also be considered. Small movements may also be achieved in other ways, for example, through plastic hinges, flexing or alternative joining methods.

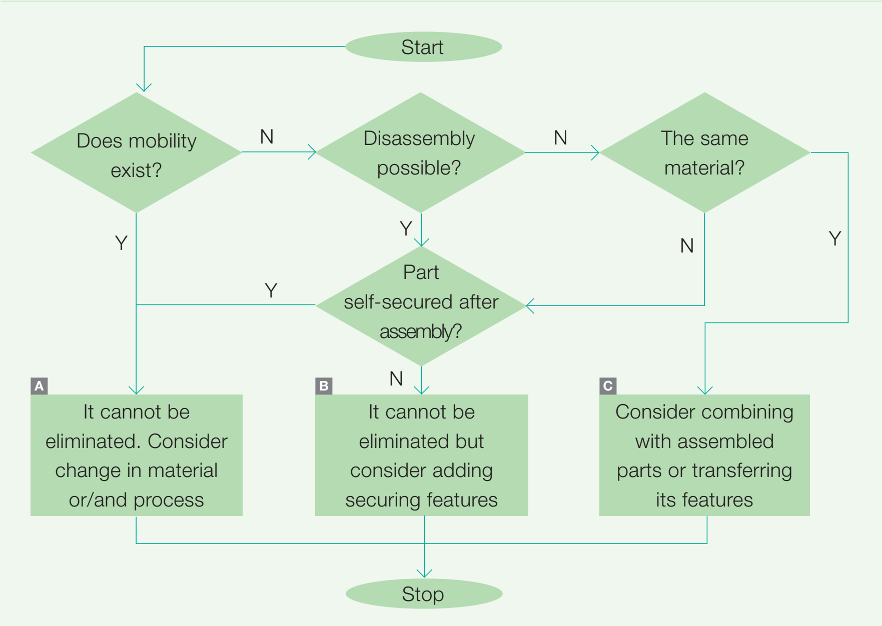
DFMA

ABB has recently begun collaborating with Professor Robert Sturges of Virginia Tech to train present and future ABB leaders in DFMA practices. What Prof. Sturges says about DFMA:
"A number of myths seem to pervade the production field, keeping us from the serious business of fundamentally understanding our processes:
- If you designed it, you can manufacture it.
- If you can draw it, you can manufacture it.
- DFMA is a non-problem, since manufacturing is performed in a structured environment.

We contrast these ideas with the realities of modern manufacturing:
- Parts are manufactured by machines but (largely) handled by people.
- If we make it easy for a machine to handle, a person can handle it better.
- If a person can't handle it easily, design the product and the process together.

DFMA gives us the tools and techniques to manage both product design and process design from a quantitative, analytic, and economic perspective."

1 Design for Assembly (DFA) – analysis of unnecessary parts



- Need for disassembly (service): Although there may be no relative movement during operation, a component may require adjustment or replacement.
- Different materials: If there is no important need for neighboring components to have different material properties, such as electrical or mechanical, the part reduction strategy may be applied.

Finally, it is neccessary to see if the part is self-secured after assembly. In this case, the elimination of fasteners and joining elements must be analyzed.

Once part reduction has been taken as far as possible, DFA then turns its attention to simplifying the assembly process. How the assembly process is realized depends largely on component design and the interfaces between parts. Therefore the geometrical characteristics of a particular component, such as shape, tolerances, and weight and size, must be analyzed. In addition, assembly aspects such as fastening, assembly motion, insertion, and alignment methods must also be considered.

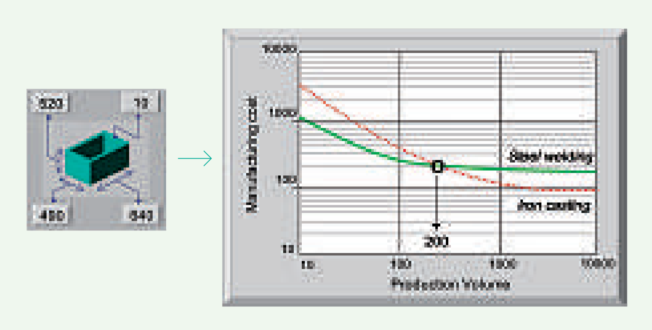
The concept of assembly process analysis relies on so-called "penalty time", a kind of artificial weight which evaluates potential assembly difficulties. Each assembly aspect is judged and awarded a time score. The exemplary penalty times for the fastening aspect of an assembly process is shown in Table 1.

A thorough DFA analysis should result in an elegant assembly process with fewer components that are both functionally efficient and easy to assemble.

Table 1 Penalty time for manual fastening operations.

Fastening method	Penalty Time
No fastening method or snap fit only (the part is placed on or in an already assembled part)	0 s
Screwing or pressing opertion	3 s
Adhesive fastening method, welding, riveting, soldering	8 s

2 Design for Manufacturing (DFM) – break-even calculations



DFM is a systematic approach that allows engineers to anticipate manufacturing costs early in the design process, even when only rough product geometries are available.

Design for Manufacturing (DFM)

DFM is a systematic approach that allows engineers to anticipate manufacturing costs early in the design process, even when only rough product geometries are available.

Engineers tend to design for manufacturing processes with which they are familiar. DFM, however, encourages development teams to go further by investigating all the major shape-forming processes and different materials so that components or products can be more economically produced. Consider, for example, the fabrication of a simple product frame. A DFM analysis shows that it is more economical to use steel welding with a production volume of less than 200 pieces. Above this volume, iron casting is deemed more economical 2.

DFM also offers specific guidelines for different fabrication processes, and this is illustrated by a simple example shown in 3. The following guidelines are suggested for a machining process:

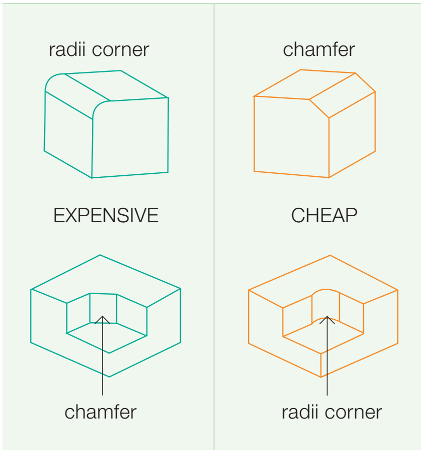
- Consider castings or stampings to reduce the machining required for higher volume parts.
- To minimize machining, near net shapes for parts that have been molded or forged are recommended.
- Design for ease of attachment by providing a large solid mounting surface and parallel clamping surfaces
- Avoid designs with sharp corners or points as these put more strain on the cutting tools.
- Thin walls, thin webs, deep pockets or deep holes should be avoided because of the risk of distortion during the clamping and machining process.
- Favor rectangular shapes over tapers and contours if possible.
- Avoid hardened or difficult-to-machine materials unless absolutely necessary.
- Put machined surfaces on the same plane, or together with the same diameter to minimize the number of operations.
- Design workpieces to use standard cutters, drill bit sizes or other tools.

Both, DFA and DFM use everyday units and easy-to-read metrics (eg, seconds, dollars), making it easier for engineers to evaluate different design and assembly alternatives, and to quickly judge production costs and times.

How DFMA works for ABB

It is sometimes the case that a typical product offered by a company is: functional but complex; reliable but

3 Design for Manufacturing (DFM) – suggestions for the machining process



Manufacturing technology

over-dimensioned; of high quality but expensive; and very often exceeds the requirements of developing markets (and is therefore beaten by cheaper competitors). The answer to this problem is to simplify the product design because, put plainly, “simplicity pays off”.

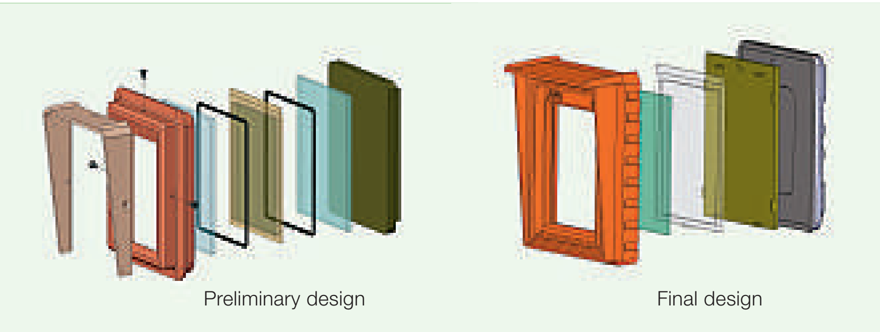
There are numerous examples within ABB where proper manufacturing and assembly oriented design has not only brought about significant quality improvements but cost reductions as well. One such example is ABB’s Passive Voltage Indicator (PVI). The DMFA method was successfully applied at a very early stage in the project, ie, when the preliminary design of the new product was defined. The end result was a significant reduction in the number of parts needed (from 11 down to 7), which in turn cut manufacturing costs and assembly times 4.

Another example concerned the redesign of ABB’s TPU medium voltage current transformer, which needed to be simplified to reduce manufacturing costs. The application of DFMA, together with some innovative design, helped bring about new design and manufacturing possibilities for this well-known and standard ABB product 5.

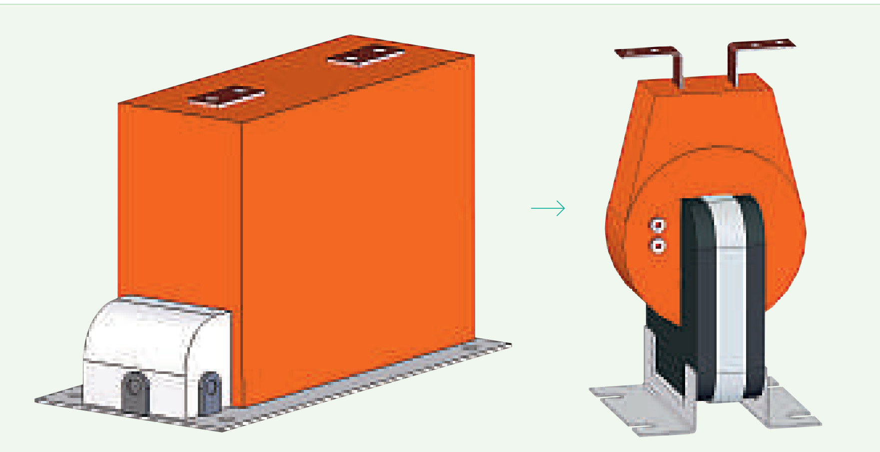
Other DFMA examples cover the redesign of products for global markets, for example: NCX Open-Fuse Cutout for the Chinese market; a new design concept for Flame Scanners developed in the USA and Italy; and the redesign of Atomizers produced in Japan.

