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Networking the Digital Factory

Rockwell is power without the smokestack and silicon without the Valley

Yesterday's desk had its stand-alone PC. Today's factory floor is still dominated by the stand-alone PLC—the "programmable logic controller," a computer that controls a machine. By and large, the controller still gets set up on the spot, for the next job at hand, to perform a specific task—sequencing a series of valves, directing motors in a lathe or milling machine to carve out a precise shape, controlling a conveyor belt's speed, or starting up a pump in response to pressure changes in a pipe or vessel.

Unlike PCs, however, PLCs aren't traded in for new versions every couple of years. They're embedded in heavy-iron industrial systems, with most of the cost in the long-lived, high-power, atom-moving end of the device. So in terms of their embedded digital intelligence, devices on the factory floor lag five to ten years behind those on the office desk. Which means that what happened to the desktop in the '90s will happen on the factory floor in the coming decade.

Most PLCs on today's factory floor are still ant-like in their intelligence. They're fast enough for the task immediately at hand, and doggedly reliable. But—unlike ants—they aren't social, they don't network easily or well, they're solitary. They combine digital power with digital logic, but not yet with sophisticated digital networks. At best, a "distributed control system" oversees a small group of PLCs, assigning to each one a simple (non-interactive) logical sequence, creating islands of isolated automation on the factory floor.

The latest PLCs are as smart as PCs, however—and they're multiplying much faster.

As smart, because they control the generation of all-electric systems we described in our Powerchip Paradigm II issue on broadband power (*December 2000*). Electricity—broadband power—supplies lighter, faster power, which can be far more precise and ultimately cheaper, but only under suitable control. It takes powerchips to control the power, and smartchips to control the powerchips. PLCs and their siblings are those same smartchips—logic boards in control of high-power, digitally switched, atom-moving machines.

And PLCs are now multiplying even faster than the PCs, because digital power has come of age, because there are more machines than there are people, and because the machines are changing faster. Until recently, the control algorithms for high-precision servo motors required far more computing power than could practically be scattered across a factory's floor. So factories remained packed with click-click, bang-bang mechanical, hydraulic, and pneumatic components, much like those under the hood of every car. But now, across the industrial landscape, large, heavy, slow, poorly controlled fluid and mechanical systems are giving way to smaller, lighter, faster, highly controlled digital-electrical ones. In mining, metal stamping, cement, pulp and paper, petroleum, chemical processing, pharmaceuticals, water treatment, and packaging. In the manufacture of consumer products, and the production of foods and beverages. Everywhere that power is used to move atoms, highly ordered power is displacing all the older, messier alternatives.

The PCs are systematically counted, and market analysts eagerly await reports of the Christmas sales rush. But nobody systematically counts PLCs. Our guess: In the United States alone, there are hundreds of millions of PLCs, smart motors with PLC-like functionality embedded in them, or comparable peripherals, such as smart sensors. There will be at least a billion of them by the end of this decade. More clients, in other words, in the desktop and handheld units that interface with human minds rather than with powered machines.

Smart networking can add as much value to factory PLCs as it does to desktop PCs. Wiring PLCs is a lot a harder, however. "Industrial" itself spans everything from coal mining to biotechnology—a tremendously wide range of materials, power, and precision. Dozens to hundreds of clients may populate a typical office LAN; hundreds of machines in a factory, by contrast, will represent thousands of sensors, valves, and actuators. The office LAN server doesn't need to communicate with the individual components inside each

PC. Serious factory automation, by contrast, depends on servers that interact not just with entire machines, but also with sensors, alarms, and actuators inside and around them. The equipment on factory floors is long-lived, which means that it always includes systems of many different vintages, and thus, incompatible standards.

But for all that, the PLCs can be networked. The $4 billion Rockwell Automation (ROK) is now doing for the blue-collar digital world—the industrial server, the PLC, and their many peripherals—what Microsoft and Oracle did for white-collar digital in the '80s and '90s. After a century's growth at the crossroads of analog, mechanical, and electrical power, Rockwell has spun off (almost) all things mechanical, and emerged as the world's leading provider of digital control systems for atom-moving enterprises. Rockwell's control systems, networks, and software work with its own legacy hardware already out on countless factory floors, and most everyone else's, too. Headquartered in Milwaukee, Wisconsin, Rockwell is power without the smokestack, and silicon without the Valley.

Digital Power Networks

Robots were all the rage in 1980. Japan had mastered them, we hadn't, and they—the robots and the Japanese, both—were going to take over all of manufacturing, and thus all the heavy lifting in the economy, which was, of course, the most important part. At the 1982 robotics trade show in Detroit, the crowd grew so large that at one point the Fire Marshall had to shut the doors and turn people away.

