Enabling an Intelligent Planet

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Strides in Automation: Streamlining the Factory Floor

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In the last 150 years, factories have gone from totally manual operations with each work station operated by a single worker, to fully automated and integrated processes that can sometimes be operated "lights out."

Manufacturing was originally done in small workshops, where one or two completely finished parts or products were made as piecework, and then sent to a larger warehouse to be sold. This was also the genesis of cost accounting, as each of these independent workshops needed to be costed separately, as most manufacturing firms owned and operated multiple workshops.

As throughput demands began to increase in the 18th and 19th centuries, factory owners began to mechanize. The availability of water power in various locales, and the invention and spread of the steam engine in the United Kingdom and then to continental Europe and the Americas, made centralized manufacturing plants possible.

Water powered factories needed to be clustered around a river or fast flowing stream, as shown in this figure. Even though the steam engine had been invented late in the 18th century—in many countries, especially North America, water was the primary manufacturing power source until the Civil War.

Factories needed to be designed to make use of a waterpower source. Processes were organized together, because power was distributed through the factory using overhead belts and pulleys as depicted below.

When steam engines began to replace water as the most important power source in manufacturing, the same power distribution systems were used. With either one water wheel or one steam engine, there was a single source of power, and power takeoffs needed to begin at that source.

This made it possible to operate many different machines from a single power source, but made it difficult to modify machines or move them. If the main belt system broke down, the plant was shut down. If modifications to the process or the machines needed to be made, the whole plant was shut down. Overhead belts were dangerous, and not easy to control. Worst of all, the factory could only operate at the speed of the slowest belt.

In manufacturing's early days, each process or operation was entirely manual. That is, there was an employee at every machine, valve, or other control whose job was to be the process controller. His situational awareness, experience and expertise as a "valve jockey" made him able to operate the control and make the process work.

Water or steam powered manual operations were limiting, but a new and exciting technology was on the horizon, one that would bring about incredible advances in manufacturing.

Problems with the Non-Automated Factory:

1.	High variance of finished products, poor quality
2.	Low throughput
3.	Poor worker safety and large headcount
4.	Difficult to re-configure for changing products
5.	Large inventory required

<u>The Assembly Line and the Advent of Electricity</u>

Standardization of parts and a first awareness of the value of quality in manufacturing produced the assembly line. The assembly line was operated at a constant speed because it was being operated by a single power takeoff, either water or steam powered. But the advent of electricity in the factory completely changed the layout and orientation of the manufacturing processes and operations.

With electric motors powered by either locally-generated or grid-generated power, each machine and manufacturing cell could be operated independently, at the highest speed possible to safely achieve maximum throughput.

In addition, simple on-off control was made practical simply by turning the machine on and off. It was quickly discovered that the rest of the factory could run unhindered when one machine was off or down for repair or reconfiguration.

In the process industries, the first means of automated control were mechanically actuated valves, controlled by temperature sensors. These replaced a worker with one eye on the thermometer and one hand on the valve wheel. These were soon joined by pressure transmitters, and eventually by pneumatic controls, which constituted the very first control loops.

Dr. Paul David has shown that the introduction of electric motors to the factory floor created a step change in productivity. Factories could be located anywhere, and the size of factory floors was no longer limited by the requirement of steam- or water-driven power takeoffs.

Islands of Manufacturing and the Second Industrial Revolution

Soon after electric motors came switches, relays and timers. Plants could now be controlled with fewer operators, because each operator could oversee many individual processes.

In the process industries, each operator could control many control loops. These loops were divided into two basic categories. The first was open loop, in which a human operator was inserted for final control. The second was closed loop, where the sensor was connected to a controller, which in turn was connected to a final control element such as a valve or motor. Closed loops allowed feedback or feed-forward control to be effected without human intervention.

Sensors that detected proximity and speed of rotation were developed, enabling precise automatic motion control. This made possible precision milling and turning centers that could produce a completed part from raw stock with minimal supervision from a trained operator. This was crucial during the manpower shortages caused by World War II, and had continuing effects throughout the 1950s and beyond.