With regard to the redesign of NCX Open-Fuse Cutout, DFMA identified three areas where engineers needed to focus to produce a low-cost competitive product: parts reduction; the use of a more economical material; and the improvement of parts manufacturability. After the redesign activities, 13 ideas grouped into two design concepts with the 10–15 percent cost saving were achieved.

4 Passive Voltage Indicator (PVI) – DMFA applied at the conceptual stage



5 TPU Current Transformer – Standard design (left) versus possible low-cost design for global markets (right)



DFMA Decalogue

- Design for the minimum number of parts
- Design parts to be multifunctional
- Use standard components, materials and processes
- Develop a modular design approach
- Minimize orientation of parts
- Apply stackable – uni-directional assembly
- Facilitate insertion and alignment of all parts
- Avoid threaded fasteners
- Eliminate adjustments
- Work as a TEAM

Summary
When it comes to new products, customers demand functionality and high quality at a reasonable price. The ability to meet these expectations at low cost is essential to continued profitability and global competitiveness. In this context, manufacturing and assembly oriented product design plays a very important role. ABB has realized this simple engineering philosophy and is continuously benefiting from it. The DFMA technique has been successfully applied to several projects, proving that collaborative design and better interaction between engineering and manufacturing departments reduces production costs by an impressive 10–15 percent without any heavy investments. “Teamwork and simplicity pay off!”

Tomasz Nowak
Marcin Chromniak
Robert Sekula
ABB Corporate Research
Krakow, Poland
tomasz.nowak@pl.abb.com
marcin.chromniak@pl.abb.com
robert.sekula@pl.abb.com

Lucus-Lu Gao
ABB Corporate Research
Beijing, China
lucas-lu.gao@cn.abb.com

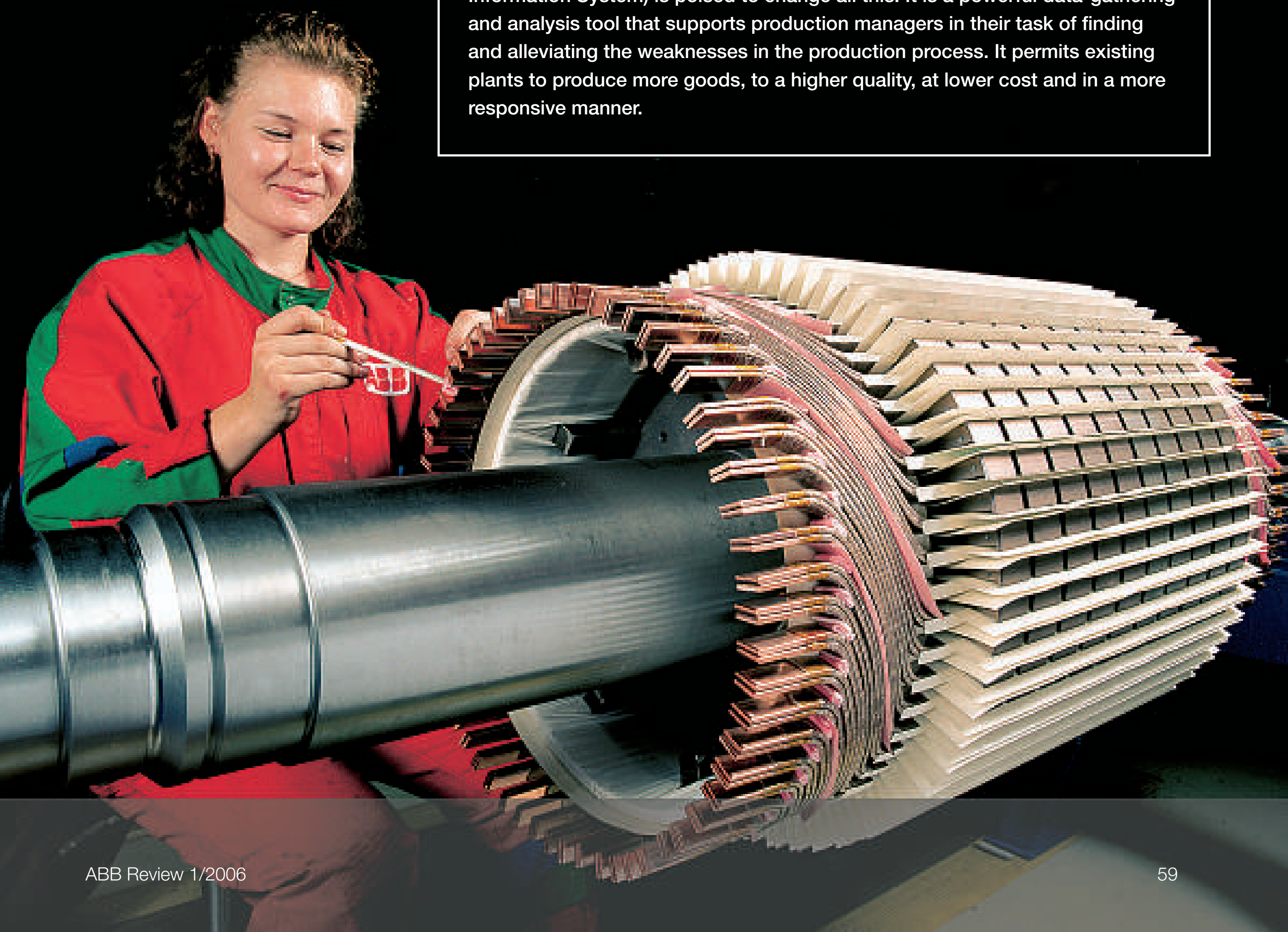
NEMESIS

Factory excellence solutions

Miroslaw Bistron, Lukasz Krupa, Krzysztof Sowa-Pieklo, Bartlomiej Wyrwa, Tomasz Nowogorski

"Knowledge is power" according to an old dictum. To get the best out of a factory in terms of resource efficiency, reaction times and product quality, there is no way around accurate and up-to-date knowledge of problems and their root causes. So much for the theory! In practice, such information is often distributed over several incompatible IT systems in different locations and in a form that does not facilitate the drawing of the right conclusions. The absence of a meaningful joined-up view means potential problems often languish until it is too late to prevent them from striking.

ABB's NEMESIS (Novel Enterprise Manufacturing Execution and Scheduling Information System) is poised to change all this. It is a powerful data-gathering and analysis tool that supports production managers in their task of finding and alleviating the weaknesses in the production process. It permits existing plants to produce more goods, to a higher quality, at lower cost and in a more responsive manner.



In manufacturing, there is always a delicate balance between time, resources, materials and capacity. Even the slightest change in this can affect productivity. To successfully manage this balance, a manufacturer needs adequate information providing a certain degree of foresight. However, for far too long, manufacturers have been forced to react to events rather than being able to anticipate problems to satisfy customer commitments.

IT systems, by definition, supply data; however, owning information is not enough. More important than having appropriate data is to know how to interpret and use it. The purpose of the IT system is to empower management in drawing the right conclusions from data and to support proper methodologies and practices. The Theory of Constraints (TOC)[1] concept which is implemented in many ABB manufacturing plants addresses these issues. A suitable IT solution was required to support this approach.

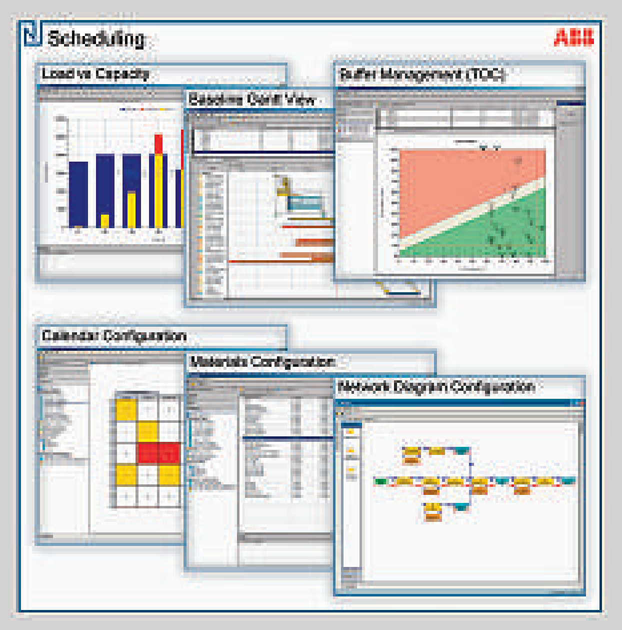
The implemented approach, NEMESIS (Novel Enterprise Manufacturing Execution and Scheduling Information System) 1, covers plant scheduling, execution, quality management and reporting. Orders are automatically transferred from the plant's Enterprise Resource Planning (ERP)[2] to the scheduling system. There they are scheduled against the current factory load. The selected jobs are transferred to the Manufacturing Execution System (MES)[2]. This system supports managers in controlling the factory's workflow and it aids in gathering process and quality data for further analysis. While a production order is in execution, production and quality managers, factory management and the sales force can track production, analyze reports and set priorities appropriately.

With the support of such scheduling and execution systems, the factory can be more responsive and reach its full potential. Beyond that, the system increases plant visibility and flexibility, which can permit an informed and safe reduction of inventory levels.