But for all they did, the robots of that era turned out to be cost-effective for only the very largest manufacturers—some two-thirds of the orders in the '80s came from the automotive industry. Robots weren't reliable, precise, smart, or cheap enough for most smaller-run or less standardized applications. Setting up a robot to perform a particular task was a lengthy and complicated process. GE, IBM, Westinghouse, Bendix, and other big-name players that had rushed into the business, got out. Many smaller players shut down or merged. U.S. orders for robots peaked at just over 6,000 in 1985, dropped almost in half, and were still lower than that in 1992.

The '80s robots were, in fact, doubly stupid. They didn't have enough digital intelligence. And they didn't have enough digital power.

Begin with the power. As we discussed last December, electric lines can supply far more power, in far less space, than any mechanical system can. The hard part is controlling it. Electrons in a metal wire can deliver so much punch, so fast, that all-electric systems tend to jitter, overshoot, and fall off the edge—they are dynamically unstable. So electric power moved only so far down the production line, and no farther. Mechanical engineers had to leave the inertia and friction on the working ends to dumb down, slow down, and stabilize things.

Even in robots. Under the hood, the '80s models still looked a lot like the cars they helped assemble—much of their "logic" still took the form of valves in hydraulic and pneumatic lines, electromagnetic solenoids, and meticulously crafted metal linkages. As a result, these robots did much less than met the eye. Their arms moved in relatively simple trajectories. They were best suited for relatively simple, highly repetitive, and indelicate tasks. Most of the rest of "factory automation" consisted of small versions of the same—simple switches and turnstiles, for example, that could sound an alarm when a box on a conveyor belt fell on its side. Useful. Important. Just as an electromechanical calculator, wristwatch, or telephone switch once was.

Though much less hyped than the robot, the humble electric motor acquired its powerchip logic drive at about the same time. The drive—an array of powerchips—shapes voltage and current to choreograph the motor's position, speed, acceleration, force, or torque. And drives have had "controllers" for a long time too. Streams of data from sensors tell the controller what the payload is currently doing. Directives from the outside define what it should be doing. The controller compares, calculates, and tells the drive what to dispatch next. High precision can require huge amounts of number crunching, which must be completed accurately, and in real time, or serious amounts of real-world hardware can go haywire.

Until recently, however, controller and drive related to each other in much the same way as a PC relates to a primitive printer. A one-to-one, one-way relationship, with a cumbersome, multi-wire link between brains at one end, brawn at the other. Digital logic in the computer linked to a digital power train inside the printer itself, but the links themselves remained short, simple, inflexible, and largely isolated from other intelligent nodes on the office LAN. Service technicians, and the people who ordered ink cartridges and paper, weren't in the loop at all. The analog links between controllers and machine drives were fast, but required complex wiring—as many as 100 wires for a single modest-sized machine. Setting up systems and troubleshooting were lengthy and complex processes. Wiring spaghetti was susceptible to electromagnetic interference.

The communications channels mainly supported one-way, master-slave communications, with limited diagnostic capabilities. They enabled individual islands

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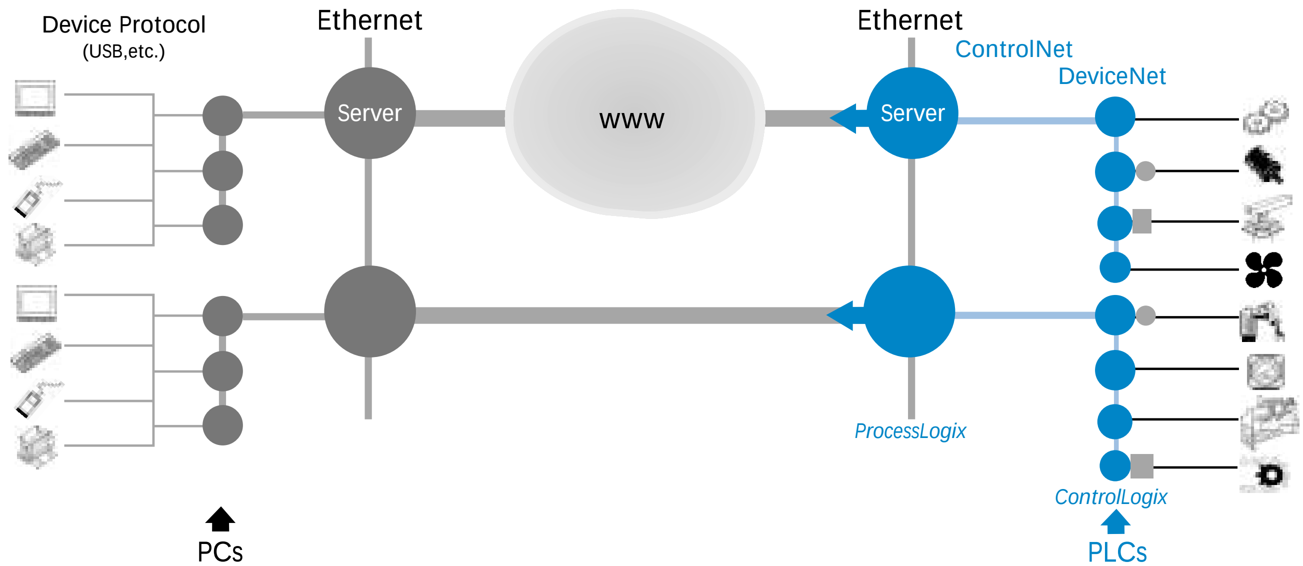