However, each cell in a factory, or each process in a process plant was an island. The controls for each cell or process were not integrated with any other cell or process. Data about quality, throughput, maintenance and other issues needed to be extracted manually and transmitted manually via paper reports.

Birth of the PLC

While processes in a refinery or chemical plant are reasonably static and fixed from their design—manufacturing operations in a discrete plant, such as an automotive plant or a consumer goods plant, are anything but static.

In the 1960s, General Motors realized that if they could find a way to replace hard-wired relays in their control systems with relays that could be easily reprogrammed, they could save millions of dollars per year in the manufacturing downtime required to reconfigure the plant for the new model year vehicles. Dick Morley, of Bedford Associates, designed the very first Programmable Logic Controller (PLC) in response to a request from GM.

The PLC had far reaching consequences as these devices became larger, more powerful, and were given new features. Relatively quickly, Modicon developed the Modbus protocol for transmitting data digitally from one PLC to another, and to computers over a network.

In addition, PLCs began to be powerful enough to do floating point mathematical operations, not just “ladder logic” for relay replacement. Very quickly, data began to move automatically out of plant floor control devices up to higher level computing systems in the plant and corporate hierarchy.

Centralized versus Distributed Control

As data became available—manufacturing managers, production planners and quality control engineers began to see the benefits of connecting the “Islands of Automation” in the plant.

In the continuous process plants like oil refineries, or chemical plants, the first widespread control integration was done with minicomputers and mainframes. This was the beginning of a centralized approach to data collection and control. As advances in microprocessors and software were realized, microcomputers and PCs replaced mini-computers and mainframes, but the basic architecture of field controllers and centralized data collection and control was unchanged.

Today, this is called a Distributed Control System (DCS). A modern DCS can be defined as a set of proprietary controllers (which may be PLCs or PC-based) connected over an Ethernet network to a Commercial Off the Shelf (COTS) personal computer that runs a suite of proprietary control software. The PC and the software together constitute the Human Machine Interface (HMI). Other proprietary PC-based software produces analytics and advanced control strategies. In most cases, multiple PCs are networked together in the DCS, and connected to other computers in the manufacturing network.

In the discrete industries such as automotive, and in many batch process industries such as fine chemicals or food and beverage plants, the control system was significantly less hierarchical. Many of the automation vendors that took this path were European-based, and they opted to provide a flatter and more local level of control, with supervision via the network and one or more COTS PCs.

In addition, beginning in the early 2000s, advances in computing power due to Moore’s Law permitted the use of relatively powerful embedded microprocessors in controllers, which ARC Advisory Group’s Craig Resnick called Programmable Automation Controllers (PACs).

American and European approaches to automation

The majority of European automation vendors have historically concentrated on discrete or batch distributed automation, while many American vendors have moved toward highly centralized control systems such as the DCS.

Advantech’s APX-5520

When manufacturing cells are independent, distributed component level control is sensible. The European vendors have mostly produced control systems whose basic building block is the local controller, whether a PLC or a PAC. This type of control strategy is also excellent for machine builders producing a single machine or multiple independent machines.

As the factory has moved toward fully integrated control of an entire plant, these manufacturing cells have been linked to industrial networks by robust Ethernet-based devices that route data from the cell to the appropriate centralized control and monitoring system, and instructions from the centralized system down to the controller.

This “European” approach is much more horizontally arranged than the typical monolithic DCS approach favored by American vendors. The controllers are simply endpoints in the network, and the network is an integral part of the control systems, along with the centralized control and monitoring systems.

As the Stuxnet and DuQu virus attacks have shown, security for control systems requires more than simply firewalls between the IT network and the control system. The ISA99 CyberSecurity standard suggests dividing the plant network into zones or areas of control, and protecting each zone independently of other zones. This is an integral part of the defense-in-depth strategy that is required in a modern manufacturing plant.

Installing additional intelligence into the network devices, with managed switches and endpoint firewalls, makes this process simpler. Of course, this takes care of only about 25% of the danger, with remaining levels of protection implemented through worker training, security discipline and constant vigilance.