Reduction of Work-in-Progress (WIP)[2] shortens cycle times, thus allowing better responsiveness to customer demands using customized products. When connected to the scheduling system, online feedback from MES strengthens the customer service department's ability to accurately quote due dates and provide status updates to customers.

1 NEMESIS – integrated enterprise system consisting of IT tools for scheduling, execution, quality analysis and reporting

2 Scheduling system providing full support for TOC and Finite Capacity approach



Integrated solution components

Production Planning and Scheduling

When dealing with plants dispatching many different product variants every day, optimal management is close to impossible without computerized support. The most important and indispensable aid for today's planner and production manager is the right scheduling tool. But what is a good scheduling tool? During scheduling workshops, various ABB factory representatives, business area managers and R&D experts were asked to answer this query. A detailed map of required functionality was derived from their responses. The most important elements of this are: support for scheduling principles – Theory of Constraints (TOC) and Finite Capacity Scheduling (FCS), support for buffer management, load vs. capacity and Work-in-Progress (WIP) control, and interconnectivity with different ERP and MES systems 2.

Two main production types can be differentiated in discrete manufacturing: project environment and production environment. The key differentiator between them is the level of uncertainty. For a project environment where the level of uncertainty is high, TOC provides the Multi Project Critical Chain (MPCC) methodology. For a production environment, where the risk of the unknown is relatively low, the Drum Buffer Rope (DBR)[3] approach is recommended.

Engineered-to-order products (ETO) are difficult to schedule with Materials Requirement Planning (MRP) systems because they are executed first as an engineering project and then as a one-of-a-kind manufacturing build. Because they are one-of-a-kind and

Footnotes

1) See page 25.

2) See glossary on page 74.

3) See footnote 5 on page 26.

sometimes first-of-a-kind, there is a high uncertainty in the engineering phase, procurement phase and manufacturing phase. Poor on time delivery (OTD), cost overruns and reductions in specification (change of scope) are well-known problems in the ETO product world.

ETO products, such as Power Transformers, Gas Insulated Switchgear and Large Electrical Machines, are essentially unique projects and are affected by the variability described above. The best-in-class method of project management that is able to deliver projects on time, in budget and in-scope is the Critical Chain[4)] method. When many projects are run at the same time, there is a modified Critical Chain method called Multi-Project Critical Chain (MPCC).

MES focuses on value-adding processes – helping reduce manufacturing cycle time, improve product quality, reduce WIP, reduce or eliminate paperwork, reduce lead time, and empower plant operations staff.

Critical Chain has been successfully applied to engineering projects and ETO product manufacturing in ABB and elsewhere. Critical Chain has enabled increases in OTD, reductions in Throughput Time (TPT) and Total TPT (TTPT), and also increased factory capacity. The productivity of highly skilled engineers and designers in multi project environments has been increased by 40 percent using Critical Chain.

TOC can also be successfully applied in production environments. For products with short cycle times, which usually are produced on a massive scale, one of the biggest challenges to factory management is the identification of the production bottleneck (the resource that has just enough capacity or less capacity than is needed to satisfy the demand placed upon it). This resource must be fully exploited. The next step is to subordinate all other shop-floor activities to this resource keeping the factory throughput at a pace not lower than the bottleneck's. DBR is a finite capacity scheduling mechanism that implements these measures.

TOC methodology was the main driver for the new ABB planning and scheduling system. NEMESIS aims to support both types of manufacturing environment by implementing MPCC and DBR methodologies. To keep the whole solution simple allowing final users to focus on their core activities, the system was developed to permit the straightforward realization, configuration and parameterization of scheduling algorithms.

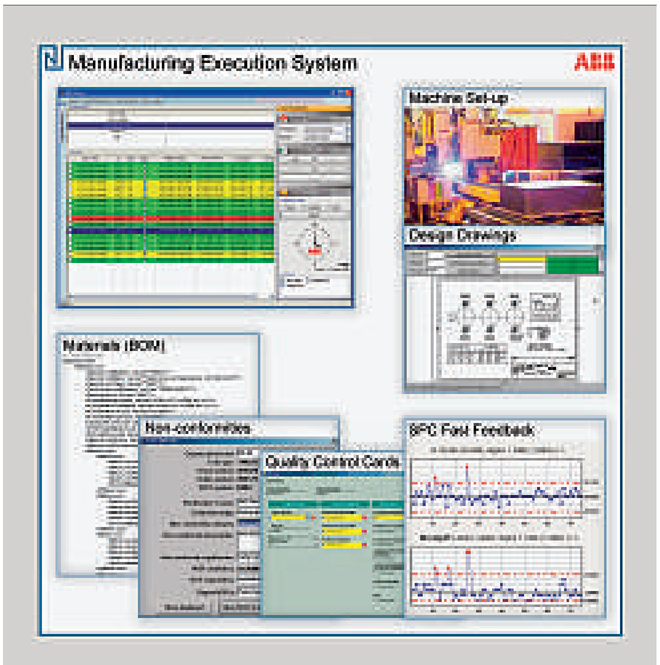
The principal features of the scheduling system developed to address these issues are:

- Fully support exploitation of bottleneck
- Subordinate preceding and succeeding operations to the bottleneck
- Use aggregated buffers in critical locations rather than hidden safety buffers everywhere
- Buffer management for execution monitoring and jobs prioritization
- Use feedback from execution system for corrective actions
- Enable load vs. capacity analysis

To permit one-click deployment in different factories, the scheduling system is fully configurable. A resource pool can be set up almost instantly, calendars configured and network diagrams specified to model the factory. Scheduling results are presented in many types of reports. The user selects different views such as "load versus capacity", Gantt view or buffer management. In addition, the system generates material reports to provide supply managers with the list of required materials together with dates that they are required to be on the shop floor.

An even greater advantage of the scheduling system lies in its analysis of real and up-to-date execution data. The scheduling system is linked to the execution system by real-time feedback from the shop floor. The scheduling system provides long and medium term visibility, comparing planned and expected to real situations.

3 Capabilities of Manufacturing Execution System (MES) for shop floor information and execution control



Manufacturing Execution System (MES)

MES 3 is an essential component of operations in today's competitive business environments. It focuses on value-adding processes – helping reduce manufacturing cycle time, improve product quality, reduce WIP, reduce or eliminate paperwork, reduce lead time, and empower plant operations staff.

The Manufacturing Enterprise Solutions Association (MESA) defines several fields of improvement an MES can achieve. MES delivers information enabling the optimization of production activities from order launch to finished goods. Using current and accurate data; MES guides, initiates, responds to, and reports on plant activities. The result-

Footnote

4) For more information about TOC and Critical Chain, refer to: www.toc.co.uk

ing response to changing conditions, coupled with a focus on reducing non-value-added activities, drives effective plant operations and processes.

MES functions include resource allocation and status, dispatching production units, data acquisition, quality management, performance analysis, operations scheduling, document control, labor management, process management and product tracking and genealogy. As the backbone of the manufacturing systems, MES fills a gap between business control (ERP and Supply Chain) and process control (automated and manual operations) to optimize manufacturing profitability. MES dispatches, monitors, tracks and controls production information to provide real-time feedback so managers can make better decisions about manufacturing operations. MES functionality covers several parts of the manufacturing chain. The most important challenge in discrete manufacturing is to integrate and leverage real-time information from multiple sources to get a product out the door. It requires integration of data from individual parts of the process – from product specifications and components inventory, to assembly, instructions, QA testing, receiving and shipping. The main benefit of such a system is the efficient handling of production data through the integration of information from different sources. MES applications organize and catalog enormous quantities of data and provide easy and immediate access to the right information at the right time. As a result, MES brings the following benefits:

- Information flow improves as a result of integration of multiple systems. MES, as the "window" into these systems enables a "paperless" manufacturing environment that eliminates non-value adding repetitive activities such as routine paperwork and enables real-time flow of information.
- Order tracking capability based on production order tracking within the plant. This assists sales staff and increases the accuracy of the information they provide to the customer.
- Quality improvement and less waste and scrap as a result of improved tracking and reporting of key quality metrics, permitting improved statistical process control and root cause analysis.
- Operator efficiency improvement by providing operators with the information they need. This can include the bill of material, product drawings and product specifications. Documents can be reviewed and the most up-to-date versions pushed to the floor electronically without disrupting production.

In several ABB factories, MES is integrated with the planning and scheduling system, Quality Management System (QMS), design repositories, shop floor machines and reporting systems.

Manufacturing Intelligence

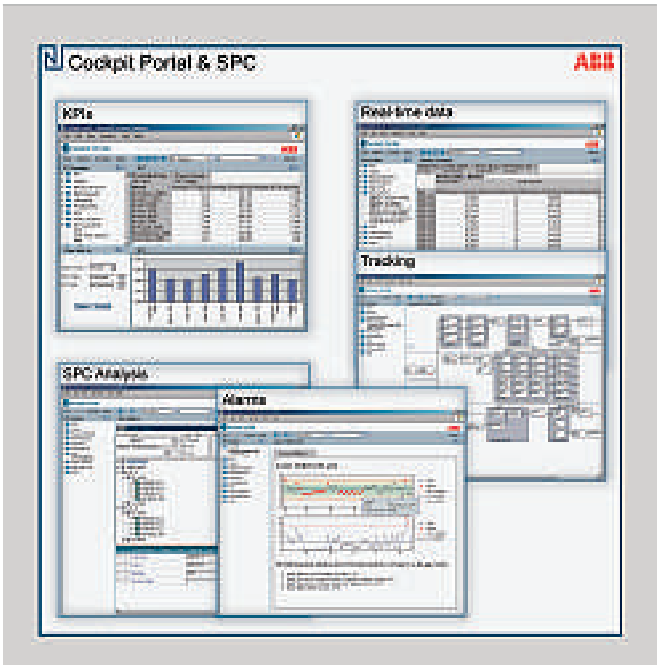
It is easy to become overloaded with raw data but still not have the information that is needed to make critical decisions. In addition to collecting and viewing historical information, a modern manufacturing business needs to gather real-time data from many sources within the plant, analyze it, and turn it into useful information. Such processes combined with manufacturing and business logic provide the basis for building operational excellence based on real time management, strategic decision support and tactical decision-making 4.