The Silicon Office came first, the Silicon Factory comes next. The office has its PCs and their clients–monitors, mice, keyboards, and printers. Tiers of smartchips in programmable logic controllers (PLCs) direct the powerchips that drive factory floor hardware. The factory floor presents a far wider range of PLC-enabled clients–motors, actuators, fans, pumps, switches, valves, and sensors. Rockwell's ControlLogix-based super-PLC (●) works alone or through competitors' PLCs (●), or legacy automation modules (■). DeviceNet enables plug-and-play networking of individual machines. It links to a factory-floor-level network (ControlNet) that makes possible factory- and enterprise-wide control.

of automation, not networks, not digital integration factory-wide and beyond. Inside the individual robot, and across the "automated" factory floor, the truly smart pieces remained widely separated by lots of dumb metal and pipe. Software to provide high-level factory-wide control didn't exist at all. The automation industry wasn't standing still, of course. But it wasn't yet ready for anything like the boom on the management side of the enterprise, where the machines weren't required to lift anything much heavier than bits.

Semiconductor factories led the way to serious automation, because they had to. Chip fabs work with materials of such high-9s purity that any people on the premises are poisonous, and must be isolated in moon suits. The fabs require ultra-fine motion control to align wafers and beams with sub-micron precision—much higher precision than can be attained with conventional mechanical systems. Digital power and comprehensive automation thus yields the highest payoff here. And in one key respect it is easier here than elsewhere: the silicon payloads are light, so they don't require much power. Rockwell itself got into this end of the market through its acquisition of Anorad, the world's leading manufacturer of linear motors (over 30,000 installed) used in electronic component assembly, lithography, laser manufacturing, and machining centers.

But Anorad represents only a tiny part of Rockwell's overall automation business, and the company has therefore been much less exposed to the wild swings in semiconductor fab fortunes. Chip fab automation grows when chips grow; industrial automation grows by infiltrating the vast base of industrial manufacturing, from cat food to chemical refineries to cars. Some 10,000 companies in semiconductor-related industries constitute a $150 billion segment of the economy. But 360,000 other U.S. old-guard industrial companies produce $1,900 billion of the GDP: food processing ($500B), chemical processing ($300B), printing ($200B), motor vehicles ($250B), refining ($150B), paper products ($150B), and textile, drug, and aerospace industries (each at roughly $100B).

Affordable technology is now at hand to automate the rest of manufacturing as comprehensively as the electronics components and chip fab industries. A mere 10 percent increase in automation of production hardware in the rest of the economy will generate more new automation business than the entire electronics industry has produced so far. And automation is now making rapid inroads into service-sector applications as well: security, health care, environmental clean-up, aviation, aerospace, and undersea exploration.

Intel, Microsoft, Oracle, and IBM build and sell hardware and software to move the bits and pixels where the white-collar types (or their casual-Friday successors) congregate. Rockwell builds and sells hardware and software that move the bits and atoms in what used to be blue-collar territory. Color-coded collars are history, or soon will be; it's all digital now. Indeed, Rockwell's space is even more digital than Intel's. Both sides of the house produce and process digital bits. But the atom-moving side does so to produce and apply high-precision digital power. High-9s power is simply an input on the Intel side of the fence—somebody else supplies the highly ordered electrons. Highly ordered power is the final output on

Rockwell's side—power so well ordered that it can transform a mountain of metal into a car, a slab of semiconductor into a microchip, or a biochemical soup into a gene, with little in the way of hands-on human help.