Advantech's ADAM-6617

Increased computing power makes manual tasks different

The advent of the PAC and other powerful embedded computers on the plant floor has made manual tasks fewer, but much more complicated. Workers now only do the tasks machines are not capable of performing by themselves.

For example, in the Audi manufacturing plant in Ingolstadt, Germany, the human workers do the installation, programming and maintenance of the robots that actually build the cars.

Human workers also do final assembly of the cabin and the cockpit where the fit and finish must be carefully performed, and visually inspected by a human being after assembly.

A modern automated manufacturing plant requires highly trained workers that can perform a variety of sophisticated tasks ranging from programming to troubleshooting to predictive maintenance.

“If manufacturing matters,” says Mr. Smith, Rolls-Royce’s manufacturing boss quoted in *The Economist* newspaper “then we need to make sure the necessary building blocks are there in the education system.”

The Factory of the Future—more jobs, different jobs

While the factory of the future may not have as many workers on the plant floor, there will be considerably more and different jobs as supply chains integrate. This will change the definition of a factory or production plant, as the production process extends out past the factory walls to include suppliers, suppliers’ providers and even product distribution.

Taken together, it is clear why manufacturing in North America is seeing resurgence. Susan Hockfield, president of the Massachusetts Institute of Technology, quoted in the same issue of *The Economist,* notes that China’s manufacturing output is now approximately the same as the United States, but that the United States achieves this with only about 10% of the workforce, in large part due to automation.

Autonomous control and processes – the factory in charge

“It is true,” says Dr. Hockfield in *The Economist*, “that if you look at the array of manufacturing technologies that are coming out of MIT, many of them are jobs-free or jobs-light.” In India, pharmaceutical tolling plants are often constructed to operate fully “lights-out”, except for abnormal situations. This requires substantial growth in the use of machine-to-machine communications and autonomous control of manufacturing processes.

Robots can do what workers have difficulty doing because of the repetitive nature of the work, safety issues or required dexterity. Robots can also do repetitive tasks significantly less expensively than a manufacturing cell full of human workers can, and with higher repeatability and quality.

Humans will do what's too complicated or requires too much analytical capability for robots or intelligent machines to do.

For example, in a fully automated assembly plant, the work order is generated by the production control computer, and is split into a picking list for the entirely automated warehouse. A manufacturing traveler is produced to accompany the bill of materials and the work in progress, and a set of specific manufacturing instructions are sent digitally to each production cell so that the machines can perform the required functions on the raw material or the work in progress. There are also instructions for quality inspection of each article, along with either warehousing instructions or shipping information for the final article.

At no point in this process would human intervention be required unless something went wrong.

Smarter machines will accomplish this with smarter embedded controllers, all communicating across a common plant Ethernet-based backbone using both wired and wireless communications technology. The smarter embedded controllers will benefit from the increasingly more powerful microprocessors based on Moore's Law, and these smarter controllers will improve the intelligence of the manufacturing platform.

Software will take a quantum leap in performance and ease of use. Easy operation software will improve human behavior, and prevent catastrophic failure modes, all leading to the benefits shown below.

Benefits of the Automated Factory

1.	More flexibility
2.	Higher throughput
3.	Improved quality control
4.	Increased safety
5.	Allows workers to focus on higher value tasks

<u>Procedural controlled automation</u>
Globally, there exists a dearth of trained and qualified automation workers in all automation disciplines from discrete factory automation to batch and continuous process, and including hybrid automation and total plant control. In many parts of the world, automation workers are retiring faster than new hires can be trained, and that includes developing countries like Brazil, China, India and Russia—as well as North America and Western Europe, and highly developed Asian nations including Japan, Korea and Taiwan.

Many serious accidents in factory settings are traced to human error or confusion, or the inability for the control system to deal with an upset. This type of abnormal situation is the subject of four organizations (the Center for Operator Performance, the Abnormal Situation Consortium, the

ISA18 standard committee and EEMUA) globally in the process industries, and other health and safety organizations in discrete manufacturing.