As the backbone of the manufacturing systems, MES fills a gap between business control (ERP and Supply Chain) and process control (automated and manual operations) to optimize manufacturing profitability.

The Cockpit system provides reporting and analytical functions for problems in the manufacturing processes. It supports manufacturing excellence by aggregating and disseminating data from multiple disparate back-end sources and delivering personalized views to authorized users through browsers or other internet-enabled devices. While aggregated totals of production counts may satisfy corporate management, the call for relentless cost reduction, raising of quality and boosting the count of produced units using existing resources can be met only by the availability of intelligent information from factory processes. Hidden constraints must be identified; these are the root causes of the quality issues that are masked by process variability, large buffers, and excess inventory levels. There also needs to be a high-level view of the plant that shows how processes function together across the entire plant. Only in such a case can the right change be effected.

The Cockpit system provides these capabilities by bridging the data from different sources of disjointed views in the factory. It closes the loop between the data generated

4 Manufacturing Intelligence Portal providing integrated information about factory for in time monitoring and analysis of business processes

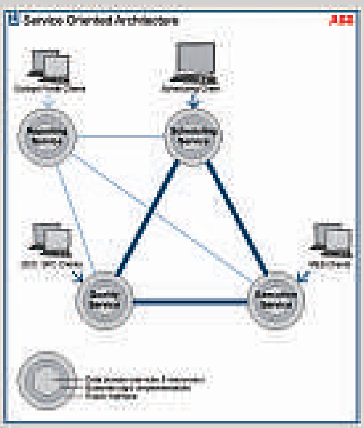


on the plant floor and other systems used to drive the plant. Cockpit imports data from IT systems from across the entire plant, storing the data in a single database and transforming it into one cohesive, integrated view of operations. The key technologies supporting this goal are data warehousing and on-line analytical processing with web access and portal functionality. Managers become empowered to act, by having access to reports on KPIs, machine utilization, quality and other key elements of factory operations. This results in increased productivity, quality, and reduced costs.

The Cockpit system not only tracks production information in real-time, but also alerts staff to problems on the floor in time to overcome them. The system gives managers and staff the opportunity to analyze the issue, drill down to the detail of single product or even its component, and identify the cause. They can determine what needs to be done about it and take timely action. By viewing relevant graphical data in real time, people are empowered to make rapid, proactive, and informed decisions. These benefits have a critically positive impact on the manufacturing business.

A manufacturing process always deals with a sequence of interdependent events, each with its own variation. Variation can be natural, inherent to the process, or caused by extraordinary factors. A systematic identification is required of the source of variability

5 Service Oriented Architecture enabling integration



that is causing the most problems across the system. Statistical Process Control (SPC) is an important methodology for the analysis of process fluctuation and for the pinpointing of conditions that cause the process to pass its control limits. This is a process charting technique that allows quick determination of variation causes. Based on a root cause analysis, the preventive action plan can be defined. The process of problem investigation using SPC methodology and the subsequent definition of a corrective plan involves people from different areas of manufacturing. Therefore it is regarded as one of the important tools in a Total Quality Management strategy.

A manufacturing process always deals with a sequence of interdependent events, each with its own variation. Variation can be natural, inherent to the process, or caused by extraordinary factors.

SPC System is a web-based service completing Cockpit's analytical capabilities by delivering a tool for measuring, understanding, and controlling variation in the manufacturing process. It targets quality experts that are equipped with extensive capabilities for observing either statistical control charts (showing measurements in context of control limits) for selected parameters and their variation. The user can apply several filters to specify what components, measurements and features should be used in the analysis. As the analysis can be very tedious, the SPC system provides functionality that helps efficiently track down suspicious parameter values and, if necessary, raises an alarm.

SPC also plays a very important role on the shop floor as part of the manufacturing execution system. It provides the so called "fast feedback" that gives an operator a simplified SPC analysis of collected measurements. The main goal of this fast feedback is to permit floor operators to react immediately when process parameters pass given limits.

When a new measurement is acquired by the MES system, it is automatically checked for correctness, ie, against boundary conditions as well as against statistical variation. The system gives the shop floor operator a prompt view of generated charts, especially if alarms are found. Thanks to this functionality, the shop floor operator is continually informed on abnormal parameter variation and can react immediately.

Implementation of SPC System results in reduction of cost of poor quality (COPQ) by providing alarms on the shop floor as well as analytical capabilities for process investigation. It enables proactive detection of problems early enough to prevent current and future problems.

Solution architecture

The integrated NEMESIS solution for discrete manufacturing factories is based on the idea of Service Oriented Architecture (SOA). The concept of the service as an independent, autonomous and self-contained piece of functionality is crucial to SOA. Service based on SOA can be considered as an element of business process logic that can be mixed and matched, and called into use by whomever or whatever needs it from anywhere within the architecture. An SOA-based system is a set of such loosely coupled but collaborating services. The success of the "Services" thinking lies in the recognition that, because systems must evolve over time, they must be flexible enough to accept additional or changing requirements. Applications should exchange data and provide services regardless of the respective platform. Today's IT world is a world of heterogeneous, distributed and yet deeply integrated systems. A product containing three main services is shown in **5**.

All collaborating services can have their own data storage. This data is imported to the data warehouse and processed and made accessible on different levels of factory management via Cockpit Portal.

Thanks to SOA, different underlying technologies and even different operating systems can cooperate and improve overall performance. This approach to IT systems facilitates their development, structuring and use. SOA services can be swapped in or out or replaced, without any effect on the users or the environment. Any individual component can easily and painlessly be replaced with a new, better, or expanded component. The choice of modern technologies such as Microsoft.NET or J2EE also supports the future growth of ABB's customers because it facilitates the delivery of scalable systems, capable of supporting the required performance as load increases. It establishes high availability of the system, which is very important as in many cases it must work 24/7 with uptime of close to 100 percent.

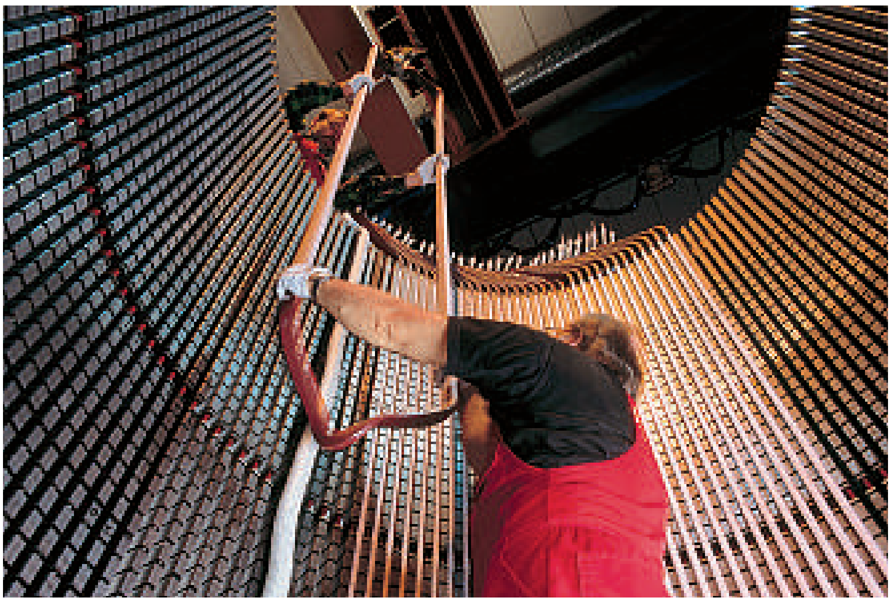
This choice also speeds up development and significantly increases reliability by facilitating security and transactions management.

In today's fast-moving economy, a company that does not use IT systems to optimize production processes, shorten lead-time, increase throughput and improve on-time-delivery is exposed to an increased risk of losing out to competition. Raising throughput, improving OTD, minimizing WIP and reducing inventories are ABB's strategy. IT solutions are critically important requirements in building manufacturing Operational Excellence. They affect all functions of business execution from sales through engineering to manufacturing by addressing new business demands:

- High flexibility to respond quickly and effectively to changing business requirements.
- Proper scheduling based on real-time status.
- Deep understanding and communication of performance measures throughout the organization with scorecards and other means of monitoring performance that make strategy directly relevant to each employee.
- Ability to understand and assess what is driving performance in every step of the process.

NEMESIS delivers a solid base for building real time enterprise, supported with detailed scheduling and business process management by seamless system reconfiguration, and rapid adaptation to business changes.

ABB marked a huge milestone in this direction by the deployment of an integrated IT solution concept in ABB's transformer factories. The aim of this concept was to integrate and optimize the entire process – including internal factory production processes – from the front-end sales tool through the ERP (Enterprise Resource Planning) system, to the MES (Manufacturing Execution System), along with shop-floor machines and the factory Quality Management System. Its implementation provided the factory with real-time information across the entire plant supported by the business intelligence system, Cockpit, delivering a unified view on plant performance with analytical and reporting capabilities. All together these integrated systems significantly improved plant visibility and manufacturing effectiveness. The implementation of NEMESIS required the building of an enterprise architecture platform supporting the integration of various existing IT systems and the development of new business components such as MES – providing shop floor control capabilities with order tracking and milestone realization monitoring. The solution delivers an enterprise system architecture model and a well defined development process allowing effective management of the system, increasing reusability, consistency and integration among subsystems. The fundamental component of this model is service-oriented architecture (SOA) utilizing web services, enabling integration across technology barriers, and higher flexibility in system management. When started, NEMESIS was alone in taking full advantage of emerging technologies and IT trends. These trends include web services, open source and commercial off the shelf components. As a result, development time was shortened, costs reduced and a highly flexible IT environment provided to meet new business requirements. The system also delivers a solid base for building real time enterprise supported with detailed scheduling and business process management by seamless system reconfiguration and rapid adaptation to business changes.