The market is now evolving so fast that nobody yet has a satisfactory name for it. It certainly isn't the $5 billion global "robotics" market, though next-generation robots will be numbered among the networked clients on this new industrial Web. The $80 billion global "industrial automation" industry covers more of the space, but "automation" doesn't begin to capture the full implications of digital control, while "industrial" gives no hint of the transformative importance of digital power. It is the market in which digital power meets digital logic to create the networked digital factory.

Apollo to Earth

The old Rockwell spent a century getting the Eagle to Tranquility Base. It built the Apollo spacecraft and its rocket engines; Collins Radio, which Rockwell acquired four years after Neil Armstrong took his one small step, built the equipment that sent the TV pictures of that step back to Earth. Having won the race to the moon, Rockwell spent the next two decades helping to win the Cold War. By acquisition and merger, the company continued to pull together mechanical drive trains, electric motors, controllers, and communications systems.

In the '90s, Rockwell consolidated the complementary pieces of the different companies it was absorbing. Then it spun off all but one of them. It merged all of the company's military electronics businesses into a new Defense Electronics organization; then it sold both its aerospace and its defense businesses to Boeing in 1996. It spun off most of its conventional automotive operations as Meritor Automotive (now ArvinMeritor) in 1997. Then it jettisoned Semiconductor Systems (as Conexant) in 1998. It sold its railroad electronics and North American Transformer businesses in 1999. Then the Rockwell Collins avionics and communications business unit, as Rockwell Collins, Inc. (COL) in June 2001.

What remained, almost exclusively, was industrial automation—and the company duly renamed itself Rockwell Automation. Rockwell's Software emerged as a world leader in development and support of automation software from the consolidation of the software expertise of Allen-Bradley (acquired in 1985), Reliance Electric (acquired in 1995), ICOM, an industrial software company (acquired in 1994), EJA Engineering (acquired in 1999), the Enterprise Technology Group and Dynapro (assets of each acquired in 1999), Systems Modeling Corporation (acquired in April 2000), Entek (acquired in March 2000), and Sequencia (software business acquired in October 2000). In April 2000, Rockwell Automation and Omron Corporation formed a strategic alliance around Omron's control components, sensors, programmable controllers, and industrial automation components.

Apart from Dodge—a vestigial division that still builds mechanical transmission systems—Rockwell is now focused on next-generation logic and power from end to end. It doesn't manufacture smartchips or powerchips. It buys them from others, to wrap them around motors and the like. And it wraps software around the chips. And service around all the hardware and software. Almost 80 percent of its revenues comes from its "Control Systems" operations: drives, sensors, I/O modules, communication networks, controllers, operator interfaces, motion controllers, computer numeric controllers, and software for communications, controls, human-machine interfaces, process visualization, and monitoring. Another 9 percent of revenues come from sales of electric motors.

Rockwell is, in short, a major software company—just not one of the NASDAQ standards that "software" usually brings to mind. And not competitively exposed to any of them, either—there's no chance at all of Microsoft someday pulling an Internet Explorer on Rockwell's Netscape. The software used to control high-power factory hardware is utterly different from the software it takes to control screens, mice, speakers, and game ports. Microsoft's original flagship was DOS—a "disk operating system," an interface between a microprocessor on the one hand, and the PC's electromechanical disk drive, screen, keyboard, and other IO devices, on the other. Rockwell's "machine operating system" interfaces between microprocessors and the power channels leading into electric motors that can run everything up to a two-ton robot and beyond.

Rockwell is the only public company with a pure focus on the networked digital factory. (Siemens, the huge German conglomerate, dominates the European market, but Rockwell has the largest share of the far more dynamic U.S. market. Tellingly, Siemens has posted serious losses recently because of slumping telecom sales; its most profitable business unit was industrial automation.) Rockwell employs approximately 25,000 people at more than 450 locations serving customers in more than 80 countries. A $100 million research subsidiary employs 400 people, including 150 Ph.D.s, and maintains partnerships with more than 200 universities, national laboratories, and research organizations; it conducts basic research for Rockwell's own operating business units, as well as for Boeing, ArvinMeritor, Conexant, and the federal government.

Integrated Control

German machine-tool manufacturers began the push to an open-standard digital interface in 1986. Several (largely) digital standards for controller-drive networking eventually emerged, and are now rapidly gaining momentum. SERCOS (Serial Real-time Communications System) and *MACRO* (Motion And Control Ring Optical) from the industrial side. And Apple's *FireWire* from the consumer products side, widely deployed for video and other high-bandwidth applications, such as PC-digital-camcorder links.