All agree that in the future, control systems will require stateful procedures for operation, abnormal situations and recovery from abnormal situations. In the process industries mainly, the ISA106 standard committee is developing standards for procedural-based automation systems that will aid less well trained and less experienced operating personnel in coping with abnormal situations.

Based on the early work of ISA88, the batch standard, procedural controlled automation produces a “recipe” for each process—whether discrete, batch or continuous—and within the recipe, detailed instructions are coded for the control system that show operators what to do at each step in the process if something goes wrong.

The increasing adoption of common software, such as IEC 61499 function block standards, and common networking and communication protocols, such as EtherNet/IP, Profibus, Modbus, and other fieldbus standards, will make possible easy connectivity in the plant and beyond.

The use of PC-based automation, using embedded computing devices and intelligent network appliances, will be the trend for high speed and complex operations. Depending on the process, local “cloud” and Internet “cloud” applications will increase operation and maintenance efficiency, while adding vast data storage and historian capabilities.

More detailed and dynamic simulation software is being developed to compress training time for new operators from years down to months. New ways to handle alarms and alarm cascades will help operators cope with and recover from abnormal operating conditions, even with little training.

Control systems made of “Lego-like” building blocks will allow plants to mix, match and be flexible. These plants can then produce what is known and needed in today’s market, and unknown and maybe not even anticipated in tomorrow’s market.

Collaborative Control – with and without human mediation

A factory is no longer a location on a map. It is instead a process, extending out in time and space and incorporating all of its suppliers, the manufacturing processes themselves, and the distribution system that brings the final product to market. According to Dr. Tom Edgar of the University of Texas at Austin, and co-chair of the Smart Manufacturing Leadership Coalition, “there’s no reason why many of these tasks cannot be entirely automatic.”

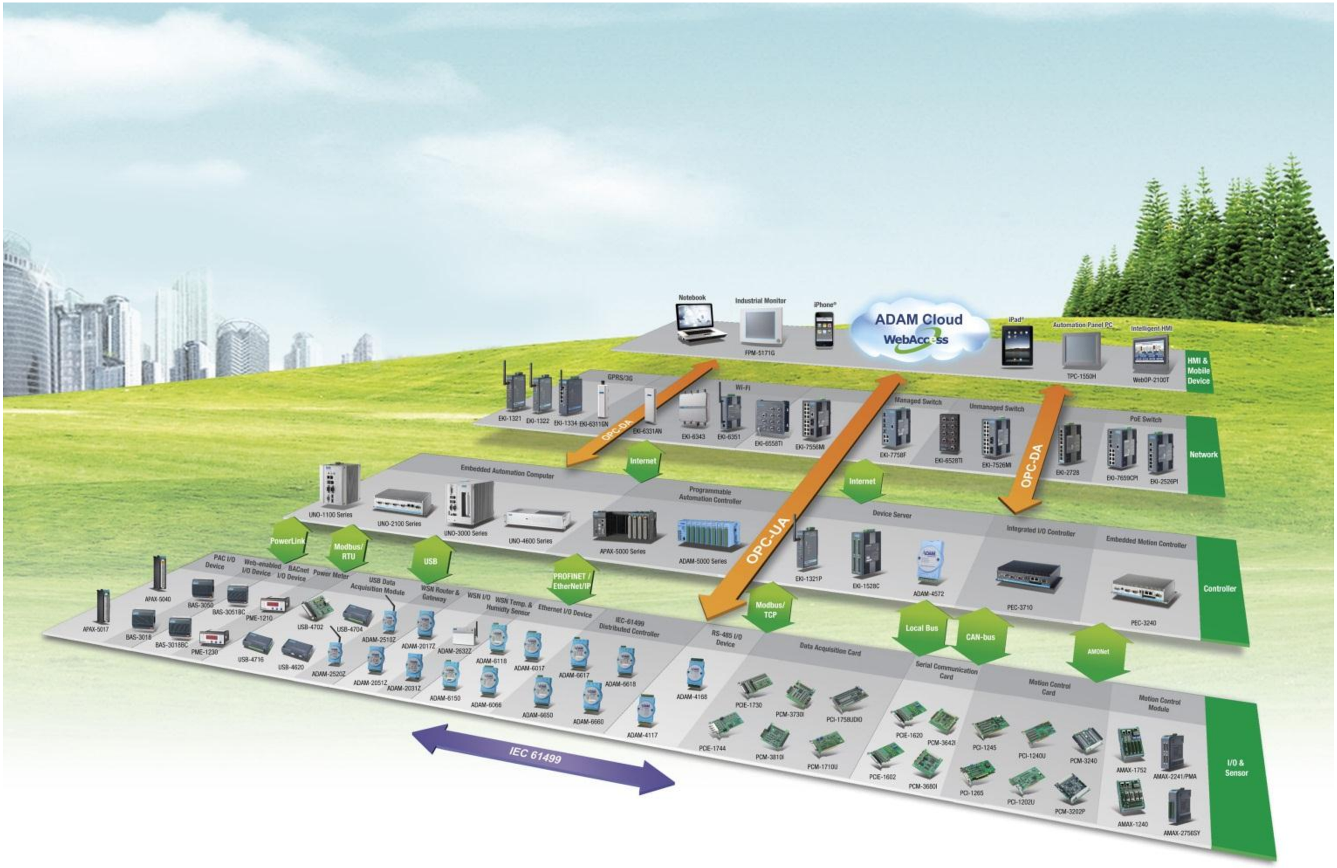
This is collaboration on a grand scale, and requires new concepts of organization as well as new mathematical models for operating manufacturing processes. In the past several decades, mathematical technologies such as adaptive control, model- and non-model-based predictive control, neural networks and adaptive machine learning technologies have been tried and used in a variety of plant operations. This is just the tip of the iceberg for such technologies; as machine intelligence, network intelligence, and even plant-wide intelligence increases—requiring ever more powerful and flexible controllers.