Miroslaw Bistron
Lukasz Krupa
Krzysztof Sowa-Pieklo
Bartlomiej Wyrwa
Tomasz Nowogorski
ABB Corporate Research
Krakow, Poland
miroslaw.bistron@pl.abb.com
lukasz.krupa@pl.abb.com
krzysztof.sowa-pieklo@pl.abb.com
bartlomiej.wyrwa@pl.abb.com
tomasz.nowogorski@pl.abb.com

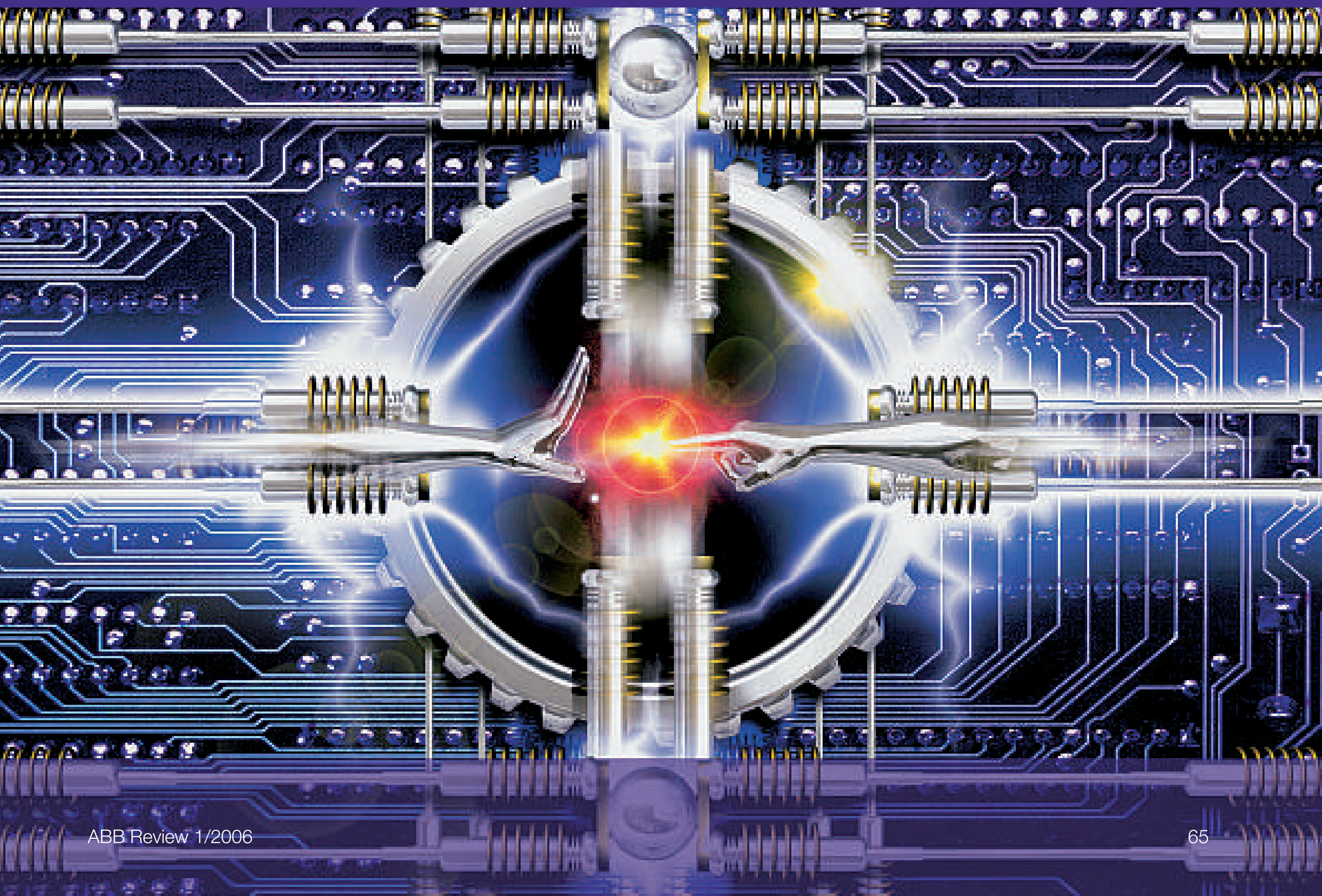
Simulating success

Simulation of manufacturing processes at ABB

Jukka Torvinen, Gerald Lee

Consider the risk involved when deciding to build a new factory or the purchase of capital equipment. Many questions need to be answered before a final decision can be made. Is the facility too large? Will it supply customer demand? Does it meet cost targets? Will the equipment work within the existing factory? These are answers every ABB engineer should know as early as possible on a project, long before any contract is signed, and with a high probability of success.

Process simulation has become an increasingly important and integral tool as businesses look for ways to strip nonvalue-adding steps from their processes and maximize human and equipment effectiveness. Simulation allows the user to model and test multiple scenarios and learn from them. Process Simulation is a tool that has been used successfully by ABB's Corporate Research Centers to answer these questions. This article looks at the simulation process, simulation packages, and examples of simulation in use at ABB factories.



Manufacturing technology

Companies are always looking for more efficient ways to run their business, improve work flow, and increase profits. To achieve these objectives, they increasingly turn to practices such as lean manufacturing. It can be said that lean manufacturing and process simulation go hand in hand: lean manufacturing is a highly productive way of manufacturing, and process simulation allows methodology to be tried and tested without any capital investments being made.

Process simulation involves the modeling of physical processes with the aim of studying their performance. Computer software models are good at examining interactions between systems that are too complex for people to comprehend or predict unless time-consuming and costly real life experimentation is used 1. There are many examples of processes being simulated in both manufacturing and everyday life: weather forecasting is used to understand the interactions between weather systems; and products are often modeled during their service life to foresee the effects of thermal cycling and load cycling for example.

Manufacturing processes are simulated to understand how they effect the composition, shape stresses and material properties of the products being made. The results are often used to reduce the variability in the manufacturing process and this helps increase process quality.

ABB is a leader in the implementation of advanced production systems in its facilities. These systems demand continuous improvement of delivery times, operating costs, capacities, material utilization and information flow. Simulation is a widely used tool by the company because of its unparalleled ability to accurately predict these performance metrics for any scenario. Companies such as ABB apply it in areas such as: investment planning; planning of a new factory; conceptual design; factory layouts; process analysis and optimization 2; 3D Visualization; ergonomics; testing new production control methods and principles; education and training; and marketing.

The risk in building reliable models highly depends on the availability of data against which to validate the model. In many cases, input data may be available from the customer's production system or collected by conducting time studies.

The simulation process

Steps involved in a typical simulation based analysis are:

- Determining the goals
- Data collection
- Modeling the (current) process
- Verifying and validating the model with the existing data
- Simulation runs
- Analyzing the results of the simulation
- Iterations (modelling-simulation-results)
- Selecting the most suitable solution
- Implementation
- Follow-up

Data required for a typical simulation analysis include: product mix; schedule, variations; process maps; labor allocation; inter-arrival times; set-up times; cycle times; planned/non-planned down times; and layout and batch sizes. The risk in building reliable models highly depends on the availability of data against which to validate the model. In many cases, input data may be available from the customer's production system or collected by conducting time studies.

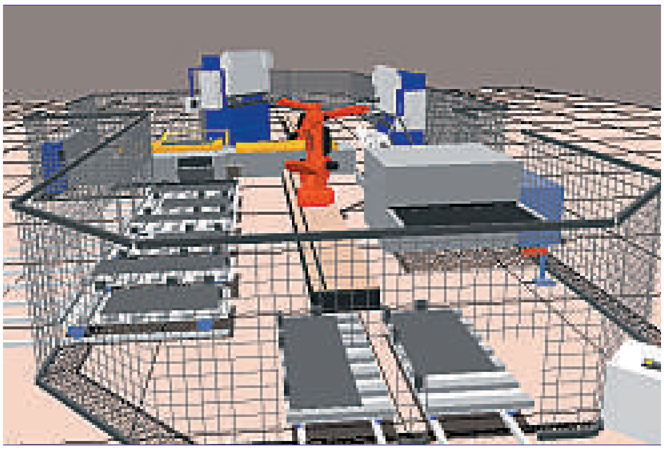
Some of the key results from the simulation runs are capacity, resource utilization, and throughput times. Optimization of these parameters leads to improved productivity, reduction in through-put time and delivery time.

Two simulation packages used by ABB are "Quest" and "Extend" and these are briefly described below.

Quest is a flexible object-based discrete event simulation tool to efficiently model, experiment and analyze facility layout and process flow.

1 Simulating a manufacturing process

From concept



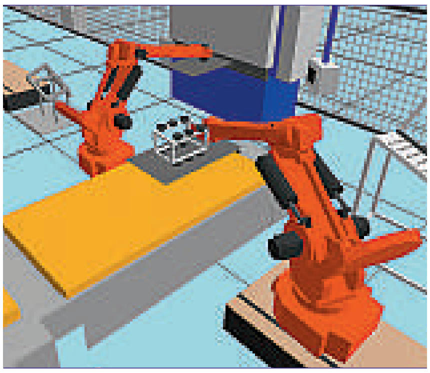
To implementation

Both 2D schematic and 3D physical models are quickly created through pushbutton interfaces, dialog boxes and extensive libraries. Real-time interaction enables modification of model variables and viewing parameters during runs.

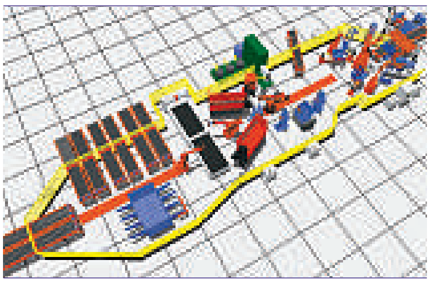
For manufacturing industries, computational efficiency and model building time are critical issues, as they determine the number of possible design iterations and experiments that can be achieved.

Extend is a 2D simulation tool that can quickly create simulation models as easily as one would create a spreadsheet. Extend uses libraries of typical user functions and reports, that can be easily modified if required. Both discrete and continuous simulation is possible. Extend also has a number of models closely approximating many functions so that it is possible to run multiple scenarios in a matter of minutes.