Each of these standards has its advantages. As in all networks, many different balances can be struck between integrating more intelligence at the end—in a "fat" client—and more in the higher tier controllers. But the overall, self-amplifying trend is more everywhere—smarter clients, smarter servers, and ever-faster networks. More digital power requires more digital logic, which draws still more digital power into the loop. Short-distance one-way, single-client controllers give way to bi-directional multi-client, factory-wide rings, and rings of rings. Isolated digital islands coalesce into the integrated digital factory.

As IBM's did in the '60s, Rockwell's dominance begins with a deep, industry-wide understanding of how its products can transform long-settled industrial habits. There are thousands of suppliers of "automation" equipment, but most supply stand-alone units dedicated to specific tasks. The next hundred billion dollars of investment on the factory floor will be spent on networking and integrated control—to do to the stand-alone on the factory floor what the Web did to the stand-alone on the desktop. That takes a lot more than a browser. The "killer application" here isn't a single program, it's application knowledge codified in successive layers of hardware, sensors, networking protocols, and software.

Rockwell's Logix software/hardware family is ambitiously designed as a general-purpose, open-architecture platform for industrial automation. Rockwell claims to have some 20,000 Logix installations—a huge base by industrial automation standards.

The key software layer, ProcessLogix, runs on Windows NT-based client and server computers. In the simplest terms, ProcessLogix gives plant-floor operators the power to coordinate and control the plant as a whole—integrated, highly sophisticated, master control of all the separate, lower-level PLCs and comparable peripherals scattered across the factory floor. It gives the plant-floor managers the power to manage machines in much the same way as a CEO uses e-mail and phone calls to manage employees.

The human-machine-interface at the top gives a good feel for what Rockwell has built underneath it, and for the unique requirements that industrial automation defines. Tellingly, Rockwell has had to produce its own range of display panels—bright, high resolution, and robust enough for factory environments. At any moment, a panel will be displaying custom graphics, alarms, trends, and reports, as it tracks events across the entire factory floor.

Behind the display are the software modules that digest incoming data and send outgoing commands. Rockwell Software supplies an extensive range of such packages itself. RSBatch, for example, provides complex recipe and batch management functions used by food processors and biotech firms, Genentech among them. Equally important, the ProcessLogix platform makes it easy for users to design, customize, and test their own control modules for inputs, sensor-based control calculations, data acquisition, and analog output.

For more complex processes, ProcessLogix interfaces intelligently with additional software packages running on the same server, or elsewhere further up the digital line—historical data bases, advanced planning and scheduling systems, and asset management systems. For example, Rockwell's own RSBizWare Compliance Track and RSBizWare Historian link the digital factory to the rest of the digital enterprise, giving the bit-crunching machines used by management, sales, and anyone else with a Web connection and access privileges a real-time quantitative window onto the factory floor. Rockwell is a founding member of a broad consortium of suppliers of manufacturing-industry software, which has incorporated Microsoft's data-interchange specifications into a general, open standard for interconnecting automation/control applications, field systems/devices, and business/office applications.

Rockwell has brought a similar philosophy to the networks that link the automation servers to the digital-machine clients. The company's NetLinx architecture is a three-layer hierarchy of the manufacturing industry's three main open networks—EtherNet/IP at the top, ControlNet in the middle, and DeviceNet at the bottom. EtherNet is, of course, what already runs office LANs. ControlNet is a 5 MB/s standard for (up to) 99-node supervisory rings that provide operator interfaces, remote device configuration, programming, and troubleshooting. DeviceNet provides the final connection to the PLC clients, supporting up to 64 nodes on a multi-drop 125 kB/s network that links switches, photoelectric cells, valve manifolds, motor starters, drives, sensors, actuators, variable frequency drives, operator displays, and other bottom-layer devices. Rockwell itself developed the latter two baseline specifications, then handed them over to independent organizations to guarantee openness and to (successfully) accelerate industry acceptance.

The network terminates at the PLCs and similar devices—digital ants that lack a social life until the network arrives. And it is here, at the very front lines, that the battle will be won or lost. The legions of loyal, battle-hardened soldier ants are already out there, and they represent far too much capital and accumulated experience to be discarded casually in favor of smarter replacements. From end to end, Rockwell's Logix platform is designed around that practical reality. The software and networking layers accept data from existing sensors, actuators, analyzers, instruments, and they generate control commands compatible with all of the principal PLC standards already found on the factory floor. Rockwell also manufactures a highly adaptable ControlLogix super-PLC that can be configured to interface with ProcessLogix on one side, and a broad range of legacy hardware already on the plant floor, on the other.