The widely spreading use of low power Personal Area Networks like Bluetooth, and intelligent mesh wireless networks for sensors and controllers such as IEC62591WirelessHART, ZigbeePro and a host of proprietary protocols, will make the vastly increased amount of information that must be moved for such collaboration practical.

The Internet of Things

The Internet of Things is the current label for what automation professionals used to call machine-to-machine communications. SAP AG, the world's leading enterprise software manufacturer, defines the Internet of Things as, "a world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these 'smart objects' over the Internet, query and change their state and any information associated with them, taking into account security and privacy issues."

CASAGRAS, an EU Framework 7 project, developed another definition in 2009: "A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communications capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and connection capability as the basis for the development of independent federated services and applications. These will be characterized by a high degree of autonomous data capture, event transfer, network connectivity and interoperability."



Advantech IoT product line

Both of these definitions of the Internet of Things, as well as others, have much in common. First is the ubiquitous nature of connectivity, and second is the global identification of every object. Third is the ability of each object to send and receive data across the Internet or private network they are connected into.

This isn't some science fiction story or a futurist's speculation, it is happening right now as we're beginning to see the Internet of Things developing in the commercial and home sectors. The recent Apple TV commercial for the iPad that intones, "You will still do…" and lists off numbers of normal endeavors, followed by "You'll just do them differently," is a clear indicator of this. The use of iPads and other connected appliances in business meetings is growing exponentially.

In automation and control, things are not so clear-cut. This is mostly because of the very long lifecycle of automation systems of up to at least 30 years and also because some manufacturing processes are highly customized. Enough value can be created using Internet of Things concepts, though, that plants are already starting to use these technologies.

Aided by wireless sensor technology and wireless mesh networking, plants are now using wireless temperature sensors to monitor and control the temperature in the workplace or the factory floor. They are also using wireless temperature sensors to model and produce 3D heat and cooling pattern visualizations inside process vessels like distillation columns.

The Future Is Wireless

Moore's Law is allowing the incorporation of ever more complex algorithms in embedded processors that can run in real time. This in turn is fueling the use of wireless in the industrial environment.