2 Automated and flexible processes



3 "Lights out" manufacturing



Simulation in practice

The first example of simulation in practice is a World Class Breaker project which was executed at ABB's circuit breaker factory in Ludvika, Sweden between 2001 and 2002. The project involved the design and validation of new production systems for breaker manufacturing, of which simulation played a major role.

Simulation was applied in the following areas:

- Testing the various production control principles and validating the selected one.
- Verifying the impact of limited work in progress (WIP) using a specific CONWIP (Constant WIP) methodology.
- Defining and visualizing the related layout changes.
- Verifying the capacity for the modified production lines.
- Definition and validation of the scheduling principle for component production.
- Verification of the production Through-Put-Time (TPT) reduction.
- Thorough analysis of the implemented production process that can be used for further development.
- Validation of the production process using real life schedule file.

Very good technical and business results were achieved including:

- A reduction of 60 percent in the production TPT.
- WIP was reduced by more than 50 percent.

A constant WIP ensures a more constant TPT, and this makes planning more accurate.

The second example uses simulation in ABB's "Focused Factory" for distribution transformers. This factory is a highly automated "factory of the future" for the production of pad-mounted distribution transformers for the North-American market.

The project was executed in Athens, Georgia, and combined an Internet capable quotation and order entry system, a fully automated tank manufacturing cell, new automated coil winding equipment, and a fast assembly line to make significant reductions in material and labor costs, and cycle times. Simulation was used extensively for:

- Defining new production processes.
- Layout design for the production line (more than 30 iterations analysed).
- Modelling the new production line and processes.
- Line balancing to maximize the capacity.

Significant achievements in this project were:

- "Lights out" manufacturing with optimized layout and production processes 3.
- Flexible, one-of-a-kind manufacturing with high capacity.
- No set-up required between different product configurations.
- Minimized WIP because cell buffers were eliminated.
- Quick implementation and ramp-up.

These achievements resulted in labor savings of 50 percent, cycle time reductions of 90 percent, and a 60 percent reduction in floor space. Ultimately, this project helped demonstrate the value of focused factories, a concept which is currently being implemented in many ABB businesses.

The value of simulation can never be emphasized enough. For manufacturing industries, computational efficiency and model building time are critical issues, as they determine the number of possible design iterations and experiments that can be achieved. Developments are occurring in hardware and software that continue to accelerate the speed at which these activities can be carried out. These improvements continue to make simulation software an excellent tool for enhancing lean manufacturing.

Jukka Torvinen
ABB Corporate Research
Vaasa, Finland
jukka.torvinen@fi.abb.com

Gerald Lee
ABB Corporate Research
Raleigh, NC, USA
gerald.lee@us.abb.com

Watchful eye

Field instrument diagnosis and its efficient use in process plants

Jörg Gebhardt, Peter O. Müller

Modern field instruments provide a large number of diagnostic functions. The discussion is therefore about how the user should handle the considerable amount of additional information. In this regard, the article represents an on-going standardization activity and describes new concepts of ABB which enable clear and efficient exploitation of diagnostic information. For the customers, this means better instrument and plant performance.

The prevention of downtimes and an increase in availability are among the greatest challenges currently facing operators of processing plants. There are years when some industrial plants, owned by leading chemical companies, have maintenance costs that exceed 50 percent of their annual profits! With this background, attempts have been made to replace expensive "preventive" maintenance by event-driven "predictive" methods.

Field instrument diagnosis plays a central role in this respect. But what does "diagnosis" entail? Errors can arise in the instrument itself (eg, an electronics error without an external effect) or be induced by incorrect use in the process (eg, the entry length is too short with certain flowmeters). Each diagnosis starts with the detection of certain symptoms in the field instrument, such as an atypical fluctuation of the measured value. Needless to say, it is not enough to display such symptom messages to the user.

Diagnosis should always lead to detailed instructions for action. These can be initially determined at the level of an individual instrument (instrument-specific instructions for action). In addition, the information should be put in the context of the entire plant to provide the end user – respectively the operator – with corresponding plant-specific instructions. This subject is currently of interest to many automation manufacturers and is the mainspring for the development of advanced global diagnostic techniques.

Guideline for self-monitoring

The Expert Committee (6.21) of the VDI/VDE's (Society of German Engineers) Society for Measurement and Automatic Control (GMA) is currently working together with the Association of Process Control Technology in the Chemical and Pharmaceutical Industry (NAMUR) and members of the International Instrument Users' Association (WIB) on a new guideline (VDI/VDE 2650) for self-monitoring of field instruments with HART or fieldbus communication. It will also be published in spring 2006 as a new version of NAMUR's recommendation, NE 107.

The objective of this work is to create an understanding between instrument users and manufacturers about frequently occurring errors and appropriate types of diagnosis in the various types of field instruments.

> The prevention of downtimes and an increase in availability are among the greatest challenges currently facing operators of processing plants.

Status signals

In addition to this, a new description of the status signals used as standard in field instruments is being drawn up. Three have so far been defined by NAMUR's Worksheet, NA64:

- *"Function check"* (symbol "C"). Work is being carried out on the field instrument and the output signal is therefore temporarily invalid.
- *"Maintenance required"* (symbol "M"). Although the output signal is still valid, the reserve will soon be exhausted, or a function will be restricted in the near future as a result of the service conditions.
- *"Failure"* (symbol "F"): The output signal is invalid on account of a malfunction in the field instrument or its peripherals.

In future, field instruments should also be able to report an "Out of specification" (symbol "S") status. In other words, the instrument is currently operating outside its specified range, or deviations have been detected which can either be attributed to internal problems or to process characteristics.

A field instrument should always display only one of the signals at any given time. While the application of "Function check" is evident, it is not so for the status signals "M", "F" and "S". The fundamental difference lies in the desired evaluation of the measured signal by the user:

- In the case of "Maintenance required" the user can assume that the specified accuracy of the measured value is still available.
- If "Out of specification" is displayed, the measured value may still be useful, but the measurement accuracy is probably adversely affected.
- A "Failure" signal indicates that the measurement should be considered invalid.

Instrument-internal diagnoses are therefore assigned to these cases in accordance with the manufacturer's knowledge and mapped to "M", "S" or "F". To illustrate this, suppose an instrument is suitable for a specified temperature range according to the manufacturer's specification. Therefore, a "failure" no longer has to be signaled immediately when marginal infringements of the range limits occur. This would certainly improve the current situation whereby the operator has to evaluate this as a complete instrument malfunction and initiate a technically unnecessary exchange of the instrument.

The new status signal accommodates customer requirements for greater flexibility. In the case described above, an "Out of Spec" signal, indicating that something is not OK at this measuring point because of instrument-internal or process-induced errors, would be more appropriate.

The display should only change to "Failure" if an instrument or application parameter, ie, the process temperature in this case, deviates significantly from the permissible range.

Instructions for action as the goal

In addition to this, the new guideline fulfils a fundamental requirement: the most important diagnostic functions and messages are those from which either the operator can derive unambiguous individual actions. This means the operator, or maintenance personal, must receive all the information required for safe operation as early as possible. It would be appropriate if the operator only sees the status signals and can assign them to precise system-specific instructions for action. On the other hand, maintenance personnel should have easy access to all the available detailed information and also receive precise, system- and instrument-specific instructions for action.

No diagnosis is better than an incorrect one

Users have strongly indicted that they would rather dispense with diagnosis than have to deal with a spate of dubious error messages. Therefore, equipment manufacturers have ensured that detailed user experiences and requirements have been incorporated into the guideline by creating lists of desired diagnoses for instrument faults and application-specific errors.

> Equipment manufacturers have ensured that detailed user experiences and requirements have been incorporated into the guideline by creating lists of desired diagnoses for instrument faults and application-specific errors.

Nowadays, many of the generally known diagnostic functions work very simply and reliably. However, even advanced diagnostic functions are not immune from errors. This can be illustrated by the following example:

Field instruments in certain applications may be affected by a certain error "F". These instruments are equipped with a self-monitoring function which definitely determines a certain symptom "S", from which conclusions can be drawn about the error F. The result of each test for the error F, using symptom S, then falls into one of the following four categories: true positive (error discovered), true negative (no error, no symptom), false positive (no error, symptom is present in spite of this, possible false alarm), false negative (error not detected).

A result distribution of 1 million checks of the symptom S is shown in 1. The conditional probability that symptom S is activated in case of error F is referred to as sensitivity. If the sensitivity is high there is a high probability that errors are detected. In this particular case, the sensitivity is approximately 83 percent. The conditional probability that no error is indicated in error-free operation is referred to as specificity. In the above case, it is calculated at 99.99 percent. High specificity means false alarms are unlikely.

Although the values in this example inspire confidence, a sophisticated evaluation of the self-monitoring results is required since the error is actually present in only five out of ten cases in which symptom S is signaled. The so called "positive predictive power" of the error test is therefore only 50 percent. Nevertheless, monitoring of symptom S has a purpose. If a symptom, S, is not present, the instrument is not affected by an error, F, in 999,989 cases out of 999,990. This high "negative predictive power" of approx. 99.99 percent helps the user to exclude errors and thus prevent the unnecessary disassembly of the instrument. The user can then focus on finding the real cause of the problem. It may in fact be more appropriate to map the error symptom, S, to an "Out of Spec" signal and initiate a check of the measuring point.