Logix can thus take over control of a plant incrementally, one sensor, motor, machine, or pump at a time, without disrupting any on-going operations. And here again, Rockwell has established a remarkable global partnership program to qualify and promote other company's automation components, and taken leadership in pursuing open network standards, as well as open standards for software integration. Rockwell's Encompass Product-Referencing Program identifies, qualifies, and jointly markets a broad range of third-party products. These include sensors, drive modules, valve controllers, purging systems, uninterruptible power supplies, signal and power surge suppressors, and calibration tools supplied by more than 100 different vendors.

The Mass-Produced Factory

Though nobody in the "automation industry" sees things this way, Rockwell's main competitive targets aren't other automation companies, they're the heavy lifters of the old industrial economy—manufacturers of electromechanical, mechanical, hydraulic, and pneumatic components and systems. Step by inexorable step, as digital logic and digital power continue to converge, precision, electrically-powered motors and lasers will displace the slower, heavier, clumsier legacies of the industrial age—the shafts, gear boxes, and mechanical and fluidic systems that convey force, torque, and pressure at the speed of sound, rather than high-power electrons and photons at the speed of light.

Rockwell has been installing industrial hardware (dumb, smart, and automated) for nearly a century, and the first target for enhanced automation is the installed base of Rockwell's own equipment already on customer premises around the world—a total base of $25 billion. Yet by shedding so much of its old self, Rockwell has also solved a big problem that will continue to bedevil many of its competitors. It's very hard for any well-established company to invent, develop, and promote the things that are going to destroy the core of its existing business. Rockwell no longer faces that dilemma. Most of its major automation competitors still do.

With only small exceptions, Rockwell's hardware operations have been trimmed down to those that fit the broadband-power future—most notably, a broad range of electric motors. Founded by the inventor of the first adjustable-speed DC motor, and with roots reaching back to Edison's time (1904), Rockwell's Reliance Electric division manufactures motors that span microchip handling to mining machinery—0.1 to 15,000 horsepower. Like other motor manufacturers, Rockwell is steadily advancing basic motor hardware. Among many other projects, Reliance collaborated with American Superconductor on a DOE project to build the first 1,000 hp super-conducting motor. And like others, it is pushing more and more intelligence into the casing of the machines themselves. The company's Allen-Bradley division makes a world-class line of PLC controllers and I/O equipment.

Rockwell builds bit "motors" for the factory floor, too—industrial-grade computers hardened for harsh environments and configured for 24/7 reliability. In packaging Silicon-Valley components for Industrial Alley, Rockwell adds corrosive-resistant chassis, gold-plated connectors, shock-mounted drives, thicker circuit boards, component tie downs, fan filters, robust power supplies, and embedded hardware diagnostics to monitor voltage, temperature, and cooling-fan speed. Ultra-thin clients without fragile hard drives are designed for the most extreme environments.

Several of Rockwell's main competitors, by contrast, still look very much like the old Rockwell, in that their interests in the old factory floor remain much deeper than their interests in the new. The company's main automation competitors include Siemens, ABB, Group Schneider, GE, Emerson (EMR), and Honeywell (HON). Three of those companies have already made it on to our Power Panel on the basis of other digital power strengths (June 2000 and October 2000). Siemens makes excellent automation products—but they account for only about one-quarter of the company's highly diversified operations. Much the same goes for Mitsubishi Electric Automation and Honeywell. Other able competitors address only particular segments of the automation market: Parker Hannifin Corporation (PH), Kollmorgen (a Danaher (DHR) subsidiary), Textron (TXT), and an Invensys (ISYS) automation division.

The global industrial market is vast and more than one major player in this market is going to prosper. But with that said, here—as in other markets centered on information, logic, and software—an early start and a big base are better than the alternatives.

The core function of an industrial automation system is to take in hundreds or thousands of streaming data inputs, process very complex relationships between them, and output control directives to units on the factory floor, operational information to plant-floor managers, and performance information to business managers elsewhere in the enterprise. To do that extremely reliably, in real time, requires a large, sustained investment in the development of software. And though all factories differ in just how they move the atoms, the same, common core of software and hardware can be used to move the bits that control the power behind a very wide range of industrial processes.