Nanotechnology is providing new and inexpensive-to-manufacture sensor technology that is easily capable of being battery- or solar-powered, and many of these sensors are going to be wireless.

One of the major reasons for using only one or two high accuracy sensors for each measurement point is that the cost of wiring often dwarfs the cost of the sensors themselves. Wireless sensors can be installed in multiples, and using matrix arrays, can produce very high precision measurements—much more accurate than any single sensor.

Low power mesh networking systems like IEEE 802.15.4, feeding IEEE 802.11 WiFi or WiMAX wireless digital data systems, will connect these sensors to the control system, to the environmental monitoring system and to the enterprise. Neural networks made up of the signals from these wireless sensor arrays will permit much higher use of advanced algorithms in the control system.

Mesh networks will allow sensors to configure their own network paths to the control system, with alternate paths in the event of loss of a repeater, or an obstruction in the path of the wireless signal. Combining wireless mesh networks with neural networks will give the sensors themselves the ability to learn and re-configure.

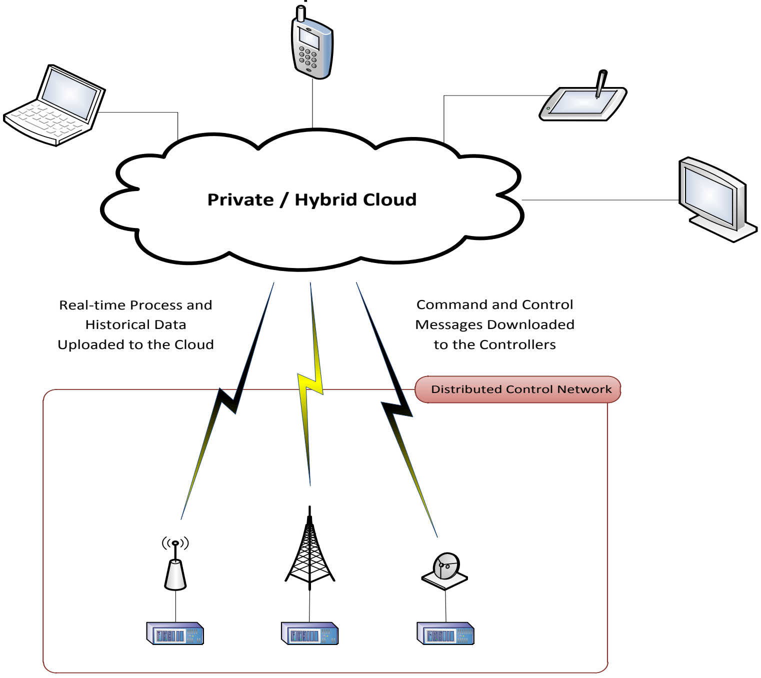
Fieldbus networks will change dramatically as wireless technology takes hold in the industrial environment. Digital fieldbus has always been about increased speed of response, much higher data throughput and greater determinism as the network itself becomes intelligent. With the growth of smarter sensors arrayed wirelessly in mesh and neural networks, fieldbus systems will make machine-to-machine communication and collaboration possible, and will also make true distributed control practical for the first time.

This all points to the growth of artificial intelligence in automation. Systems will incorporate many of the adaptive learning techniques that in the commercial market have led to the success of products like Roomba. The sensors will be intelligent, the network itself will be intelligent, and the control systems will have the processing capability to access and make use of all the data that will be flooding into them from the networks.

Toward a new theory of manufacturing automation

In *The Economist* special report, mention is made of a "Third Industrial Revolution." Such a revolution is occurring, and it is not just the new technologies such as 3D printing of parts that are causing it.

What we are seeing is a transformation of the way factories are organized, and even the definition of a factory. As we have said, a factory is no longer a location on the map, some buildings and a fence. It is much more easily described with the complexity of the processes that the factory extends to and encompasses.



The factory of the future, indeed the factory of today, must be flexible, and the complexity of its processes must, using new software and machine intelligence, be made simple to comprehend and operate. A factory will be a concept, not a place, tied together by electronic communications from customer to supplier to plant to warehouse to distribution to customer.