Typical application cases

Differential pressure gauges are among the most frequently used instruments in the process industry. They measure the pressure drop at numerous points in a process line when an orifice is passed through to determine the flow. One problem, which frequently occurs in instruments used in the oil industry, is responsible for a major part of the maintenance costs for this type of instrument. The pressure measuring points upstream and downstream of

1 Example distribution of one million error tests on a field instrument

	Error F is present	Error F is not present	
Symptom S is present	Correct-positive 5	Incorrect-positive 5	Number of cases in which the symptom is present 10
Symptom S is not present	Incorrect-negative 1	Correct-negative 999989	Number of cases in which the symptom is not present 999990
	Number of cases in which the error is present 6	Number of cases in which the error is not present 999994	Considered number of checks of the symptom S 1000000

Diagnostic methods

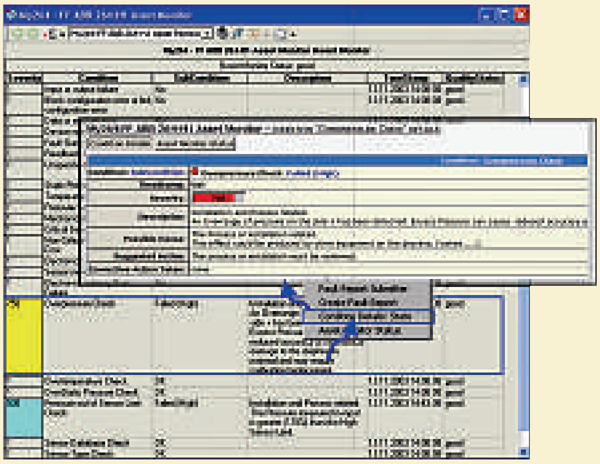
Diagnostic methods are frequently classified with regard to the use of physical models on the one hand and historical data on the other. The analytical models, based on very detailed knowledge of the device or the process, are at one end of this spectrum. The other extreme is composed of methods which are based purely on the processing of historical data. If industrial sensors and actuators, in particular, are considered, a somewhat more detailed classification is possible, namely with regard to the following:

- Test of the signal processing and electronics
- Switch-over to reference conditions
- Test signals
- Redundant sensor elements in the field instrument
- Additional non-redundant auxiliary sensors in the field instrument
- Internal signal data analysis
- Previous knowledge and experience with regard to the measurement signal (neural networks, pattern recognition)

The potential for future developments consists above all in diagnosis by means of test signals, internal redundant sensors and data analysis.

the orifice and the measuring instrument are frequently connected by means of differential pressure lines (so-called "impulse lines") which occasionally become blocked through flocculation of the process fluid. The problem in this case is that the measured value does not fall to zero, but "freezes" and is often not detected by the operator for a lengthy period. A considerable outlay must currently be invested in the regular testing of these lines to prevent an undetected "Plugged Impulse Line" situation, ie, the blocking of one of the two differential pressure lines.

2 Asset Monitor of a pressure transmitter displaying the "condition details" page



The development of an innovative diagnostic functionality would be a suitable solution. The new differential pressure gauges from ABB are equipped with a so-called "Plugged Impulse Line Detection" functionality. These ultra-modern pressure gauges can independently determine which of the two impulse lines is blocked. The respective instrument shows this on its local display.

> Asset Monitors can be used at any level of the plant hierarchy. As a result, intelligent field instruments and groups of field instruments can also be continuously monitored as well as control loops, plant components, plant units or overall plants.

The added value of the integration of this instrument with its diagnostic functionality into ABB's 800xA automation is significant: regular local checks of the instrument to detect an impulse line blockage is no longer required as the signals of all instruments can not only be centrally monitored at one location, but the system also directly initiates the next steps. For example, an impulse line blockage is immediately and automatically retransmitted to the "Maintenance Workplace" via fieldbus. The Maintenance Workplace informs the responsible maintenance engineer by SMS. He also receives detailed information about the problem and a precise recommendation for troubleshooting from the **Asset Monitor** (see below).

Surveys of one ABB customer in the oil industry have shown, for example, that removing blockages in the differential pressure lines accounts for a large percentage of the overall maintenance costs of the pressure gauges. ABB Asset Optimization minimizes the time required for identification of the problem and only initiates maintenance if it is needed. A considerable outlay for routine testing is currently required to identify such impulse line blockages as early as possible. This outlay can be reduced to a fraction by means of modern pressure gauges and their integration in System 800xA.

Many further savings can be made in a great variety of areas by means of the 800xA automation system.

The interpretation of diagnostic data

If certain tasks are solved at the level of the individual instrument, the plant owner is faced with new organizational and IT challenges. Ultimately, this manager must derive efficient maintenance strategies from the field instrument diagnostics such as: who is to receive the corresponding message; what this person should do; and whether or not all the information and tools are there to initiate the correct measures?

ABB has developed a special concept in answer to these questions: System 800xA integrates the control system and Asset Management in a uniform data structure, which is served via various workstation interfaces. These so-called "Asset Monitors" scan the data from the intelligent field instruments at configurable intervals – usually in the range of a few minutes – and, if required, submit a detailed Asset Condition Document (ACD) with instructions for action. The user can electronically process this immediately and seamlessly connect to a Computerized Maintenance Man-agement System (CMMS) which he uses.

The following principles are typical of ABB Asset Monitors:
- Continuous status monitoring for all types of field instruments in the system.
- With troubleshooting tools.
- A standardized user interface.

In System 800xA, each field instrument is represented as an "Aspect

Object", a highly flexible data structure, which gives easy access to the extensive data of modern field instruments such as manuals, operating data history, data sheets or driver software simply by clicking a mouse button. 2 shows the Asset Monitor for a pressure transmitter, which has been subjected to an inadmissibly high pressure. The Asset Monitor has detected the condition "Overpressure". With the click of a button, the user can immediately call up detailed information on this condition such as:

- Time-stamp
- Severity of the error
- Description of the error
- Information about possible causes
- Suggested actions

Asset Monitors for all plant levels

Asset Monitors can be used at any level of the plant hierarchy. As a result, intelligent field instruments and groups of field instruments can also be continuously monitored as well as control loops, plant components, plant units or overall plants. Cascadability is an eminently important technological and practical property. In the case of the ABB concept, it means Asset Monitors can be created for assets ("Parents"), which in turn consist of sub-assets ("Children") with their own asset monitors. Pre-configured monitors are already in existence for many applications, namely:

- Basic Asset Monitors:
  These carry out various tests on the basis of information from plant systems, eg, quality, Boolean values, differential flow, limits or deviation.
- Field instrument Asset Monitors:
  Field instrument Asset Monitors for the generally used fieldbus protocols (HART, Foundation Fieldbus, Profibus) are supplied with the respective Device Integration Packages (DIPS). There are generic asset monitors for each protocol which access the respective standard error signals. In addition, specific asset

Diagnosis of low-voltage switchgear

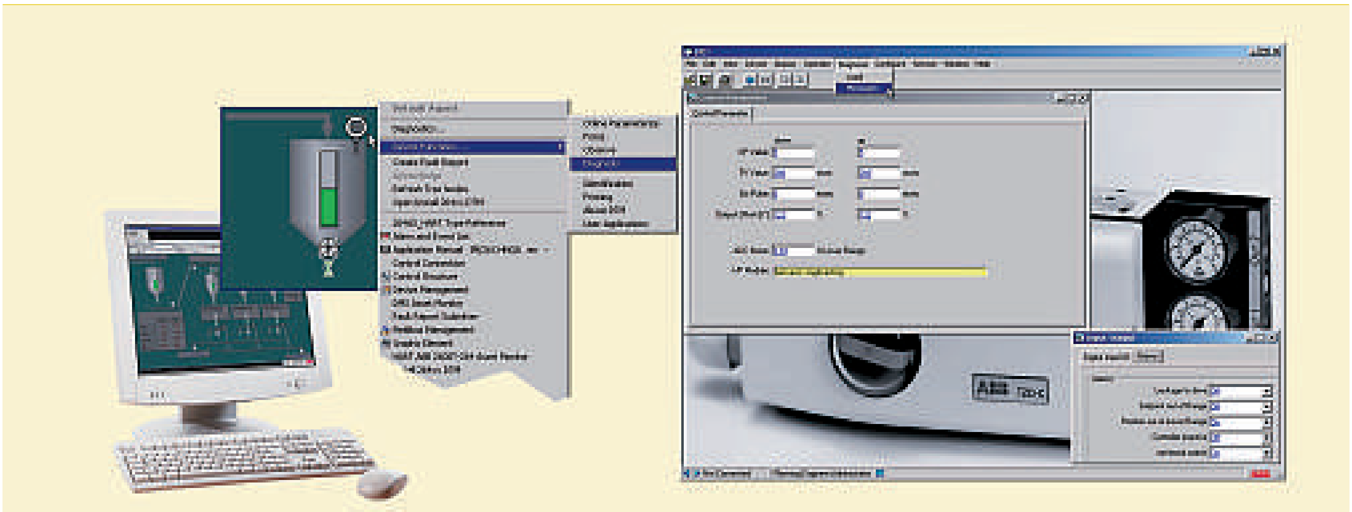
Instrument diagnosis can extend far beyond the classic area of field instruments:

The "Universal Motor Controller UMC22-FBP" was one of the first actors to be completely integrated in the 800xA asset management system. It combines high-grade motor protection and sophisticated motor control functions in one instrument. It can be used for currents from 0.24 to 63 A without the need for extra external current transformers. Digital inputs and relay outputs enable the implementation of extensive pre-defined control functions and applications such as direct starting, star-delta starting and servodrive including local control through the digital inputs.

The UMC has a so-called neutral fieldbus interface. The UMC is turned into a PROFIBUS, DeviceNet or Modebus instrument through the simple attachment of a fieldbus connector. The statuses of the inputs and outputs, detailed diagnostic information, motor current, instrument parameters and service data can be accessed via the various fieldbuses.

As a result, all the requisite information for necessary maintenance and/or repair instructions, if applicable, is available to the asset monitor. By means of the asset monitor, the maintenance personnel can recognize more quickly, whether an error is to be searched for in the instrument itself, the external electrical wiring or in the connected process.

Device Type Manager (DTM)1) diagnostics display



1) A DTM mirrors field device information into software applications.

monitors are offered which exploit the entire diagnostic know-how of respective manufacturer.