Considering the extremely broad range of customers that it serves, Rockwell Automation's products already seem remarkably standardized. A turnkey Rockwell-supplied Logix system comes down to a software core, a choice among a dozen or so industrial PCs and displays, three basic network architectures, and several dozen classes of controllers and motor drives. Here, as elsewhere, the better the digital systems grow, the more flexible, scalable, customizable, and adaptable they become. Digital power, digital logic, programmability, and open standards are transforming highly specialized, product-specific manufacturing machines into general-purpose, atom-crunching material processors.

At the end of the line, of course, the processing of atoms into rolled steel still looks very different from the processing of atoms into a bio-engineered pharmaceutical. There are over 300,000 different industrial companies in the United States alone, and no two of them are identical. Automating them one by one requires deep, industry-specific expertise. Selling the automation hardware and software begins with defining the problem to be solved. Rockwell excels at that, too.

The company's nameplate, its long and venerable history, gives it access and credibility. Rockwell has painstakingly built up a sales force of very knowledgeable analysts. They have deep expertise in specific industry sectors—forest products, metals, petroleum and mining, transportation, chemicals, pharmaceuticals, foods and beverages, chip fabs, or utilities, for example. And in specific technologies—batch control, programmable logic controllers, supervisory control, or drive systems, for example. They work in teams to deconstruct a customer's operations and map out optimal solutions. They provide after-market support from Rockwell's repair centers, offices, and facilities in countries around the world.

Independent customer surveys routinely rank Rockwell as the leading industrial automation integrator. And Rockwell numbers among its customers the likes of Dow, Exxon, Shell, DuPont, Eastman Kodak, Alcoa, Nucor, USX, International Paper, Weyerhaeuser, 3M, Kellogg, Unilever, Coca-Cola, Disney, Proctor & Gamble, Nabisco, Boeing, Daimler-Chrysler, Ford, GM, Goodyear, Toyota, Intel, Motorola, and PG&E.

Bits and Power

The Digital Factory represents a convergence of two transformative technologies, digital logic and digital power.

On the power side, highly ordered electrons and photons take charge of moving atoms directly, right down to the end of the line, the final payload. The number of MOSFETs, IGBTs, semiconductor lasers, and other powerchips per unit area of factory floor doubles every year or two from here on out. The number of digital clients—the number of independently controllable digital units in the individual machines and on the factory floor as a whole—rises much faster in the '00s than PCs multiplied on desktops in the '90s. Mechanical and fluidic systems retreat. Human wetware distances itself further and further from the atom-moving tasks. Whether manned by unions in Detroit or slave labor in North Korea, the factory gets powerchips or it goes bankrupt.

On the logic side, digital bit networks take control of the digital power networks. A first tier of smartchips located in individual control modules, directs the powerchips up close. A second tier provides additional control at the level of the individual machine. A third, at the level of the factory floor. And so on up, linking manufacturing to quality control, purchasing, sales, finance, and upper management, shop floor to top floor, blue collar to white.

The upper tiers are already networked with each other, of course—this is where Oracle, Sun, Microsoft, IBM, and others have already established the standards, deployed the hardware, and developed all the software that was supposed to define the new economy. In under two decades, datacom/telecom soared from an infinitesimal specialty sector to 10 percent of the entire economy. But 30 percent of the economy—the industrial and manufacturing sector—remains stubbornly lodged in the lower layers. And much of what happens in the other 60 percent—the service-sector layers—involves factory-like atom-moving skills, too. It has taken longer to make these rest-of-the-economy layers digital, because they require much more. Not just smartchips and their networks, but also an entire new generation of powerchips and sensors, and analog/digital converters. The smartchips arrived in the '80s and '90s. The high-power powerchips and the high-precision embedded sensors arrived later. The Silicon Office came first. The Silicon Factory comes next.

Compared to "robots" or yesterday's "factory automation," the new world represents a huge increase in both complexity and adaptability. The number of sensors and smartchips on the premises doubles and redoubles again and again. Every smartchip is programmable. Every smartchip can communicate in both directions, to receive real-time direction, and to dispatch real-time reports. Every smartchip, along with every sensor, sends a stream of digital data on up to the higher tiers of the network. Within a decade, these lower bit-electron tiers of the digital pyramid will represent more embedded microprocessors and more in-use bandwidth, than all the more visible and familiar layers higher up.

The amount of hardware and software required to control those lower tiers will grow geometrically. Software, network, and number-crunching requirements will increase fourfold, at the very least, for each doubling in the base of digital-power actuators under digital-processor control. Similar rules apply in the upper tiers, of course, where bits feed on bits, and we're dealing with familiar machines and software —spreadsheets, word processors, databases, and the Web's established protocols. And we know who owns the space at the top. But both technology and competitive opportunity remain wide open in the lower tiers, where bits are now converging with power.

No company has yet emerged as the Cisco, Netscape, Novell, Oracle, or Microsoft of this other Web—the industrial Web, the Web on which powerchips are the ultimate clients. Rockwell is chasing that prize. It could well win it.

Peter Huber and Mark Mills
August 30, 2001

The Power Panel

Ascendant Technology	Company (Symbol)	Reference Date	Reference Price	8/29/01 Price	52wk Range	Market Cap
Digital Power Networks	Rockwell Automation (ROK)	8/29/01	16.22	16.22	14.40 - 49.45	3.0b
Sense & Control	Analog Devices (ADI)	7/27/01	47.00	48.76	30.50 - 103.00	17.6b
Electron Storage & Ride-Through	C&D Technologies (CHP)	6/29/01	31.00	22.05	18.55 - 61.88	576.5m
	Maxwell Technologies (MXWL)	2/23/01	16.72	14.12	13.31 - 22.56	143.6m
	Active Power (ACPW)	8/8/00	17.00*	6.05	5.50 - 79.75	241.6m
	Beacon Power (BCON)	11/16/00	6.00*	3.12	2.46 - 10.75	133.3m
	Proton Energy Systems (PRTN)	9/29/00	17.00*	6.01	5.25 - 36.00	199.4m
Photon Power	Coherent (COHR)	5/31/01	35.50	36.19	25.00 - 82.00	1.0b
Powerchips	Cree Inc. (CREE)	4/30/01	21.53	21.40	12.21 - 71.72	1.6b
	Microsemi (MSCC)	3/30/01	14.00***	27.75	9.47 - 36.62	390.0m
	Fairchild Semiconductor (FCS)	1/22/01	17.69	20.79	11.19 - 42.75	2.1b
	IXYS (SYXI)	3/31/00	6.78	9.00	8.70 - 44.00	240.5m
	International Rectifier (IRF)	3/31/00	38.13	36.10	27.38 - 69.50	2.3b
	Advanced Power (APTI)	8/7/00	15.00	13.50	8.44 - 49.63	117.5m
	Infineon (IFX)	11/27/00	43.75	23.43	20.26 - 70.00	14.7b
Network Transmission and UPS: High-temperature superconductor	ABB (ABB)	9/29/00	24.24**	11.00	10.22 - 18.95	n/a
	American Superconductor (AMSC)	9/30/99	15.38	13.72	10.75 - 61.50	279.5m
Power: Heavy-Iron-Lite	General Electric (GE)	9/29/00	57.81	40.61	36.42 - 60.50	403.5b
	Catalytica Energy Systems (CESI)	9/29/00	12.38	8.00	7.71 - 24.00	137.7m
Distributed Power Generation Microturbines Fuel Cells	Capstone Turbine Corp. (CPST)	6/29/00	16.00**	4.87	4.63 - 98.50	374.2m
	FuelCell Energy (FCEL)	8/25/00	24.94	15.01	13.25 - 54.38	564.2m
Silicon Power Plants In-the-room DC and AC Power Plants	Emerson (EMR)	5/31/00	59.00	54.30	51.00 - 79.75	23.2b
	Power-One (PWER)	(see below)				
Motherboard Power Bricks, High-end DC/DC converters	Power-One (PWER)	4/28/00	22.75	11.00	10.95 - 89.81	867.0m

Note: This table lists technologies in the Powercosm Paradigm, and representative companies that possess the ascendant technologies. But by no means are the technologies exclusive to these companies. In keeping with our objective of providing a technology strategy report, companies appear on this list only for the core competencies, without any judgment of market price or timing. Reference Price is a company's closing stock price on the Reference Date, the date on which the Power Panel was generated for the Digital Power Report in which the company was added to the Table. All "current" stock prices and new Reference Prices/Dates are based on the closing price for the last trading day prior to publication. IPO reference dates, however, are the day of the IPO. Though the Reference Price/Date is of necessity prior to final editorial, printing and distribution of the Digital Power Report, no notice of company changes is given prior to publication. Huber and Mills may hold positions in companies discussed in this newsletter or listed on the panel, and may provide technology assessment services for firms that have interests in the companies.

** Offering price at the time of IPO.*

*** Effective April 6, 2001, ABB was listed on the NYSE. The reference price has been adjusted to reflect this change. The 52-week range covers the period from April 6, 2001 only.*

**** Microsemi's reference price has been adjusted to reflect a 2-1 stock split.*