- Motors and drives: Asset Monitors are also available for motors and the associated devices, such as pumps, compressors and fans. Abnormal or unstable process and equipment statuses which can lead to overload of the electrical equipment and to wear and failures over time are detected. Asset Monitors here cover various degrees of complexity from basic functions, such as the monitoring of the operating hours and the number of starts of a motor, to special functions such as the monitoring of intelligent "Motor Control Centers". Asset Monitors tailored to closed-loop-controlled drives determine possible overloads.
- PCs, networks and software: Pre-defined Asset Monitors are available for computers, printers, switches or software programs. Various degrees of complexity are also covered – from simple tests (paper supply in the printer) to complex tests (utilization of the working memory).

Asset Monitors and status signals are available for the wide range of applications described above in much the same way as they are for field instruments, ie, with a user interface, alarm "severity" steps and logical content (instructions for action) that comply with the standards for instrumentation diagnostics.

Asset Monitors customized to project – and plant – specific "macro" assets can be developed beyond the existing libraries of asset monitors by means of Software Development Kits (SDK) – with full access to the existing asset monitoring system. If the data of all the instruments integrated both in the control system and in the asset management system is available, this is advantageous for efficient data transfers. To illustrate this, suppose an operator establishes that the performance of an appliance, for example a boiler or a heat exchanger, is deteriorating. Previously in such a case, he would have received a process alarm, checked the process graphics and alarms and thereby determined what was causing the problem. The operator would then either have immediately sent a maintenance job request in the form of a log entry, a hand-written memo or an e-mail, or would have laboriously searched through various systems at different locations for information on requested or scheduled maintenance measures.

In System 800xA, the maintenance engineer is now automatically informed about a maintenance event by means of the Asset Monitors. The problem and its cause are described in the associated Asset Condition Document. As a result, the user can quickly access the associated maintenance information in the CMMS by displaying the active job requests and thus determine whether a new job request is necessary.

Predictive maintenance pays off

This information can be collected, combined, analyzed and compared with historical data across the plant by means of the described functions for condition monitoring and the preparation of reports. Warnings about the deteriorating performance of appliances, components and processes and their possibly imminent failure can be detected in good time, issued to the maintenance personnel and processed in a comprehensible manner. Maintenance work can be better planned, and downtimes can be minimized. In other words: predictive maintenance, which was until recently connected with cost-intensive special measures and cost-effective only for critical and expensive process equipment, is now economically acceptable for many applications.

Autodiagnosis up to date

The example of the integrated empty pipe detection of a magnetic-inductive flow meter (FSM 4000 from ABB) is typical for modern self-monitoring by means of internal test signals, which is actuated by several application-specific errors:
The monitoring of the electrode impedance in this field instrument provides reliable information (instrument-specific) about whether changes have occurred in the measuring system (deposits or similar) or in the fluid (composition, deterioration of the conductivity) during operation. The main task of the empty pipe detector is to monitor the pipeline for partial filling, because this causes a considerable number of measuring errors.

The appropriate actions (plant-specific) taken by an operator or maintenance personnel can be configured at system level, because the instrument can communicate detailed information via the standard protocols (HART, Profibus PA, Foundation Fieldbus) with any desired filtering. There is an "Asset Monitor" for the instrument, by means of which the diagnostic information can be displayed to the user in real time.

Jörg Gebhardt
ABB Research Center, Germany
joerg.gebhardt@de.abb.com

Peter O. Müller
ABB Stotz-Kontakt GmbH
peter.o.mueller@de.abb.com

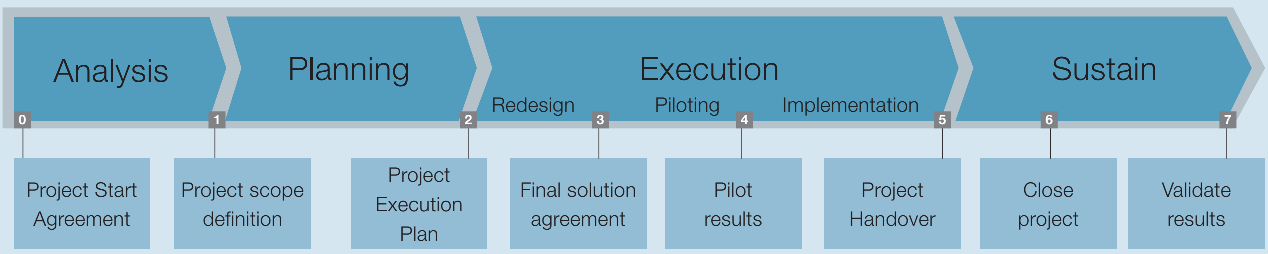
Further reading:

1) Johannes Prock et al.: VDI/VDE Richtlinie 2650 „Anforderungen an Selbstüberwachung und Diagnose in der Feldinstrumentierung", (2005) [VDI/VDE guideline 2650 "Requirements of self-monitoring and diagnosis in field instrumentation"]
2) Jörg Gebhardt, Peter Müller, Eberhard Horlebein, Horst Schwanzer, Ralf Huck, Wolfgang Scholz, Thomas Kleegrewe: "Diagnostics and Self-Monitoring of Field Instruments", 12th GMA / ITG – Fachtagung Sensoren und Meßsysteme [Sensors and measuring systems symposium], Ludwigsburg (2004)

Glossary

ABB Gate Model	A project decision support model 1 using **gates**. At every gate reached, progress is reviewed and future actions decided.
CONWIP (Constant Work in Progress)	A **Pull** system in which the number of jobs in progress is kept below a defined threshold.
CP3 (Common Pull Production Practices)	An implementation of the **ABB Gate Model** using eight **gates** and four main phases 1.
Critical Chain	A sophistication of **Critical Path** that additionally considers resource dependencies.
Critical Path	The sequence of work packages in the **project network** with the longest overall duration.
DFMA (Design for Manufacturing and Assembly)	A set of methodologies and principles of product design for optimizing all lifecycle functions. It consists of two complementary methodologies – DFA (Design for Assembly) and DFM (Design for Manufacturing).
ERP (Enterprise Resource Planning)	ERPs are management information systems that integrate and automate business activities for production or other operational activities.
Gate	A time-tag marking the planned completion date of an important project milestone.
Gateways	A backbone for ABB Components order-delivery process. The approach basically has two parts: *Gateways instruction:* a "pack-list" of internal deliveries, specifying what should be included in the deliveries. *Gateways visualized:* a schedule for all internal supplies using **gates**.
Lean Manufacturing	Manufacturing that produces with less human effort, less inventory, less space and less time than traditional methods, while at the same time being very responsive to customer demand and fulfilling high quality standards.
Little's Law	Little's Law states that at any given production rate, the average production **TPT** is directly proportional to the amount of **WIP**. See textbox on page 10.
MES (Manufacturing Execution System)	An MES is an automated system that helps control processes, materials, manpower and all the other inputs required for the smooth functioning of a manufacturing unit. It makes manufacturing very responsive to market trends, demand, and inventory levels.
MRP (Material Resource Planning)	An MRP is a production planning and inventory control tool used to manage manufacturing processes.
OEE (Overall Equipment Effectiveness)	The industry accepted tool to measure and monitor production performance. It can be applied at the machine, manufacturing cell, or plant process level. See textbox on page 41.
PR (Production Rate)	The rate of production flow.
Project network	A flow chart depicting the sequence in which a project's work-packages should be completed.
Pull	In a Pull system, a replenishment request is issued when material is "pulled" from an inventory, or when a due date is reached.
Re-order point method	An inventory control method whereby stock is re-ordered when inventory falls below a defined level.
SPC (Statistical Process Control)	A statistical method for determining whether an observed process is under control.
Supply Chain	A coordinated system of entities, activities, information and resources involved in moving a product or service from supplier to customer. The entities of a Supply Chain typically consist of manufacturers, service providers, distributors, and retail outlets. Supply chain activities transform raw materials and components into a finished product.
SCM (Supply Chain Management)	The process of planning, implementing, and controlling the operations of the **Supply Chain** with the purpose of satisfying customer requirements as efficiently as possible.
TPT (Throughput time)	Time elapsed from "order released to manufacturing" to "ready for shipment".
TTPT (Total TPT)	Time elapsed from definite order to shipment.
Two-bin system	An application of the **re-order point method** whereby stock is held in two bins. A replenishment is requested when one bin is empty. The other bin holds sufficient material to maintain production until the new stock arrives.
VSM (Value Stream Mapping)	A tool to support **lean manufacturing**. It maps the order-delivery process of a factory to show the material and information flow of the process and also to identify value- and non-value added activities performed in the factory.
WIP (Work in progress)	Average amount of products in production on which work has started but not been finished.

1 The ABB Gate model



Publisher's office
ABB Schweiz AG
Corporate Research
ABB Review / REV
CH-5405 Baden-Dättwil
Switzerland

The ABB Review is published four times a year in English, French, German, Spanish, Chinese and Russian.

The ABB Review is free of charge to those with an interest in ABB's technology and objectives. For a free subscription please contact your nearest ABB representative or the publisher's office.

Printers
Vorarlberger Verlagsanstalt AG
AT-6850 Dornbirn / Austria

Layout
DAVILLA Werbeagentur GmbH
AT-6900 Bregenz / Austria

ISSN: 1013-3119

www.abb.com/abbreview

Preview 2/2006

Constantly rising productivity underpins modern societies, their economies and their competitiveness. It is widely accepted that such productivity growth is dependant on innovations and technological progress, which in recent years has been largely driven by developments in Information and Communication technologies, ICT. Falling behind in the adoption of ICT is quickly reflected in slower growth rate and lower productivity gains. The convergence of low power computing with ubiquitous networking is leading to a major shift in the way business and government are conducting their daily operations. Embedded intelligent devices enable new applications and new services. Embedded devices are present everywhere and are changing how the world communicates and interacts. It was estimated that an average of 8 billion embedded micro components existed worldwide in 2003. Conservative estimates suggest a doubling of this figure to 16 billion by 2010, or the equivalent of three embedded devices for every person on earth!

The next issue of ABB Review will take a look at how this pervasive technology is inspiring the scientists within ABB to innovate and create new products and services. Embedded technology appears in the form of both hardware and software components to form new applications that solve our customers' issues. How these technologies are applied in the fields of power and automation are revealed.